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Review

Hydrogen Fuel Cell Technology for the Sustainable Future of Stationary Applications

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Received: 29 September 2019; Accepted: 29 November 2019; Published: 3 December 2019

Abstract: The climate changes that are becoming visible today are a challenge for the global research community. The stationary applications sector is one of the most important energy consumers. Harnessing the potential of renewable energy worldwide is currently being considered to find alternatives for obtaining energy by using technologies that offer maximum efficiency and minimum pollution. In this context, new energy generation technologies are needed to both generate low carbon emissions, as well as identifying, planning and implementing the directions for harnessing the potential of renewable energy sources. Hydrogen fuel cell technology represents one of the alternative solutions for future clean energy systems. This article reviews the specific characteristics of hydrogen energy, which recommends it as a clean energy to power stationary applications. The aim of review was to provide an overview of the sustainability elements and the potential of using hydrogen as an alternative energy source for stationary applications, and for identifying the possibilities of increasing the share of hydrogen energy in stationary applications, respectively. As a study method was applied a SWOT analysis, following which a series of strategies that could be adopted in order to increase the degree of use of hydrogen energy as an alternative to the classical energy for stationary applications were recommended. The SWOT analysis conducted in the present study highlights that the implementation of the hydrogen economy depends decisively on the following main factors: legislative framework, energy decision makers, information and interest from the end beneficiaries, potential investors, and existence of specialists in this field.

Keywords: alternative energy; energy efficiency; fuel cell; hydrogen energy; stationary application

1. Introduction

Unconventional energy sources have gained and will continue to gain an increasing share in energy systems around the world [1], due to both the research and political efforts [2–8] involved in their development, as well as due to the price increases of energy obtained by traditional methods [9]. The primary energy sources, generally called renewable, are those sources found in the natural environment, available in virtually unlimited quantities or regenerated through natural processes, at a faster rate than they are consumed. Officially recognized renewable energies originate from the Sun's rays, the internal temperature of the Earth or the gravitational interactions of the Sun and the Moon with the oceans. The processes and methods of producing or capturing these types of alternative energy are in the process of being improved, the lower costs of infrastructure investments and the improved efficiency of conversion processes have made renewable energy sources provide a small part of the energy needs on a planetary scale [10]. The more optimistic forecasts estimate that renewable energy production will enjoy a 30–50% share of the total energy market by around 2050, but this depends on reducing production costs and finding massive energy storage possibilities [11]. In addition, none of these forms of energy can also provide fuels in satisfactory quantities for use in various stationary, mobile or industrial applications [5].

In this context, we are currently looking for alternatives for obtaining energy by using technologies that offer maximum efficiency, high reliability and minimum pollution. Such a technology, considered at the moment the cleanest, through which sustainable energy can be obtained, is based on fuel cells [12]. As fuel cells develop, hydrogen-based energy production has become a reality [13]. The future hydrogen-based economy presents hydrogen as an energy carrier within a secure and sustainable energy system [14]. Humanity is on the verge of a new era characterized by advanced technologies and new fuels. We will witness new and completely different ways of producing and using energy. The energy could be generated by sources with virtually zero pollution. Hydrogen can be considered as a synthetic fuel, carrying secondary energy in a future era after the fossil fuel economy [15–18].

In order to outline an overview of the sustainability elements, the potential of using hydrogen as an alternative energy source for stationary applications and for identifying the possibilities of increasing the share of hydrogen energy in stationary applications, in this paper, a SWOT analysis was performed.

The work was structured as follows: the first part introduces the topic, presents and briefly describes the issues addressed. In Section 2 the Materials and Methods used in the present study are described. The data of the theme regarding the technical aspects and the sustainability elements are presented in Section 3—Hydrogen energy and Fuel cells—Hydrogen conversion technology. For the identification of the own potential of harnessing the hydrogen energy in stationary applications, but also of the opportunities and possible threats from the external environment, a SWOT analysis was developed in Section 4 and all aspects involved are discussed and critically analyzed, with the aim to evaluate the options and establish strategies to address the issues that best align the resources and capacities of hydrogen energy to the requirements of the stationary applications domain. The conclusions are presented is Section 5 as short bullet points that convey the essential conclusions of this paper.

2. Materials and Methods

The documentation for carrying out the study is based on the specialized scientific literature, articles in journals, papers presented at conferences on the hydrogen applcation topic and on-line scientific databases and web pages, including Google Academic, Google Scholar, MDPI, Science Direct, Scopus and research platforms or topic-specific web pages. In addition, this paper utilizes and analyzes a large number of reports, informations regarding the hydrogen & fuel cell strategic research agenda and documents published by the European Union (EU), the United Nations Organization (ONU), the International Energy Agency (IEA) [19–21] and other important dates from research and development institutions that are relevant to hydrogen economy, including E4Tech [22,23], International Association for Hydrogen Energy (IAHE) [24], National Research and Development Institute for Cryogenic and Isotopic Technologies (ICSI) Râmnicu Vâlcea, Romania.

The instrument used in this paper in order to verify and analyze the overall position with respect to general acceptance status regarding the harnessing energy potential of hydrogen technology and its use as an alternative energy source for stationary applications is the SWOT analysis.

SWOT analysis provides an overview of the characteristics specific to the objective/domain of analysis and the environment in which it will be implemented. The SWOT analysis functions as an x-ray of the concept of hydrogen energy implementation in stationary applications and at the same time evaluates the internal and external influence factors of the concept, as well as its position in the applicability environment in order to highlight the strengths and weaknesses of the concept, in relation to the opportunities and threats existing at the moment [25].

The steps to perform the SWOT analysis are shown schematically in the diagram in Figure 1 in order to identify the strengths, weaknesses, opportunities and threats characteristics of the concept of hydrogen energy for stationary applications.

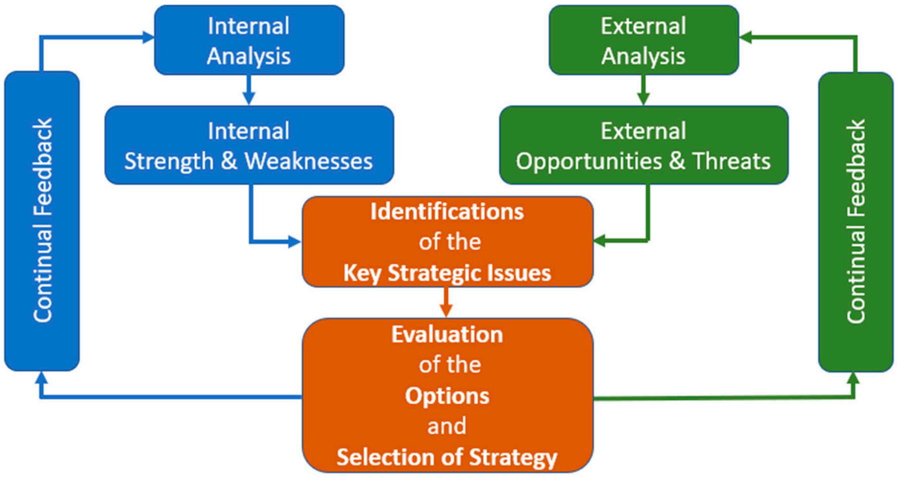


Figure 1. The SWOT process.

As a rule, SWOT analysis allows investigators to improve the performance of current strategies by using new opportunities or by neutralizing potential threats [25]. Therefore, this analysis could be useful in helping decision makers and stakeholders to have a better overview of the concept of hydrogen energy used in stationary applications, facilitating the improvement of the current situation. As a result, SWOT analysis can be considered as an appropriate instrument for this research with scope to identify significant elements and advantages regarding the use of hydrogen energy in stationary applications, research/implementation/solutions/market status and possible changes, challenges, perspectives and improvements.

In order to perform the proposed SWOT analysis, the development in the form of the schematic matrix illustrated in Figure 2, the following stages were required:

Stage 1: Documentation, collection, interpretation of materials and data, and critical analysis.

Stage 2: Discussions with several experts, researchers and PhD students on the topic of hydrogen economy, but also of civil engineers given the scope of the concept, namely stationary applications.

