Hydrogen Production and Applications: A review

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Abstract. A hydrogen fuel cell car, known as a Fuel Cell Electric Vehicle (FCEV), is essentially an electric vehicle that primarily relies on a fuel cell to generate energy. It also includes a secondary role for a battery within the powertrain. This technological configuration operates through four main scenarios, with the primary energy source being Hydrogen from onboard tanks, which powers the vehicle through the fuel cell and its associated components. Here's a breakdown of how it functions: Hydrogen enters the anode and interacts with a catalyst that separates hydrogen atoms, releasing electrons and protons. A conductive current collector connected to the vehicle's high-voltage circuitry collects these electrons. This electricity can charge the battery and/or drive the motors responsible for propelling the wheels. Fuel cells come in various types, characterized by the type of electrolyte they use, such as the Proton Exchange Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC), and Molten Carbonate Fuel Cell (MCFC). While all these fuel cell types can generate electricity, their efficiency can range from 30% to 60%. Although hydrogen fuel cell vehicles have shown promise, their adoption is still in its early stages due to challenges related to infrastructure, costs, and ongoing technological advancements. Our current research focuses on hydrogen production from renewable sources and its application in fuel cells to provide the required electrical power for electric vehicle propulsion. We aim to improve energy efficiency over a specified cycle and present a comprehensive analysis of our findings.

1 Introduction

Electric technology continues to evolve, offering longer electric-only ranges. The evolution of electric technology continues, resulting in extended electric-only driving ranges [1]. This development underscores the unwavering commitment of the automotive industry to sustainable transportation solutions. The electric vehicle (EV) sector is experiencing rapid growth thanks to an expanded array of choices, declining costs, government incentives [2], and continuous improvements in battery technology. An electric car is propelled by an electric motor rather than a petrol or diesel engine [3]. These electric motors are powered by rechargeable batteries that can be conveniently recharged using standard household electricity [4].

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In some instances, Hydrogen plays a crucial role as a generator to produce the electricity required for these vehicles [5].

Hydrogen production involves the generation of hydrogen gas (H2) from various sources, often intending to utilize it as a clean and versatile energy carrier. Hydrogen plays a pivotal role in the transition towards a more sustainable and low-carbon energy economy due to its ability to mitigate greenhouse gas emissions and enable a wide range of applications [6]. Hydrogen production encompasses various methods and technologies, each with unique advantages and challenges [7]. When striving to produce Hydrogen in an environmentally friendly manner, a viable approach involves harnessing renewable energy sources like solar and wind. Both methods share a common principle: converting power from different sources to fuel electrolysis for hydrogen generation. However, it is essential to acknowledge that these sources currently face challenges regarding production efficiency compared to fossil fuels [8].

Presently, Hydrogen finds applications in various fields, including the realm of electric vehicles (EVs). Fuel cells represent advanced electrochemical devices that produce electricity by reacting Hydrogen with oxygen through a clean and efficient chemical process. These fuel cells consist of two electrodes immersed in an electrolyte, and the automotive industry commonly employs a type known as the proton exchange membrane fuel cell (PEMFC) [9].

Despite the immense potential of Hydrogen as a clean and versatile energy carrier, a range of issues and challenges must be addressed. These challenges encompass concerns related to production efficiency, the sustainability of energy sources, difficulties in storing and transporting Hydrogen, energy losses during conversion and distribution, safety considerations, economic viability, integration with renewable energy sources, complexities in regulatory and policy frameworks, public perception and awareness, and the vulnerability of supply chains [10]. Addressing these challenges is crucial for unlocking the full potential of Hydrogen in our quest for a more sustainable and environmentally friendly energy landscape.

2 Hydrogen Production

Hydrogen production can draw from various domestic resources, including fossil fuels, biomass, and water electrolysis with electricity [11]–[13]. Hydrogen's environmental impact and energy efficiency are closely linked to the production method. This paper aims to provide a comprehensive overview of various studies conducted on different hydrogen production systems. These studies explore the utilization of solar energy [14], wind energy [15], or a combination of both to enhance efficiency [16]. The following section provides an overview of these studies and their respective analyses.

