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Barriers of scaling-up fuel cells: Cost, durability and reliability

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ABSTRACT

Since its creation over 170 years ago, and despite major investments and efforts by stakeholders over the last few decades to move this technology to the mainstream, today fuel cells continue to be regarded as a fledgling industry. In spite of the commitment by industry leaders, analysis shows that their actions do not address the critical questions facing this technology: Why has scaling-up of fuel cells failed so often when many researchers have stated their successes in the small scale? Why do fuel cell stacks have lower durability, reliability and robustness than their individual cells? Could investments of a hydrogen fueling infrastructure stimulate advancements in the key issues of durability, reliability and robustness and substantially reduce fuel cell costs? In this paper, we will analyze and confront these fundamental questions to improve understanding of the challenges of scaling-up technologies and identify key barriers. Then we will examine options and suggest a procedure for change to substantially improve the durability and reliability of fuel cells and reduce their costs.

1. Introduction

Due to the growth of the world's population, our energy demands continue to increase. The question of using increasing amounts of fossil fuels to keep our cars, homes and businesses running without destroying our environment becomes a major challenge as these fossil fuels have caused a growing number of greenhouse gas emissions. A major change to the energy economy from fossil energy carriers to renewable energy fluxes is necessary in this century [52]. A hydrogen economy is one of a number of alternative portfolios of energy economies. Hydrogen can be a renewable resource when it is produced from water electrolysis using electricity from solar, tidal, wind and bioenergy (Fig. 1) [66,93,118]. Hydrogen also is an attractive alternative because, whether it is burned to produce heat or reacted with air in a fuel cell to produce electricity, the byproduct produced is water [13]. As a result, when used in a comprehensive and balanced portfolio, hydrogen and fuel cell technologies have the potential to address two essential energy challenges facing the world today: significantly reducing CO_2 (carbon dioxide) emissions; and reducing the overall dependence on fossil fuels. However, to achieve a hydrogen economy, there are many significant challenges: efficient conversion of renewable energy (solar, wind, tidal, or bioenergy) into electricity, efficient electrolysis of water into hydrogen and oxygen, the storage of hydrogen or the production of a further synthetic fuel, and fuel cell technology [3,13,26,35,51,117,118]. As a core technology of a future hydrogen economy, fuel cells will play a pivotal role in revolutionizing the way we power our world; offering cleaner, more-efficient alternatives to the IC (internal-combustion) engine in vehicles and gas turbines or coal fired boilers and steam turbines at distributed power generating stations [33,40].

The history of fuel cells is comparable to that of the IC and steam engines [4,87]. Steam engines powered the industrial revolution until the advent of the IC engine, which appeared around the same time as fuel cell exploration. Despite many successfully specialized applications of fuel cells, such as UAV (unmanned aerial vehicles), submarines and the Apollo and Shuttle space missions [31,44,61,73,107], these extraordinary applications are not the primary markets for fuel cell and hydrogen industries for a future hydrogen economy. To date the cost and quality of fuel cells are not comparable to those of the IC engines or gas turbines.

Over the last 50 years, a large number of research institutes, private companies and government labs have conducted research and development on fuel cell products because of its high efficiency and environmental-friendly operation. More than US$22 billion has been invested in research and development of fuel cell technology in Japan, USA and Europe over the past 18 years [9]. The results from these efforts are reflected by a rapid growth in the number of peer-reviewed publications and authorized patents. For example, in

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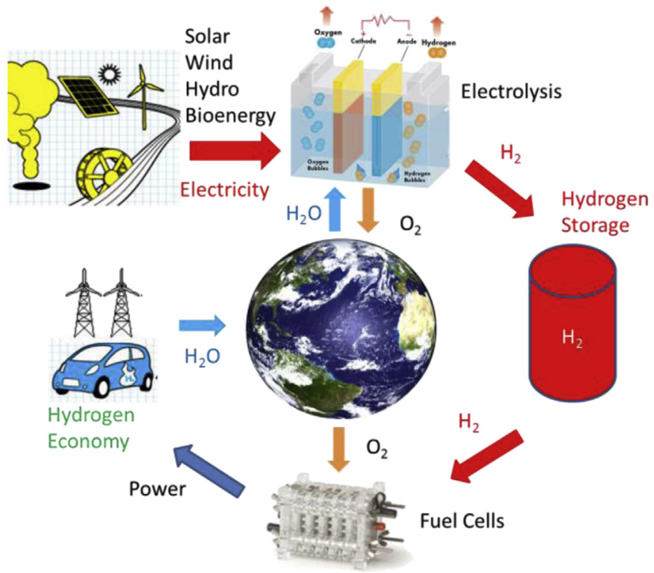

Fig. 1. Renewable energy, fuel cells and hydrogen economy.