Stage 3: Based on the data and results obtained from the previous stages, all the significant elements regarding the strengths, weaknesses, opportunities and threats are critically discussed, analyzed, classified and the SWOT matrix was drawn.

Stage 4: The SWOT matrix was used to determine strategies for strengths-opportunities (S&O), strategies for weaknesse-opportunities (W&O), strategies for strengths-threats (S&T) and strategies for weaknesses-threats (W&T). To develop S&O strategies, internal strengths are correlated with external opportunities, and strengths are key elements that will take advantage of opportunities. W&O strategies were developed by matching them internal weaknesses with external opportunities and overcoming weaknesses by taking advantage of opportunities. S&T strategies correlate internal strengths with external threats, and strengths are used to avoid threats. W&T strategies correlate internal weaknesses with external threats, and weaknesses are minimized to avoid threats.

	Strengths *internal*	**Weaknesses** *internal*
Opportunities *external*	**S&O**	**W&O**
Threats *external*	**S&T**	**W&T**

Figure 2. SWOT analysis matrix [25].

3. Considerations Regarding Hydrogen Fuel Cell Technology

3.1. Hydrogen—Energy Vector within a Sustainable Energy System

Today hydrogen is recognized as a non-polluting energy carrier because it does not contribute to global warming if it is produced from renewable sources [26]. In addition, hydrogen is the only secondary energy carrier that is suitable for a wide range of applications in the market [27]. At the center of attention is the fact that hydrogen can be obtained from a wide range of primary energies [28]. It can be used advantageously for a wide range of applications, ranging from transport and portable to stationary use [29]. In addition, hydrogen can also be used in decentralized systems without emitting carbon dioxide [30]. Hydrogen is already a part of today's chemical industry, but as a source of energy its rare benefits can only be achieved with technologies such as fuel cells [31].

Since hydrogen can be produced from a wide range of primary energies and can be consumed in a larger number of applications, it will become an energy center, just as electricity today is [32]. The advantage of hydrogen over electricity is that it can be stored in the medium and long term [33]. As a consequence, an energy carrier helps to increase the stabilization of energy security and price, giving rise to competition between different energy sources [34].

Veziroglu [35,36], editor of the journal specialized in hydrogen technology and energy, the *International Journal of Hydrogen Energy* summarizes several features that recommend the use of hydrogen as a secondary energy vector produced using unconventional technologies:

- Hydrogen is a concentrated primary energy sources, which can be made available to the consumer in a convenient way.
- It offers the possibility of conversion into different forms of energy through high efficiency conversion processes.
- It is an inexhaustible source, if it is obtained electrolytically from water; hydrogen production and consumption represents a closed cycle, the source of production—water—is kept constant and represents a classic cycle of recirculation of this type of raw material.
- Is the easiest and cleanest fuel; the burning of hydrogen is almost entirely devoid of pollutant emissions.
- It has a much higher gravimetric energy density compared to other fuels.
- Hydrogen can be stored in various ways, such as gas at normal pressure or at high pressure, in the form of liquid hydrogen or as solid hydride.
- It can be transported over long distances, stored in the native form or in one of the modalities presented above.
- Hydrogen-based fuel cells have efficiencies of up to 60% [35,36].

Hydrogen is considered by more and more specialists to be a true fuel of the future. Hydrogen is condensed to −252.77 °C, and the specific weight of liquefied hydrogen is 71 g/L, which gives it the highest energy density per unit of mass between all fuels and energy carriers: 1 kg of hydrogen contains as much energy as 2.1 kg of natural gas or 2.8 kg of oil. This characteristic of it, made of hydrogen the fuel used in the propulsion and energy supply of the spaceships. Unlike other fuels, such as oil, natural gas and coal, hydrogen is renewable and non-toxic when used in fuel cells. Hydrogen has a very high potential as environmentally friendly fuel and in reducing the import of energy resources [37–42].

Even if the use of hydrogen at present seems unprofitable, due to the improvement of the technologies, we could assist in the not too distant future in the development of a hydrogen-based economy [43].

Etymologically, the word hydrogen is a combination of two Greek words, meaning "to make water" [44]. Produced from non-fossil sources and raw materials, using different forms of alternative energy (solar, wind, hydroelectric, geothermal, biomass, etc.), hydrogen is considered to be a prime fuel in the supply of so-called "green energy" [45]. Thus, hydrogen-fueled systems can be considered as the best solution for accelerating and ensuring global energy stability [43]. Hydrogen is expected to play an important role in the future energy scenarios of the world, the most important factor that will determine the specific role of hydrogen will probably be the demand for clean growing energy [35]. At the same time, hydrogen can, to some extent, replace fossil fuels and become the preferred clean, non-toxic energy carrier in the near future [36]. The main characteristics of hydrogen [35,37], presented in Table 1, recommend it as an alternative fuel to the classic ones.

Table 1. Hydrogen characteristics.

Characteristics	Unit	Value
Density	kg/m^3	0.0838
Higher Heating Value (HHV)/liquid hydrogen (LH_2)	MJ/kg	141.90–119.90
HHV/cryogenic hydrogen gas (CGH_2)	MJ/m^3	11.89–10.05
Boiling point	K	20.41
Freezing point	K	13.97
Density (liquid)	kg/m^3	70.8
Air diffusion coefficient	cm^2/s	0.61
Specific heat	kJ/kg K	14.89
Ignition limits in air	% (volum)	4–75
Ignition energy in the air	Millijoule	0.02
Ignition temperature	K	585.00
Flame temperature in air	K	2318.00
Energy in explosion	kJ/g TNT	58.823
Flame emissivity	%	17–25
Stoichiometric mixture in air	%	29.53
Air/fuel stoichiometry	kg/kg	34.30/1
Burning speed	cm/s	2.75
Power reserve factor	-	1.00

In order to highlight the advantages that hydrogen has, compared to other fuels, the main properties of the various fuels currently used are presented in Table 2.

Table 2. Comparison between the main properties of hydrogen and other fuels [46,47].

Fuel Type	Energy/Mass Unit (J/kg)	Energy/Volume Unit (J/m^3)	Energy Reserve Factor	Carbon Emission Specific (kgC/kg Fuel)
Liquid hydrogen	141.90	10.10	1.00	0.00
Hydrogen gas	141.90	0.013	1.00	0.00
Fuel oil	45.50	38.65	0.78	0.84
Gasoline	47.40	34.85	0.76	0.86
Jet fuel	46.50	35.30	0.75	-
GPL	48.80	24.40	0.62	-
GNL	50.00	23.00	0.61	-
Methanol	22.30	18.10	0.23	0.50
Ethanol	29.90	23.60	0.37	0.50
Biodiesel	37.00	33.00	-	0.50
Natural gases	50.00	0.04	0.75	0.46
Coal	30.00	-	-	0.50

Analyzing the table information it can be concluded that the main arguments in favor of the use of hydrogen as synthetic fuel, obtained from renewable sources, are the following: it has the highest energy/mass unit of all the fuel types; it is ecologically friendly, as from its combustion produces only water vapor, indicating that for hydrogen the amount of carbon emissions is zero; it has the highest energy reserve factor, and the largest conversion factor into electricity, respectively, and for this reason it is considered the best of the fuels presented, and the energy efficiency is very high. Hydrogen is expected to play an important role in future energy scenarios globally [46,47]. The advantages that promote it as an energy vector in relation to other forms of energy are:

- Hydrogen can be transported remotely through pipes, in safe conditions.
- Hydrogen is a non-toxic energy carrier, with a high specific energy per mass unit (for example, the energy obtained from 9.5 kg of hydrogen is equivalent to that of 25 kg of gasoline).
- Hydrogen can be generated from various energy sources, including renewable ones.
- Compared to electricity or heat, hydrogen can be stored for relatively long periods of time.
- Hydrogen can be used advantageously in all sectors of the economy (as a raw material in the industry, as a fuel for cars and as an energy carrier in sustainable energy systems to generate electricity and heat through fuel cells).