2.1 Hydrogen generation from solar energy

Generating Hydrogen through solar power is widely employed in solar hydrogen production. Photovoltaic (PV) systems generate electricity, which is then utilized to power an electrolyze, enabling the splitting of water (H2O) into Hydrogen (H2) and oxygen (O2) through electrolysis. However, it is essential to note that this approach's production and installation costs are higher than fossil fuels, making the process less efficient [17]. Several studies have been conducted to demonstrate and calculate the energy efficiency of green energy solutions.

Innovative approaches, such as using magnetic fields, light energy, and ultrasonic techniques, have been explored to enhance the efficiency of solar-powered water electrolysis [18]. Additionally, another study focused on improving the efficiency and performance of refueling stations for Hydrogen [19]. Notably, one study achieved a cumulative hydrogen production rate surpassing the maximum reported for pure $TiO2$-based photocatalysts [20].

Fig.1 visually represents the hydrogen production process using solar energy. The figure illustrates a series of components, including photovoltaic panels, an electrolyzer, water ($H2O$), and the resulting Hydrogen ($H2$) and oxygen ($O2$).

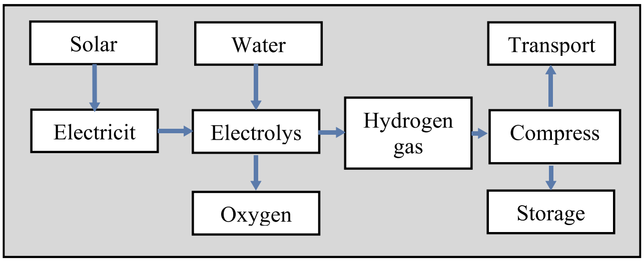

Fig. 1. Schematic diagram of Hydrogen production from solar energy

However, it's worth considering that solar energy may face limitations in meeting production requirements due to its availability primarily during the daytime, challenges related to shadows, and temperature variations.

2.2 Hydrogen generation from wind energy

Harnessing wind energy to produce Hydrogen is one of the most straightforward and environmentally friendly methods and boasts the highest efficiency among renewable energy sources. This technology operates similarly to solar energy but offers distinct advantages. Nevertheless, it requires a robust wind infrastructure, an electrolyze, and an effective hydrogen storage system to function optimally [21].

Numerous studies conducted in different regions, including Iran, Ukraine, and South Africa, have been aimed at determining the annual hydrogen production capacity. These studies have revealed impressive production potentials of 19.844 tons/year, 43 million tons through electrolysis, and 6.51 to 226.82 metric tons, respectively. However, it's important to note that production efficiency is intricately linked to the prevailing wind speed, and consequently, various theoretical approaches have been proposed to address the challenges. One such method aims to mitigate fluctuation risks and enhance system stability. Another strategy involves minimizing energy generation errors by developing an optimal and innovative wind portfolio system tailored to specific harvesting regions [22].

Despite its many advantages, the reliability of wind energy systems remains a concern for sustainable energy regeneration, primarily due to the inherent difficulty in efficiently predicting wind speeds [23].
Fig 2 illustrates the fundamental structure of a wind energy-hydrogen system. This schematic diagram provides an overview of the critical components and processes in converting wind energy into Hydrogen. It showcases the integration of a wind turbine, an electrolyzer, and a

hydrogen storage system, highlighting the flow of energy and materials throughout the system. This figure serves as a visual guide to understanding the foundational elements of a wind energy-hydrogen production setup.

