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FUEL CELLS: SUSTAINABLE ENERGY SOLUTIONS THROUGH ELECTROCHEMICAL REACTIONS, GREEN TECHNOLOGY'S

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Abstract

The state of the art in fuel cell technology has been thoroughly examined in this essay, which has been written by the author. Polymeric Electrolyte Membrane Fuel Cells (PEMFC), Direct Methanol Fuel Cells (DMFC), Alkaline Fuel Cells (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC) are the six most important fuel cell technologies. Following a general description of the fuel cell base structure, the advantages and disadvantages of each fuel cell technology are discussed, as well as the primary applications of each fuel cell technology. The developments that are to come are also displayed.
When considering the rapid climate change, the conflict in Ukraine, and the epidemic of the coronavirus disease that occurred in 2019, there is an immediate need for new technology, systems, societal organisation, and policies that are geared towards energy conservation. For instance, concerns about market and governmental reactions that could lead to additional lock-ins, such as investing in liquefied natural gas infrastructure and using all available fossil fuels to compensate for Russian gas supply cuts, may impede efforts to decarbonise the nation's energy supply.

Keywords:- *Fuel cells, energy solutions, electrochemical reactions.*

INTRODUCTION

Fuel cells are widely regarded as one of the most important solutions for the 21st century. They make it possible to generate electricity and heat in an environmentally friendly and efficient manner from a variety of basic energy sources.

In order to generate electricity and heat, fuel cells are electrochemical devices that make use of hydrogen (H2) or fuels that are rich in hydrogen, in conjunction with oxygen from the air environment. Nevertheless, this fundamental process can be modified in a variety of ways, depending on the type of fuel cell and the fuel that is utilised.

Portable power generators, micro power generators, auxiliary power generators, stationary power generators, distributed power generators, and portable power generators for transportation, military projects, and the automotive market are some of the numerous applications that are extremely fascinating for this technology.

All of these applications are going to be utilised in a wide variety of settings and industries all over the world where they will be used.

In 2007, fuel cells began to be marketed to endusers with written warranties and service capability, and they also satisfied the rules and standards of the markets in which they were sold. This marked the beginning of fuel cells' transition into the commercial market for a range of applications. As a consequence of this, a number of market categories no longer exhibit characteristics of oversupply and overcapacity but rather exhibit demand-driven behaviour. Particularly, thousands of PEMFC and DMFC auxiliary power units (APU) have been commercialised for use in recreational applications, such as boats and campervans. Additionally, a substantial number of micro fuel cell units have been sold in the portable sector, including in toys and educational kits. As a result of the demand from the military, hundreds of DMFC and PEMFC portable power units were put into service for infantry soldiers. These units provided power to communications and surveillance equipment, and they also decreased the stress of carrying hefty battery packs for the dismounted soldier.

OBJECTIVES

1. To study fuel cells.
2. To study green technology.

Fuel cells

Fuel cells are a type of energy conversion device that are capable of continually converting the chemical energy contained in a fuel into electrical energy. This process occurs so long as both the fuel and the oxidant are present. It possesses beneficial properties that surpass those of conventional combustion-based technologies that are currently being utilised in some crucial industries, such as electronic, household power, power plants, passenger vehicles, and military applications. Such technologies are currently being utilised in these fields. Fuel cells have been shown to have an electrical energy conversion efficiency of at least sixty percent, far higher than that of combustion engines, while also producing fewer emissions with its operation. As a result of the fact that hydrogen fuel cells only produce water as a byproduct of their power generating process, there are no emissions of carbon dioxide or other air pollutants that contribute to the formation of smog or cause health issues while the cells are in operation. Additionally, fuel cells produce a low level of noise during operation due to the fact that they have a reduced number of moving parts. Although there are many different types of fuel cells, they all function in a manner that is essentially the same. An anode, an electrolyte, and a cathode are the three components that make up a fuel cell. These three components are adjacent to one another. As hydrogen undergoes an oxidation reaction at the anode ($H2 \rightarrow 2H^{+} + 2e^{-}$), it generates cations that go to the cathode through the electrolyte. Additionally, it generates free electrons that travel through the external circuit. In contrast, a reduction process takes place at the cathode, where the cations and electrons are responsible for reducing oxygen to water; this reaction takes place.

green technology's

For home heating systems that are powered by oil or natural gas, there are a number of environmentally friendly alternatives that may be utilised to assist in the reduction of carbon emissions and the improvement of energy sustainability. Heat pumps that draw their energy from the air or the earth are more environmentally friendly and efficient than conventional heating systems. At the same time, biomass boilers are able to supply

heat by burning wood pellets, chips, or logs. This can be a more environmentally friendly alternative to the use of renewable fossil fuels. On the other hand, they need to be maintained on a regular basis and have a bigger capacity for energy storage.