Barriers to be overcome refer to issues regarding:

- Hydrogen burns in the presence of air, which can cause operational safety problems.
- Storing hydrogen in liquid form is difficult because very low temperatures are required to liquefy hydrogen.
- High costs of hydrogen technologies and processes.
- High costs of hydrogen energy conversion technologies through fuel cells.
- The viability/cost ratio of hydrogen and fuel cell technologies is relatively low.
- The current lack of logistics, transport infrastructure and distribution of hydrogen to final consumers requires costly investments.

Schematically the pro/against hydrogen arguments are shown in Figure 3.

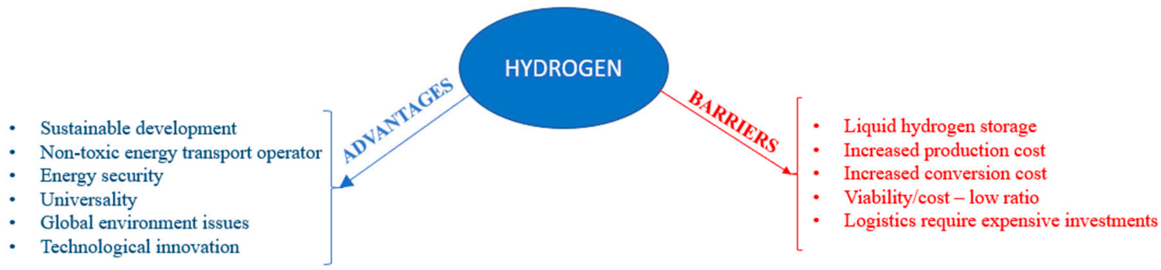


Figure 3. Advantages and barriers regarding the use of hydrogen as energy vector [40].

In view of the research and development programs supported in this field, the technical problems regarding the production, storage and distribution of hydrogen, together with the reduction of costs and the increase of the life of the equipment used in the generation of energy based on hydrogen, will be solved shortly time, and hydrogen will become a possible solution for providing fuels, at the same time being an alternative energy resource to the traditional ones.

3.2. Fuel Cells—Hydrogen Conversion Technology

Science has shown that there are two alternatives for sustainable energy supply: renewable sources and fuel cells—hydrogen-based energy—which will play a complementary role in ensuring global energy resource security [36].

By promoting the use of hydrogen-based energy technologies as clean energy technologies for stationary applications [48], at the level of local communities, industrial and commercial communities, the research topic in this field will help the practical development of sustainable and clean energy systems.

3.2.1. General Aspects

Short History

The beginning of the 19th century represents the starting point of research in the field of fuel cells. In 1801 Humphry Davy demonstrated the principle that underlies the functioning of the fuel cell, and later in 1839 the lawyer and amateur scientist William Grove accidentally discovered the principle of the fuel cell during an electrolysis expereriment, when he disconnected the battery from the electrolysis device and touched the two electrodes [49]. He called this cell "gas battery", which consisted of platinum electrodes placed in tubes containing hydrogen gas and oxygen, respectively, tubes submerged in dilute sulfuric acid. The generated voltage was around 1 V. Sometime later, Grove connected several such "gas batteries" in series and used this thus obtained voltage source to supply the electrolyzer that separates the hydrogen from the oxygen. Due to electrode corrosion problems and the instability of the materials used, Grove's fuel cell did not produce practical results [50]. Langer and Mond developed Grove's invention by observing that over time the reactivity phenomenon of platinum black in contact with electrolytes is diminished, and the life of the fuel cell is prolonged by keeping the electrolyte in a non-conducting porous material [42,51], and using in 1889 for the first time the term fuel cell.

Subsequently, the studies were deepened with significant progress, and the 1960s–1970s brought the first practical applications of fuel cells, these being used by NASA for spacecraft. At the same time, the General Electric company was developing fuel cells with proton exchanger membranes, which were the basis of the fuel cells used for the generation of electricity in the Gemini program missions and the Apollo space program [51,52]. Starting in 1990, the research aimed to implement fuel cell technology in stationary applications, and fuel cells of different capacities for use in this field have been developed. Progress on membrane durability and improved energy performance of fuel cell assemblies has prompted the use of phosphoric acid fuel cells (PAFCs) in cogeneration applications and their widespread use [19,31,51].

Also, proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) technology has been developed for this field, especially for small stationary applications. The year 2000 also marks significant contributions in the field of portable devices, when fuel cell technology with direct methanol (DMFC) is widely adopted and used in this type of applications [19,31,51].

In the last two decades there has been a rapid acceleration in the increase of the use of fuel cells covering a wide diversity of applications in the portable, mobile and stationary fields. These increases are due, on the one hand, to technical progress in the field of fuel cells, and on the other hand, they are driven by global concerns about energy security, efficiency, energy sustainability, reducing greenhouse gas emissions and not least, decreasing dependence on the use of fossil fuels.

Fuel Cell Concept

Fuel cells are now increasingly being researched, considering that they are revolutionizing the ways in which energy is produced. They use hydrogen as a fuel, while also ensuring the possibility of generating clean energy, with the protection and even improvement of the environmental parameters [17,18].

By definition, the fuel cell is an electric cell, which, unlike battery cells, can be continuously fed with fuel, so that the electrical power from the output of this electric cell can be maintained indefinitely [38,39,42]. Therefore, the fuel cell converts hydrogen or hydrogen-based fuels directly into electricity and heat through the electrochemical reaction of hydrogen with oxygen. The process carried out at the fuel cell level is the inverse of electrolysis:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{energy} \quad (1)$$

where, the conversion of the chemical energy of the fuel (hydrogen) and the oxidant (oxygen) into continuous current, heat and water as reaction products [42] takes place. Due to the fact that in the fuel cell the hydrogen and oxygen gases are transformed by an electrochemical reaction into water, this has considerable advantages over the thermal engines: higher efficiency, practically silent operation, lack of pollutant emissions where the fuel is even hydrogen, and if hydrogen is produced from renewable energy sources, the electrical power thus obtained is indeed sustainable [38,39,42].

Component Elements

In order to analyze the importance of all the phenomena that take place in a fuel cell, it is necessary to know the component elements (Figure 4).

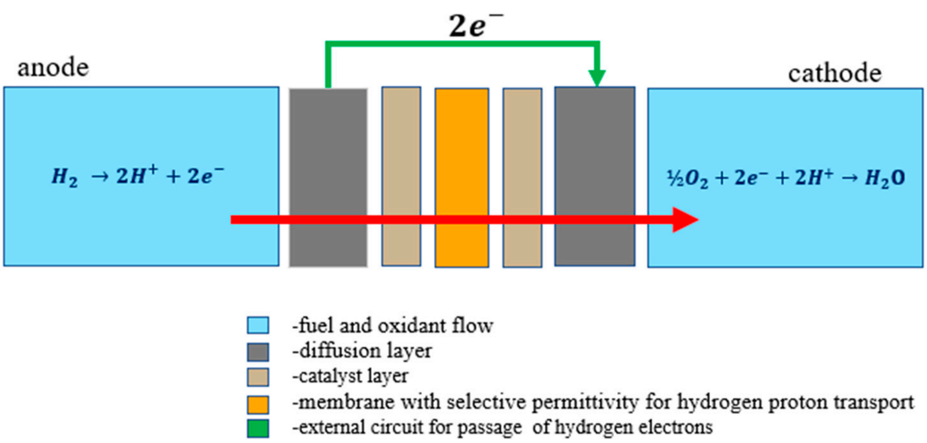


Figure 4. Components of the fuel cell [24,42].

There are some distinct elements in a fuel cell [42], namely:

Electrolyte. In order for a substance to fulfill the role of electrolyte in a fuel cell it must fulfill several conditions, as follows: high chemical stability with respect to the two electrodes, in order not to react with them; high melting and boiling points for cells operating at high temperatures; predominantly ionic conductivity and absence of electronic conductivity. The main types of electrolyte are liquid electrolytes (the most common are basic or acidic solutions, the ion transport phenomenon being similar to the one from the electrolysis of aqueous solutions), solid electrolytes (ion exchange membranes and crystalline solid electrolytes are used), melted electrolytes and liquid electrolytes with dissolved fuel [42].