Japan, the number of patents granted to companies in 2010 was 23 times as many as those in 2000 [9]. However, progress has been incremental, resulting in only slightly improved performance, but durability and reliability have shown no major breakthroughs or real competitive benefits. The process of commercializing any new technology is fraught with a multitude of challenges. New products introduced to the market face financial, technical, regulatory and competitive obstacles but are usually commercially successful if they deliver on their initial promise; that they are competitively priced, reliable and dependable in the free and open market. In fact, a widespread adoption of fuel cells has yet to take hold because of their unacceptably low durability and reliability and, in many cases, unacceptably high cost.

In spite of the lack of any real breakthrough with the technology, the potential benefits of fuel cells continue to be promoted by some stakeholders to generate public interest and leverage investment without actually delivering on these promises. Throughout the history of the development of the fuel cell, many companies, investors and governments believed that the technology was just a few years away from commercial success and the investment of a little more time and money would lead to a breakthrough [116]. This achievement continues to elude them. Recently, the EU has launched a new framework program [37], (2014–2020), in which €2.8 billion was allocated to the development of fuel cell and hydrogen technology that leans heavily upon the development of a hydrogen fueling infrastructure [37]. Mr. Hancock (Minister of Business, UK) announced funding of £11 million for a pilot project of public sector hydrogen vehicles and an initial network of up to 15 hydrogen refueling stations by the end of 2015 [41]. These ambitious goals are perfectly defensible and indeed desirable if we have the means to achieve them. However, these programs are long on ambition and short on scientific detail. In fact, there is still no clear vision of either a theoretical solution or real world technical answers on how to solve the quality (e.g., durability, reliability and robustness) issues in this technology. If the public trust is not lost with the repeated delays in product delivery, it is certainly eroded when the scientific infrastructure is unaccountable to its investors, governments and stakeholders; when there is not enough emphasis on translating research discoveries into the commercialization of the technology; and when target deadlines are repeatedly missed and marginal advances are over-hyped [12,10,7]. So far, fuel cells have not achieved reliable operation or cost benefits comparable to IC engines. Thus, the resulting disappointment has led to a breakdown of the initial high expectations of governments and the general public. As a result, in spite of their many claimed successes, the fuel cell industry faces a serious loss of public trust and a precipice [1]. It is a top priority to produce high quality fuel cells with high reliability and long-term durability at a low cost in R & D. However, unless one understands the challenges of commercialization, there is little chance of meeting them.

The immediate aim of this paper is to stimulate debate on the open issues of fuel cell technology, and to propose changes for improvement. Why has scaling-up of fuel cells failed so often when many researchers have stated their successes at the small scale? Could investments in an infrastructure of hydrogen stimulate a breakthrough to the key issues of cost, durability, reliability and robustness of fuel cells? It is necessary to understand in depth the scaling-up technologies. Ambiguities need to be clarified between fuel cell technology and a hydrogen economy. Key technical barriers must be identified for commercialization of fuel cells.

The second aim is to elaborate on why durability and reliability of fuel cells are the biggest technical barriers to commercialization rather than establishing hydrogen fueling infrastructures. An integrated approach is required for the fuel cell technology to ensure that scaling-up targets for durability and reliability are met. Further, root causes for the challenges of durability, reliability and robustness of fuel cells will be analyzed. Finally, future opportunities for the commercialization of fuel cells will be discussed with recommendations for change.

2. The hydrogen economy, hydrogen fueling infrastructure, and fuel cell technology

Hydrogen fueling infrastructure and fuel cell technology are parts of the Hydrogen economy. Therefore, hydrogen fueling infrastructure and fuel cell technology are assumed to have a close relationship [33]. There are major challenges for the hydrogen economy and fuel cell technology causing them to be viewed as post 2030 technologies [7,12,80,85]. However, the fuel cell itself is independent of the hydrogen economy. As engines, fuel cells can use different fuels, such as natural gas, methanol and ethanol, and can have different applications (Fig. 2) [27]. There are two main flaws in the relationship between hydrogen and fuel cell technology: the chicken-egg problem; and the barriers to scaling-up fuel cells.

2.1. Chicken-egg issue

The chicken-egg issue with regard to fuel cells is a longstanding assumption that the hydrogen fueling infrastructure would lead to a substantial reduction in the costs of fuel cells through mass-manufacturing, and the performance of fuel cells would be improved definitely as planned steps [56,34]. The commercialization of fuel cells has intentionally created a chicken-egg relationship between hydrogen fueling infrastructure and fuel cell vehicles [2,56,69,90,8,114,34]. The issue was described thus: “no hydrogen fueling infrastructure, therefore, no demand for hydrogen vehicles and no hydrogen vehicles, therefore, no incentive to build a hydrogen fueling infrastructure” [91]. The chicken-egg issue has been shared by automotive industries and research communities and has been used deliberately to serve the fuel cell industry's interests.

They suggest that technical problems could be overcome by a deployment of hydrogen fueling infrastructure and mass vehicle