In addition, solar thermal panels are able to harvest energy from the sun and utilise it to heat water or air for the purpose of space heating. This can be a renewable and environmentally friendly alternative to conventional heating systems. Infrared heating panels take advantage of infrared radiation to heat the things in the room. This results in heating that is more targeted and efficient, and it requires less maintenance. Geothermal heating, which is an alternative to conventional heating systems that is both environmentally friendly and energy efficient, is a method of heating and cooling that makes use of the heat that is naturally produced by the earth. It is essential to seek the advice of an expert in order to ascertain the green heating solution that is most appropriate for the region, climate, size of the property, and the renewable energy sources that are available.

Research Methodology

In light of the fact that the purpose of the study is to conduct a literature review of methods that may be used to assess the economic, ecological, and/or social sustainability of fuel cells and the results of their application, we have made the decision to employ the methodology of systematic literature research by searching through databases. During the month of December in 2022, research was held. The terms that we searched for are displayed in Figure 1, which can be found below them.

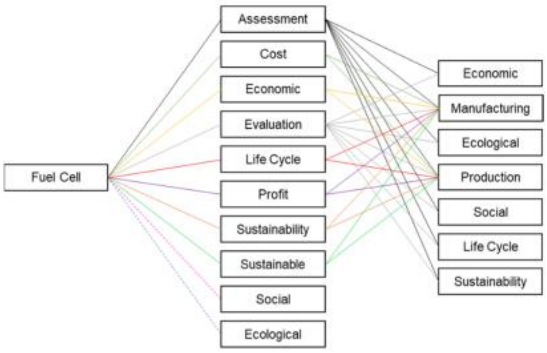


Figure 1.Used keywords.

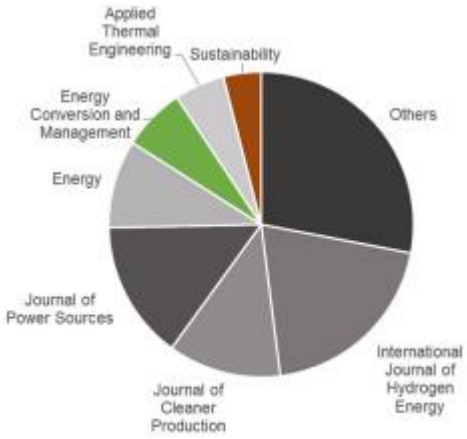
As can be seen in Figure 1, the keyword fuel cell was included in each and every search combination. This is due to the fact that the fuel cell is the object that we are taking into consideration. Always make sure that the search words are included in the titles of the papers that are being searched. In order to narrow the scope of the search, additional search terms were merged with the initial keyword using the Boolean operator "AND." These search terms either contain a reference to production, a connection to a general evaluation, or a relation to sustainability. In each of the examples, a search with two keywords yielded two exceptions (fuel cell AND social; fuel cell AND ecological). Because there were so many hits, a third search term was added in these instances, and it was also accompanied by the Boolean operator "AND." For instance, the two terms fuel cell and assessment were associated with a great number of other phrases, such as fuel cell AND assessment AND economic. The method of collecting literature is presented in Table 1, which may be viewed here. We obtained a total of 1169 results, which included doublings inside the databases, and 1030 results

that did not involve any doublings within the single databases. Following that, we eliminated all database-comprehensive doublings, leaving 375 results available for further consideration. After that, we went through all of the titles and made sure that the only papers that came up were those that discussed the economic, ecological, and/or social evaluation of fuel cells. After reading the abstracts of the remaining 178 papers, this led to the decision to exclude 29 of the papers from consideration. It was decided to do an in-depth reading of 86 of the 149 papers that were produced as a result. These papers were selected because they had an H-index that was greater than 80 and/or a VHB (the abbreviation for "Verband der Hochschullehrer für Betriebswirtschaft"). The provision of a score of A, B, or C for journals in terms of their academic quality is one of the objectives that the association is tasked with. This grading is intended to encourage transparency and orientation.

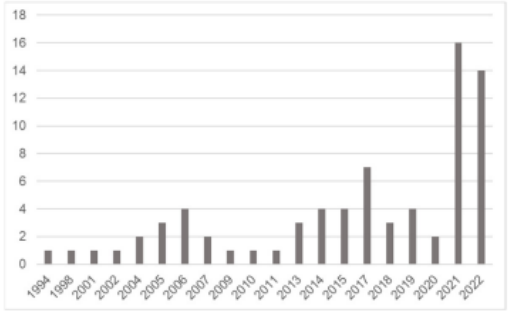
Table 1. Literature research

Database	**ScienceDirect**	**Web of Science**		**EBSCOhost**	**Scopus**
Results with doublings within the databases	229	291		249	400
Results without doublings within the databases	193	260		221	356
Results without database-comprehensive doublings			375		
Results after checking titles			178		
Results after reading abstracts			149		
Results with H-index > 80 and/or VHB-Ranking (A, B, C)			86		
Results after in-depth reading			75		

A more in-depth analysis was performed on the remaining seventy-five manuscripts. In Appendix A, you can find a summary of the papers that were presented. When it comes to the journals in which they are published, it is notable that they cover a wide range of topics that are more technical, more economic, or more ecological in nature (see Figure 2a). There are publications in journals that have a more technical foundation, such as the Journal of Power Sources, for instance, while there are also publications in journals that have a more ecological focus, such as the International Journal of Hydrogen Energy, which has published fifteen of the papers. In addition, it is interesting that there is a significant rise in the number of publications released in the years 2021 and 2022. On the other hand, publications have been accessible since 1994, and there is a relatively even distribution of papers across the years up until 2020 (see Figure 2b).