Catalyst layer (at the anode and cathode). All electrochemical reactions in the fuel cells take place on the surface of catalyst layers. To increase the reaction rate of the cell, the electrodes (catalyst layers) contain catalyst particles. Thus, the electrode of a fuel cell is made of a porous carbon support on which the catalyst is deposited. The thickness of an electrode is usually between 5–15 µm, and the charge of the catalyst is between 0.1 and 0.3 mg/cm^2 [42].

Bipolar plate (at the anode and cathode). Bipolar plates play a dual role, guiding the reactant gases to the electrolytic exchange surface of the fuel cell and driving the obtained electric current. Materials used for bipolar plates must have a high conductivity and be gas-tight. They must also be corrosion resistant and chemically inert. Taking into account these considerations, graphite or steel can be used, but also composite materials. The gas flow channels are "engraved" in the bipolar plates, which otherwise should be as thin as possible to reduce the weight and volume of the battery.

The geometry of the flow channels has an influence on the flow velocity of the reactants and the mass transfer, implicitly they have a determining influence on the performance of the fuel cells, being necessary to optimize the flow surface so that the reaction surface is as large as possible [42].

Operating Principle

Although there are different types of fuel cells, they all work on the same principle:

- Hydrogen or a hydrogen rich fuel is introduced to the anode, where the anode-coated catalyst separates electrons from positive ions (protons).
- At the cathode, oxygen is combined with electrons and, in some cases, with protons or water, resulting in hydrated water or ions.
- The electrons that form at the fuel cell anode cannot pass directly through the electrolyte to the cathode, but only through an electrical circuit. This movement of electrons determines the electric current [38,39,42,52].

The electrochemical conversion consists of the direct conversion into electrical energy of the chemical energy stored in various active materials. This type of conversion is called direct because no other intermediate form is interposed between the initial and final energy forms. Indirect energy conversion systems contain several transformation stages, between which the form of thermal or mechanical energy is obligatory. Direct energy conversion eliminates the “link” thermal or mechanical energy by achieving higher efficiency, which does not depend on the limited efficiency of the thermal machines. The idea of obtaining electricity by direct conversion of chemical energy arose when the problem of unfolding and reverse of the phenomenon of water electrolysis (which results in its components), that is to say, to obtain electric current from the reaction between hydrogen and oxygen [53]. The schematic in Figure 5 illustrates a comparison regarding the operating principle of fuel cells—direct systems of conversion of energy forms and the classical technologies devoted to conversion — indirect systems [54,55].

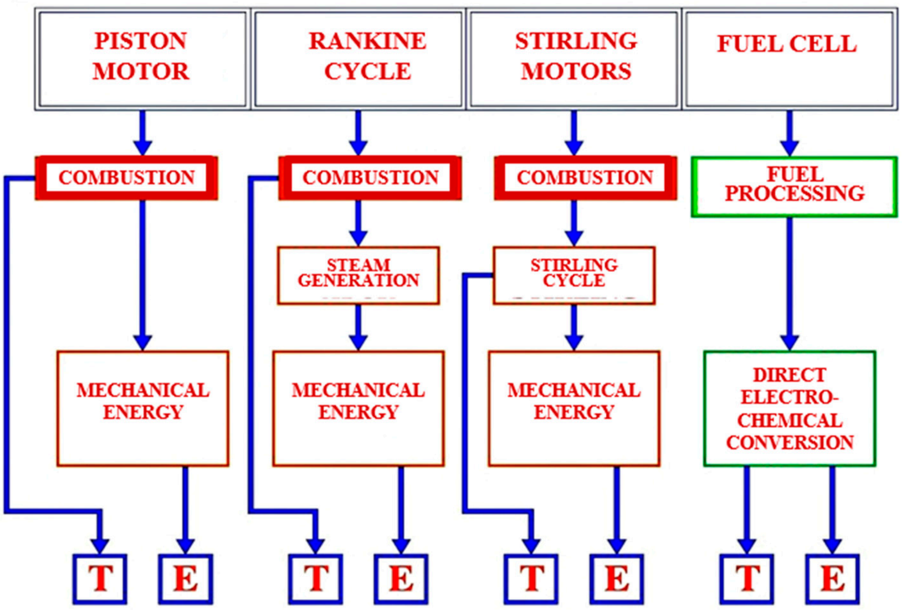


Figure 5. Fuel conversion process. Comparison of the operation principles of various technologies.

Fuel cells are electrochemical electricity generators characterized by a continuous supply of reactants to the two electrodes. The fuel rating comes from the fact that they use as sources of chemical energy, natural or synthetic fuel substances, which are subjected to oxidation and reduction reactions.

The anode, or fuel electrode, is the place where the oxidation of the fuel (H_2, CH_3OH, N_2H_4, hydrocarbons, etc.) takes place. The cathode, or oxygen (air) electrode, is the place where molecular oxygen reduction occurs [31,42,48].

Electrochemical oxidation of hydrogen is carried out at an anode of a conducting material (eg platinum dispersed on activated carbon) constituting the negative pole of the cell [42,44]:

$$\text{acid electrolyte:} \qquad H_2 \rightarrow 2H^+ + 2e^- \tag{2}$$

$$\text{alkaline electrolyte:} \qquad H_2 + 2OH^- \rightarrow 2H_2 + 2e^- \tag{3}$$

The electrochemical reduction of oxygen occurs at a catalytic cathode constituting the positive pole of the cell:

$$\text{acid electrolyte:} \qquad \frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \tag{4}$$

$$\text{alkaline electrolyte:} \qquad \frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^- \tag{5}$$

The catalytic functions of the electrodes are very important, namely: the hydrogen electrode (the anode) must ensure the adsorption of the hydrogen molecule, its activation, promoting the reaction with the hydroxyl ion; the oxygen electrode (cathode) must allow molecular oxygen adsorption, promoting reaction with water.

The anode and cathode are separated by an ionic conductor, electrolyte, and/or a membrane that prevents the reactants from mixing and the electrons pierce the heart of the cell. Initially, the energy released from the oxidation of conventional fuels, generally used in the form of heat, can be converted directly into electricity with excellent efficiency, in a fuel cell. Because in almost all oxidation reactions an electron transfer between fuel and oxidant occurs, it is obvious that the chemical oxidation energy can be converted directly into electricity. There is an oxidation-reduction reaction in which the oxidation of the fuel and the oxidant reduction occur with a loss on the one side and an electron gain on the other. Any galvanic element involves oxidation to the negative pole (loss of electrons) and reduction to the positive one (gain of electrons) and, as in all galvanic elements, the fuel cells tend to separate the two partial reactions in the sense that the changed electrons pass through an external use circuit [39,42,44].

The Main Types of Fuel Cell

The classification of fuel cells can be done according to several criteria that take into account certain common features. Thus, depending on the type of fuel (gases, solids, liquids), depending on the electrolyte used (liquid or solid), depending on how the fuel is consumed (directly and indirectly), but the most widely used classification method is the one takes into account the operating temperature:

- Low temperature (cold) fuel cells, operating between 20–100 °C;
- Medium temperature (hot) fuel cells, operating between 200–300 °C;
- High temperature fuel cells, operating between 600–1500 °C [41,42].

Currently in (or close to) current usage, there are six types of fuel cells, with various operating temperatures, as follows [38,42]:

- Alkaline fuel cells (AFCs), with operating temperatures around 70 °C.
- Direct methanol fuel cells (DMFCs), operating at temperatures between 60–130 °C.
- Molten carbon fuel cells (MCFCs) at temperatures up to 650 °C.
- Phosphoric acid fuel cells (PAFCs) at temperatures of 180–200 °C.
- Proton exchange membrane fuel cells (PEMFCs). These work at low temperatures of 100 °C, but also at temperatures of 150 °C to 200 °C.
- Solid oxide fuel cells (SOFCs). They operate at high temperatures from 800–1000 °C.

Each of these fuel cell types has specific characteristics. They have obvious advantages, but also disadvantages (in fact limited possibilities of use, now or in the near future) [24,41,42,56]. Apart from these six types there are others, more or less different from the first ones, which will probably be used in the near future: the zinc-air fuel cell (ZAFC) which uses a zinc anode similar to a battery; the ceramic proton exchanger fuel cell (PCFC), a relatively new type of fuel cell; the regenerative fuel cell (RFC) which is based on the most attractive way of generating hydrogen and oxygen by electrolysis, having the Sun as an energy source; in the fuel cell hydrogen and oxygen produce electricity, heat and water, which is then recycled and used for electrolysis.