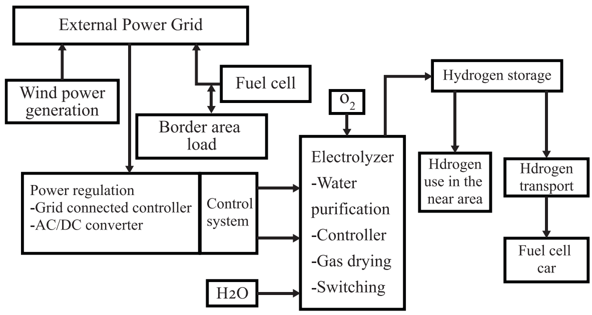

Fig. 2. Wind Energy-Hydrogen System Efficiency Factors

3 Hydrogen application: fuel cells

Fuel cells are advanced electrochemical devices that generate electricity from Hydrogen and oxygen through a clean and efficient chemical reaction. It comprises two electrodes immersed in electrolytes. There are several fuel cell types available. Proton exchange membrane fuel cells (PEMFCs) function at a low-temperature range (<80°C) and are helpful for many applications. Electric vehicles (EVs) are our case study [24].

Indeed, the FCEV powertrain can be separated into three categories: fuel cell (FC) and battery (B); Fuel Cell and Ultracapacitor (UC); Fuel Cell, Battery, and Ultracapacitor. (FC + B) is the main design configuration and is applied in most FCEVs since the FC+B+UC configuration is complex and the energy density of ultracapacitors is low [25]. This configuration is divided into four different topologies:

- Fuel cell system and battery connected directly to the DC/AC inverter of the motor converter
- The fuel cell system is connected to a DC/DC converter, and the battery is directly related to a DC/AC inverter motor
- The fuel cell system is directly connected to a DC/AC inverter and the battery to a DC/DC converter.
- The fuel cell system and battery are connected to a DC/DC converter, which is the most used one in research due to its flexibility in controlling the power flow [26].

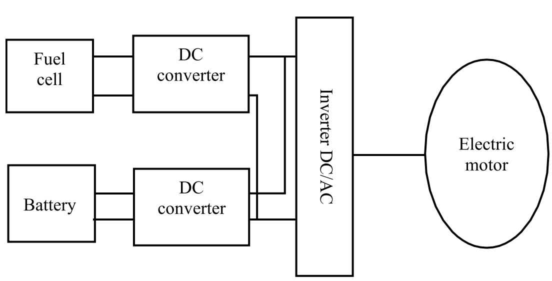

Fig. 3. Topology of fuel cell electric vehicles

4 Issues and challenges of FCEVs

FCEVs require many considerations in terms of the development of hydrogen infrastructure. This is why they are still not commercially available. Several components of EVs may affect the efficiency of the energy management system (EMS) [27]. The main issues are listed below.

4.1 Battery lifetime

A battery is the main component in an electric vehicle (EV), leading to the development of batteries with different materials. The most commonly used one is the NiMH and Li-Ion Batteries [28]. Each type of these batteries is characterized by its efficiency, material availability, and reliability. The life of the battery matters; it depends on the state of charge (SOC) and depth of discharge, making the choice of battery performance more complex [29].

4.2 Economic impact

A cost comparison was made between FCEVs and battery electric vehicles BEVs that are commonly used to reveal that FCEVs are more expensive than BEVs [30]. The high cost could be explained due to the necessary expenses of manufacturing and transporting hydrogen fuel.

5 Conclusion

Hydrogen has a considerable solid potential to meet the energy demand and zero emissions objectives. To do so, renewable energy sources are the best alternatives to achieve this target. However, they still face some challenges related to energy efficiency compared to fossil fuels. Green Hydrogen can be applicable in different fields. In this study, we have focused on electric vehicles powered by fuel cells. Fuel cells (FC) are unique in terms of the variety of their applications. Indeed, they can utilize a wide range of fuels and feedstocks and provide power for systems as large as a utility power station and as small as a laptop computer. Different topologies were listed to define the more suitable for the EV application. Thus, the FCEV issues were discussed from the perspective of battery lifetime and economic aspects. Starting from this analysis, we aim to develop hydrogen production efficiency from a renewable source, the hybrid system based on solar and wind energy, as the demand will increase. Thus, the hybrid system reduces the risk of decreasing the electrolysis efficiency, leading to an essential increase in hydrogen production.

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