(a)



(b)

Figure 2. (a) Journals with publications; (b) publications per year.

Results and Discussion

We conducted an analysis of the publications with regard to a number of criteria, including the focus of evaluation (economic, ecological, and/or social), as well as the techniques and target numbers that were utilised. In the following, we differentiate between works that pertain to the social, ecological, and economic domains of subject matter. In addition, we take into consideration the articles that concentrate on undertaking an integrated analysis (for instance, by taking into account both economic and ecological issues). When it comes to these various categories, we take into consideration the target figures as well as the strategies that are utilised. The objects that were taken into consideration in the investigations are also analysed by us. In this way, we differentiate between the application field, the system boundaries, and the type of fuel cell (for example, a solid oxide fuel cell (SOFC) or a polymer electrochemical fuel cell (PEMFC).

The purpose of this study is to provide a comprehensive overview of sustainability-oriented assessment methodologies utilised for fuel cells in general. On the one hand, it encompasses a greater variety of items that are taken into consideration, and on the other hand, it encompasses strategies. The evolution of the technology, for example, or certain types of fuel cells or evaluation methods, for example, are frequently the focal points of evaluations that are already in existence. Nevertheless, in this assessment, a number of different contentious issues arise as a result of the wide range of objects and approaches that are taken into consideration. There are two distinct categories that can be applied to these elements. Within the first category, we discuss the limits of our study in terms of its methodology. The second category is comprised of the insights that were gained on the procedures and results of the studies that were taken into consideration.

(1) With regard to the limits of the methodology, it is important to note that the results of the literature research are heavily influenced by the databases that were utilised and, most importantly, the keywords that were utilised. In order to acquire a comprehensive understanding of the evaluation of fuel cells via the lens of sustainability, the keywords were retained in a manner that was both wide and broad. In light of the fact that the results that were discovered are extremely diverse, it would be a good idea to modify the search in order to answer a more specific query. For instance, you could restrict the search to a particular type of fuel cell (for example, only PEMFC) or a particular system application (for example, only cars). As a consequence of this, the search words would need to be modified so that they are more closely tailored to the new inquiry. In addition, a reduction in the number of keywords that were used would also result in a shortening of the amount of results that were discovered, and a variation in the keywords that were used would have led to different results (for instance, the term ecological might have been replaced with the term environmental). In addition, the studies that are discovered could be different based on the databases that are utilised for the investigation of the literature. In light of this, it would have been possible to make use of additional databases, such as Google Scholar. In addition to the search terms and databases that were utilised, the inclusion and exclusion criteria also serve to restrict the studies that were examined and have an impact on the outcomes that were obtained. Among the 86 papers that were considered for this study, 75 papers were chosen for a more in-depth reading. The selection was made based on whether or not the papers had a VHB score of at least C and/or an H-index of at least 80. The number of articles that were included in the study would change in accordance with the modification of any of these inclusion or exclusion criteria (for example, if an H-index of at least 50 were to be considered sufficient), the number of papers that were included in the study would increase.

(2) The insights that were gained pertain to the procedures and findings that were provided within the research that were taken into consideration, and they are detailed further below.

Conclusion

As was mentioned in the chapters that came before this one, there are a great number of fuel cell technologies now in existence, and each of these technologies has its own set of advantages and disadvantages. Each of these technologies is exceptionally well-suited for particular application environments; however, they are plagued by a multitude of problems that prevent them from being fully commercialised. However, there are four technologies that, both because of the widespread interest in the benefits they could bring and the level of development of the fuel cell type, are probably the most suitable technologies to be fully commercialised into the market in the near future. These technologies are fuel cells. Phosphoric acid fuel cells (PAFCs), solid oxide fuel cells (SOFCs), polymer electrolyte membrane fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs) are the technologies that fall under this category.

Although there are many technologies available, the first two are arguably the ones that are most suited for applications that include the generation of static electricity. In point of fact, the technology retains the most significant advantages in terms of the following: efficiency, fuel cell life cycle, flexibility with regard to the fuel that is used, simplicity of design, and contained costs.

The second and third technologies are the ones that the majority of people across the world are most interested in. These technologies are used for a variety of additional applications, including distributed power production, portable applications, and all of the applications that pertain to the automotive and transportation industries. The creation of a viable hydrogen network, which involves effective production and efficient distribution (which involves finding effective solutions for the safety issues associated with hydrogen storage), is the only thing that will make this a possibility.

By contrasting the various fuel cell technologies, the purpose of this article is to serve as a useful resource for all researchers and professionals who are interested in working in an area that is incredibly significant for both the environment and the electrical energy industry.

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