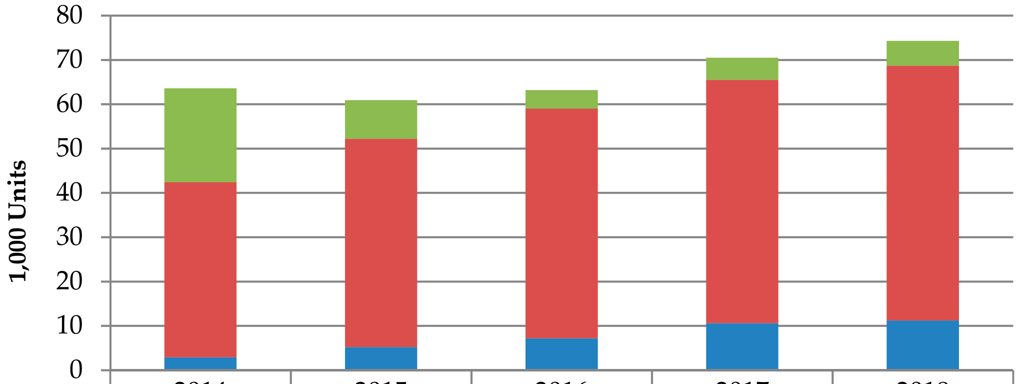
With regard to the applicability of these typologies of energy conversion technologies for the stationary applications, five of them have been identified in the specialized literature which are used to serve stationary consumers, as follows: DMFC is particularly suited to the supply of electricity in small domestic applications, while MCFC, PAFC, PEMFC, SOFC are used to serve the large consumer market in the stationary field [45,56–58].

3.2.2. Practical Applications of the Fuel Cell

Based on the literature, especially the most current reports prepared in 2014–2018 by *Fuel Cell Today*, which is the main source of information, studies and analysis covering the global fuel cell market and *Fuel Cells and Hydrogen Joint Undertaking - New Energy World*, which represents the organization whose main objective is hydrogen and its technology at the European Union level, aspects of recent information from the last five years, regional and global developments regarding the implementation of these equipments has been synthesized [19–24].

Various pilot projects aiming at hydrogen technology are being validated, and the performances of fuel cell systems operating under real conditions are analyzed and reports on technology performance, progress and new challenges are being prepared. This analysis includes fuel cell assemblies of various types, namely proton exchange membrane fuel cells, solid oxide fuel cells, phosphoric acid fuel cells and molten carbon fuel cells, having dimensions of power generation systems with generated power ranging from 5 kW up to 2.8 MW, and the equipment has nominal powers ranging from 0.5 kW up to 400 kW [20,21]. Fuel cell systems are used in stationary applications [59–63] where they can be used for various purposes, namely as back-up power supplies, power generation for remote locations, stand-alone power stations for one or more consumers, distributed generation for buildings and cogeneration (in which excess thermal energy resulting from the production of electricity is used to provide the thermal agent) [24,40].

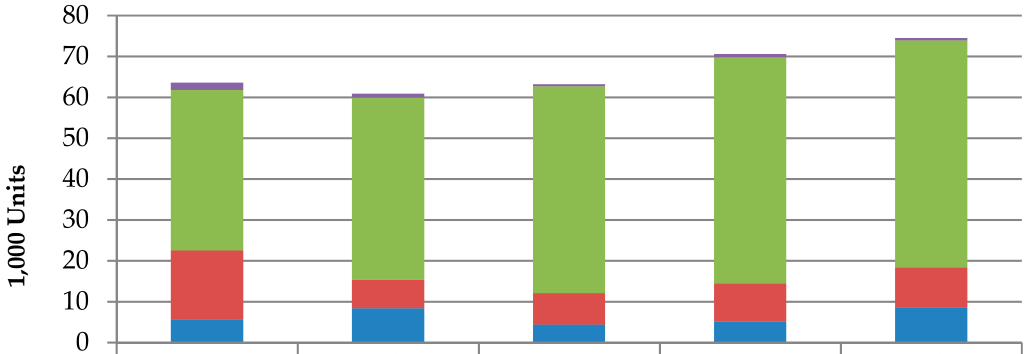
In commercial markets, fuel cells destined to the stationary sector show an increasing trend of technology transfer from the producer to the final consumer (Figure 6), being currently recognized as a feasible option compared to the conventional technologies of generator type, internal combustion engines or batteries. At the level of 2014, this technology transfer amounted to a value of 395,000 units regarding the delivery to the stationary field of fuel cell equipment, and for 2018 it increased to 575,000 units [22–24], this being possible due to the increased use of fuel cells as a practical application in which they play the role of energy backup (back-up system), but also due to the success of the residential fuel cell program "ENE-FARM" developed in Japan.



	2014	2015	2016	2017	2018
Portable	21.2	8.7	4.2	5	5.6
Stationary	39.5	47	51.8	54.9	57.5
Transport	2.9	5.2	7.2	10.6	11.2

Figure 6. Shipments by application.

The distribution by region of this number of units transferred to practical applications is graphically illustrated in Figure 7 [22–24].

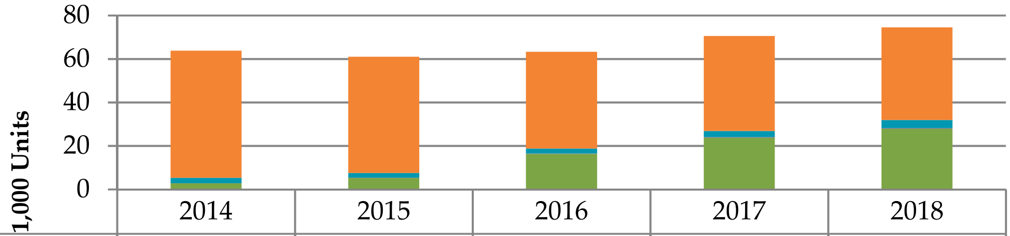


	2014	2015	2016	2017	2018
RoW	1.8	1	0.5	0.8	0.6
Asia	39.3	44.6	50.6	55.3	55.5
N America	16.9	6.9	7.7	9.4	9.8
Europe	5.6	8.4	4.4	5.1	8.6

Figure 7. Shipments by region of implementation.

It is noted that Asia is the region with the largest number of fuel cell units in practical applications over the last five years, with an increase due to the commercial development of micro-cogeneration fuel cells produced in Japan, so for 2018 a number of 55,500 units was reported, being 29.20% higher than in 2014. The North American region reported in 2014 a number of 16,900 units transferred to practical applications, and in 2015 there was a 59.20% decrease compared to the previous year, followed by an increasing trend, in 2018, 9800 units were reported to practical applications. With regard to Europe, they remained relatively constant during the period analyzed, except for a decline in 2016, but also in 2017 they maintain the same stagnation trend.

When analyzing the value data reported over the last five years regarding the distribution of the technological transfer according to the fuel cell typology (Figure 8), it is observed that the fuel cell with proton exchange membrane is dominant. This is due to the possibility of using this type of fuel cell for a wide range of applications for all three segments (portable, stationary and transport), from small applications, micro-cogeneration systems to centralized power generation through high power applications.



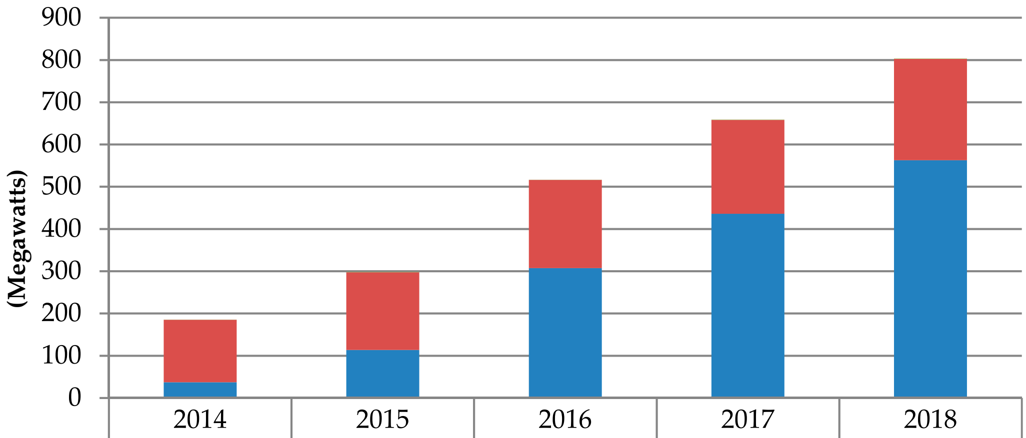
	2014	2015	2016	2017	2018
PEMFC	58.4	53.5	44.5	43.7	42.6
DMFC	2.5	2.1	2.3	2.8	3.7
PAFC	0.05	0.1	0.1	0.2	0.2
SOFC	2.7	5.2	16.2	23.7	27.8
MCFC	0.1	0.03	0.07	0.05	0.08
AFC	0.01	0.08	0.1	0.1	0.11

Figure 8. Shipments by fuel cell type.

It is noted that with the development and extensive use of PEMFC the other types of fuel cells, like DMFC, MCFC, and PAFC, recorded during the five years small ascending or decreasing variations, but this is also due to the fact that most types of cells are integrated into projects and programs that are in pilot phase, where the results are being validated.

With regard to SOFC technology, there was also a significant increase in the number of units transferred to practical applications since 2016, this is due to the transfers to the stationary area that are the subject of the Japanese Ene-Farm project and scheme. If in 2014, approx. 2700 units were reported, in 2018, a significant increase was achieved, reaching 27,800 SOFC units transferred to their practical applications [19,22–24].

Based on the number of units transferred to practical applications, *Fuel Cell Today* made a calculation regarding the sum of the fuel cell capacities that were installed to support these applications. The total capacity obtained is schematically illustrated in Figure 9.



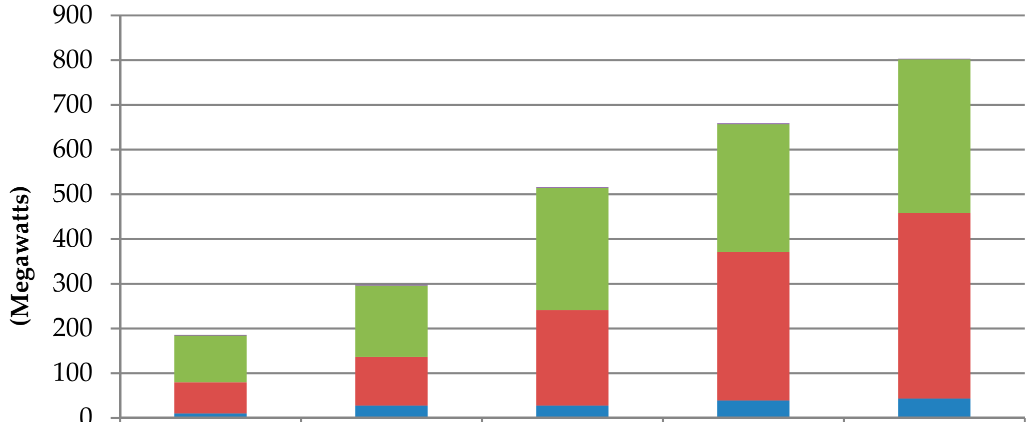
	2014	2015	2016	2017	2018
Portable	0.4	0.9	0.3	0.6	0.7
Stationary	147.8	183.6	209	222.3	239.8
Transport	37.2	113.6	307.2	435.7	562.6

Figure 9. Megawatts by application.

The analysis of the data regarding the stationary sector shows a tendency of continuous growth starting with 2014. At the level of 2018 a total capacity transferred from the producer to the practical applications of 239.8 MW worldwide has been reported [19,22–24]. This was due in particular to the large number of micro-cogeneration units implemented in Asia, but the development of large capacity applications of central type of distributed hydrogen energy generation within which they are integrated and fuel cells with high power, totaling a significant number of megawatts is also worth noting. It should be also noted that the applications of hydrogen energy in the field of electromobility and transport registered a spectacular growth in 2018 compared to 2014.

Stationary applications for hydrogen fuel cells refer to fuel cell units designed to provide power at a 'fixed' location. They include small, medium and large stationary prime power, backup and uninterruptable power supplies (UPS), combined heat and power (CHP) and combined cooling and power. On-board APUs 'fixed' to larger vehicles such as trucks and ships are also included [22–24].

The distribution of total capacities installed by regions is graphically illustrated in Figure 10. Over the last five years, America and Asia have competed for the leading region in terms of implementation and adoption of fuel cells in stationary applications.

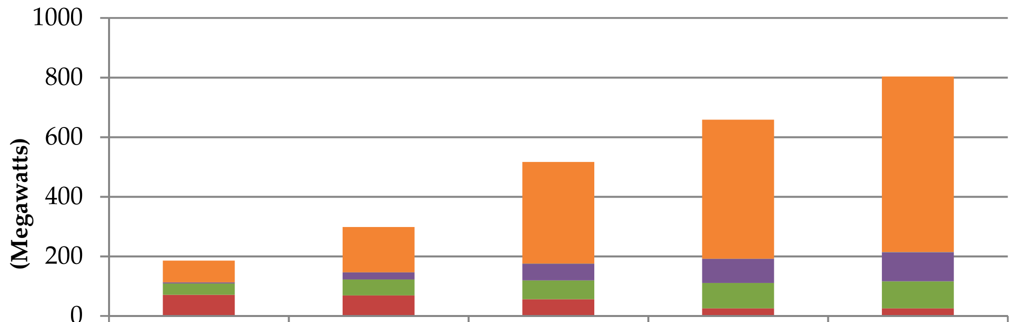


	2014	2015	2016	2017	2018
RoW	1.2	2.3	1.7	2.1	1.4
Asia	104.5	159.7	273.8	285.8	343.3
N America	69.8	108.4	213.6	331.8	415
Europe	9.9	27.7	27.4	38.9	43.4

Figure 10. Megawatts by region of implementation.

If in 2014 Asia surpassed America, with 34.7 MW total installed capacity, in 2018 America became the leader because it already has fuel cell systems in place, reaching a total capacity of 415 MW, whereas in Asia, compared to 2014, a growing trend was reported with only 343.3 MW installed. Europe is experiencing moderate growth in this sector, but compared to America which currently holds the leading position, values are reported as 90% lower in Europe, respectively 43.8 MW.

If one looks at the aspect of the total installed capacity in relation to the fuel cell typology (Figure 11) it is found that the PEMFC technology is used in a wide range of segments of the practical applications, therefore it contributes with the greatest number of megabytes of total installed capacity from 2014 to 2018. Considering the validation and demonstration of the large size capabilities of many PAFC and SOFC units implemented in the stationary field starting with 2014, there is an increasing trend in the use and implementation in stationary applications of these types of fuel cells [19,22–24].



	2014	2015	2016	2017	2018
PEMFC	72.7	151.8	341	466.7	589.1
DMFC	0.2	0.2	0.2	0.3	0.4
PAFC	3.8	24	56.2	81	97.3
SOFC	38.2	53.3	62.9	85.2	91
MCFC	70.5	68.6	55.7	24.7	25.2
AFC	0.1	0.2	0.5	0.6	0.1

Figure 11. Megawatts by fuel cell type.

The prospect of significant growth in the number of fuel cell applications for the stationary field has real potential in the coming years. On a large scale, fuel cells for the power generation sector based on hydrogen as a raw material for the production of electricity in the centralized system (power plants) have shown real success in Japan, Korea and North America, and Europe offers, also, a number of opportunities in this sector [19–24].

From a sustainability point of view, the reduction of carbon dioxide emissions in all fields of activity by using fuel cells and the production of hydrogen from renewable electricity is advantageous for reducing the level of carbon dioxide emissions in the electricity sector. For the purpose of stability of the electricity distribution network, hydrogen-based power plants will contribute to their balance and will locally provide the necessary energy supply near the renewable energy production sites [34].

A number of major plans targeting this segment are announced at global and regional levels, and governments and partner organizations specialized in hydrogen and fuel cells make a concerted joint effort to ensure centralized production, storage and distribution infrastructure and supply end-users with hydrogen, as well as a wide variety of technical, financial and management issues are being reviewed to develop a future hydrogen-based economy [24,43]. The main arguments worth highlighting regarding fuel cell power generation systems in stationary applications are as follows:

- By using hydrogen technology in the generation of electricity, a degree of autonomy of 100% can be obtained compared to the national centralized network for the supply of electricity.
- Hydrogen and fuel cells meet 100% of the consumer's energy needs, with no unmeted energy demand.
- Renewable sources can be better harnessed by completely eliminating the deficiencies related to their meteorological intermittency, but also to the issues related to the storage in batteries, eliminating totally the losses associated to these disadvantages by the technology of hydrogen, particularly electrolytic production of hydrogen based on renewable energies and storage via hydrogen, a secondary energy carrier, which can release this energy stored by the electrochemical conversion carried out by the fuel cell.
- The excess energy resulting from the operation of the systems can be harnessed by hydrogen either as green energy exported to the centralized electricity network or as a useful fuel for other types of applications.

- Electrolytic hydrogen production is directly influenced by the availability of renewable energy resources, having a variable character over time, which implicitly influences the electricity production of the fuel cell, which is also directly proportional to the availability of hydrogen.
- The carbon dioxide emissions in the case of energy systems with fuel cells are much lower, registering an average of over 80% decrease compared to the conventional energy systems that support standard applications.
- The costs of the equipment components of the energy systems regarding the hydrogen technology and the costs with the purchase of the hydrogen fuel have a high influence in the diagram of the total costs of these systems, but the technology of electricity generation based on hydrogen and the methods of production, storage and distribution of hydrogen are the object of continuous research and development, and over time a number of pilot projects currently in progress in this field will be validated, which will influence and determine cost reductions in the near future, and this equipment, and also hydrogen fuel, will be competitive with the classic technologies in the field of energy production and storage [12–24,35–43].
- The optimization of the fuel cell systems in order to increase the overall efficiency of the hybrid power generation systems can be performed by nonlinear control [64], extremum seeking [65], and global optimization [66,67] techniques.

3.2.3. The Main Modalities to Energy Supply through Hydrogen Fuel Cell Technologies

The main types of fuel cell technologies presented above, having different operating characteristics and principles, can serve different segments of the energy generation market, either in CHP or power generation. Each type of technology has advantages and disadvantages that motivate its end use in specific applications and domains. In brief, the applications for which different types of fuel cells are suitable, but also their advantages and disadvantages, are presented in Table 3.

Table 3. Suitability in practical applications of the fuel cells types adapted from [68].

Fuel Cell Type	Typical Electrical Efficiency (LHV)	Power (kW)	Applications	Advantages	Disadvantages
AFC	60%	1–100	Back-up power; Electromobility; Military; Space.	Stable materials allow lower cost components; Low temperature; Quickly start-up.	Sensitive to CO_2 in fuel and air; Electrolyte management (aqueous); Electrolyte conductivity (polymer).
MCFC	50%	300–3000	Electric utility; Distributed generation.	Fuel flexibility; High efficiency; Suitable for hybrid/gas turbine cycle; Suitable for carbon capture; Suitable for CHP.	High temperature corrosion and breakdown of cell components; Long start-up time; Low power density.
PAFC	40%	5–400	Distributed generation.	Suitable for CHP; Increased tolerance to fuel impurities.	Expensive catalysts; Long start-up time; Sulfur sensitivity.
PEMFC	60% direct H_2 40% reformed fuel	1–100	Back-up power; Distributed generation; Electromobility; Grid support; Portable power; Power to power (P2P).	Solid electrolyte reduces corrosion & electrolyte management problems; Low temperature; Quickly start-up.	Expensive catalysts; Sensitive to fuel impurities.
SOFC	60%	1–2000	Auxiliary power; Distributed generation; Electric utility.	Fuel flexibility; High efficiency; Potential for reversible operation; Solid electrolyte; Suitable for CHP; Suitable for hybrid/gas turbine cycle.	High temperature corrosion and breakdown of cell components; Long start-up time; Limited number of shutdowns.

The main modalities of energy support of the stationary applications by hydrogen fuel cell technology that have been identified in the specialized literature refer to the following aspects:

CHP With Fuel Cells in the Buildings Domain

Fuel cells are suitable for micro-cogeneration and CHP because the technology inherently produces electricity and heat from a single source of fuel such as hydrogen, and systems can also run on traditional fuels, such as natural gas. Currently, the CHP fuel cell units are installed in buildings, being functional in individual regimes, but such systems with low power capacities are under development, the projects having the objectives oriented towards the energetic support of the collective houses with several apartments. In this type of application, the fuel cell with proton exchanger membrane is commonly used, which works and ensures the energy demand both during the day when peaks are recorded and at night. Solid oxide fuel cells can also be used in residential micro-cogeneration systems, having a relatively efficiency equal to that of PEMFCs. Because SOFCs use higher operating temperatures than PEMFCs, they are more tolerant to carbon monoxide in the fuel, and this allows for some simplification in terms of system configuration.

All CHP technologies offer increased combined efficiency compared to traditional solutions for separate generation of electricity and thermal energy. Cogeneration with fuel cells can exceed the value of the "traditional frontier" in terms of energy efficiency due to the special performances that this type of technology achieves (Table 4) [69,70]. PEMFC and SOFC are usually used for energy supply systems for small residential applications, and SOFC, PAFC and MCFC for systems that energetically support large commercial and industrial applications.

Table 4. A brief summary of the CHP performance of fuel cells adapted from [69,70].

	MCFC	**PAFC**	**PEMFC**	**SOFC**
Electrical capacity (kW)	300+	100–400	0.75–2	0.75–250
Electrical efficiency (LHV)	47%	42%	35–39%	45–60%
Thermal capacity (kW)	450+	110–450	0.75–2	0.75–250
Thermal efficiency (LHV)	43%	48%	55%	30–45%
Application	Residential & Commercial	Commercial	Residential	Residential & Commercial
Degradation rate (per year)	1.5%	0.5%	1%	1–2.5%
Expected lifetime (hours)	20,000	80,000–130,000	60,000–80,000	20,000–90,000

The starting point for this sector is the project initiated in the 1990s by the Japanese government which supported the research activity in order to develop a city-gas-derived hydrogen system that would generate both electric and thermal energy for individual residential buildings, following which was developed the system of residential micro-cogeneration recognized worldwide under the name of Ene-Farm [71]. At the end of 2018, 200,000 PEMFC units were reported as being implemented as part of the Ene-Farm project [23]. In the future, a system similar to the one developed by the Ene-Farm project is planned by Japan to be installed in collective apartment buildings. The success of Ene-Farm has inspired various demonstration projects in other parts of the world, including Korea, Denmark, Germany, the USA and the UK [23,71].

Backup Power Systems wich Using Renewable Energy Sources or Converting Waste into Energy

This type of function involves storing and increasing the degree of use by avoiding the losses associated with the excess energy produced in the power plants that operate by exploiting the renewable energy sources. Various concerns in this sector have laid the foundations for the research and development projects of these systems, being currently in progress or in validation of the obtained results. As an example: Solar to Hydrogen—MYRTE combines solar energy with electrolyzers, hydrogen storage and fuel cell usage, and the project was a partnership between French Nuclear and Alternative Energy Commission, the energy company AREVA and the University of Corsica [72].

It is worth mentioning the recent initiative undertaken by the European Commission that funded through the public-private partnership Fuel Cells and Hydrogen Joint Undertaking (FCH JU) within the Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Seasonal Storage of Renewable Electricity by Hydrogen Underground Storage in Europe project (HyUnder) [73]. The idea behind the project was to establish a European initiative for the implementation of energy technologies based on hydrogen generated by increasing the percentage of the use of renewable resources. This project aimed at researching large-scale hydrogen storage in underground caverns, an aspect related to the energy market and existing storage technologies, and aims to identify and analyze the areas of applicability, potential stakeholders, safety rules, the regulatory framework and the societal impact on public acceptance. Within this project, case studies were provided in several areas of Europe. Each case study analyzed the competitiveness of hydrogen storage compared to other types of energy storage, the geological potential of hydrogen storage and the way in which this hypothesis hydrogen storage can be implemented on the energy market. National Research and Development Institute for Cryogenic and Isotopic Technologies—ICSI Rm. Valcea, Romania, participated in the mentioned project through the National Center for Hydrogen and Fuel Cells.

Hydrogen production by water electrolysis leads to the consumption of water resources. In some areas, this is not a problem, but elsewhere it is a huge barrier to the implementation of hydrogen fuel cell technology. For these reasons, a series of studies have been directed towards methods of obtaining hydrogen from various wastes of which can be exemplified: preparation and catalytic steam reforming of crude bio-ethanol obtained from fir wood [74], pyrolysis-catalytic steam reforming of agricultural biomass wastes and biomass components for production of hydrogen/syngas [75], methodology for treating biomass, coal, msw/any kind of wastes and sludges from sewage treatment plants to produce clean/upgraded materials for the production of hydrogen, energy and liquid fuels-chemicals [76], biohydrogen production from solid wastes [77], not least, carbohydrate-to-hydrogen production technologies [78]. Table 5 presents the main hydrogen production methods in terms of efficiency and energy consumption.

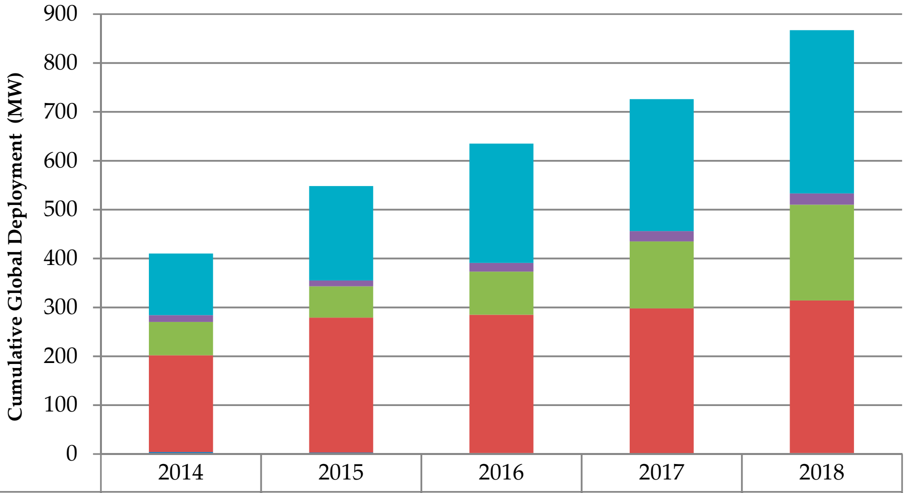
Table 5. Hydrogen production methods-efficiency and energy consumption adapted from [70,79,80].

	Energy Consumption (kWh/kgH_2)	Efficiency (LHV)
Biomass gasification	69–76	44–48
Coal gasification	51–74	45–65%
Electrolysis	50–65	51–67%
Methane reforming	44–51	65–75%

The production of hydrogen from fossil fuels and biomass, including the catalytic reforming of natural gas, appear to be environmentally unresponsible methods [81], especially due to carbon emissions that qualify the processes as a negative emission technology. In this regard, concentrated research efforts are being made to develop cleaner hydrogen production systems. Thus, a series of high purity hydrogen production installations, which work with carbon capture and storage (CCS) or post-combustion carbon capture (PCC), are demonstrated. Noteworthy in this direction is the research activity supported by Graz University of Technology, Institute of Chemical Engineering and Environmental Technology, Austria by Bock, Zacharias and Hacker. They studied and demonstrated the production of high purity hydrogen (99.997%) with the co-production of pure nitrogen (98.5%) and carbon dioxide (99%) with a raw material use of up to 60% in the largest loops with fixed beds worldwide [82].

Prime Power Generation Large Capacity Electric Power Stations

Several types of fuel cells find applicability in power generation for large stationary applications. AFC, PAFC, PEMFC, SOFC and MCFC systems are used worldwide for the generation of distributed electricity for local use [83]. Figure 12 illustrates the relative weight of the various high-capacity fuel cell technologies installed by the end of 2018 [22–24]. It is noted that the sector is dominated by three types of technologies, MCFC having the highest weight, followed by SOFC and PAFC. To date, only a small number of high-capacity installations based on PEMFC and AFC technologies have been implemented.



	2014	2015	2016	2017	2018
SOFC	126	193	244	270	334
PEMFC	14	12	18	21	23
PAFC	68	64	88	137	196
MCFC	198	276	283	297	312
AFC	4	3	2	1	2

Figure 12. Large scale stationary fuel cells.

4. Results and Discussion

The important elements to be discussed regarding hydrogen fuel cell technology were schematically presented in Figure 13, being widely developed within the SWOT analysis [84] and refer to technological, environmental, social and economic factors.

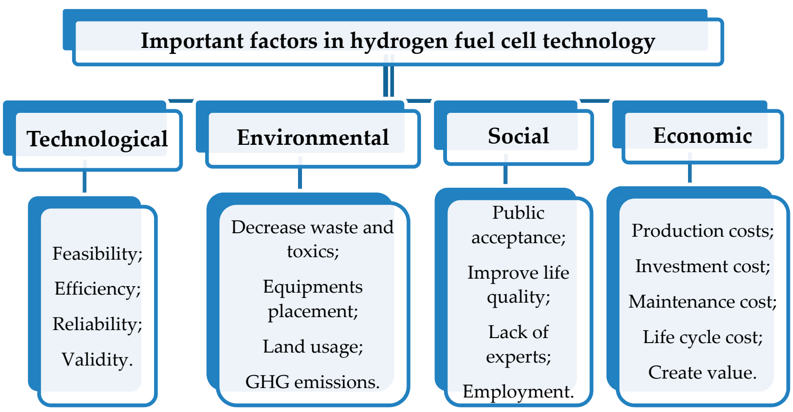


Figure 13. Hierarchy of important factors in hydrogen fuel cell technology.

4.1. Strengths–Weaknesses–Opportunities–Threats (SWOT) Analysis

Based on the data from the specialized literature collected, studied, analyzed critically, the SWOT matrix was developed (Table 6), the specific main characteristic elements of hydrogen fuel cell technology being presented, its worthy to be considered if we talk about energy for stationary applications towards a green to green paradigm.

Table 6. Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis.

Strengths	Weaknesses
S1. Technical strengths: - hydrogen has the highest energy/mass unit of all fuel types; - 1 kg of hydrogen contains as much energy as 2.1 kg of natural gas or 2.8 kg of oil; - fuel cell technolohy has an overall efficiency of up to 60%; - the fuel cell converts hydrogen directly into electricity + heat through the electrochemical reaction of hydrogen with oxygen; - hydrogen concentrates primary renewable energy sources, which it makes available to the consumer in a convenient way; - can be produced on-site at the consumer's place - reduce the dependence on long distance pipelines; - hydrogen can be stored for the medium and long term; - integration with smart grid - hydrogen can stabilize power fluctuations in the grid; - can be transported over long distances stored in various forms or has potential of utilizing current fuel transportation infrastructure. **S2. Environmental strengths:** - it is an inexhaustible source, if it is obtained by electrolysis of water, hydrogen production and consumption is a closed cycle; - the burning of hydrogen is almost entirely devoid of pollutant emissions; - hydrogen is a non-toxic energy transport operator; - environmental friendly and reduces the amount of GHG emissions from the energy system; - low noise pollution compared to other energy production methods. **S3. Sustainable development strengths:** - consequent energy supply and energy security (hydrogen could be considered as a never ending source of energy); - hydrogen as a non-polluting energy carrier; - huge development potential; - possibility of production on site for stand alone applications and remote areas; - hydrogen can be obtained from a wide range of primary renewable energies; - hydrogen is the only secondary energy carrier that is suitable for wide applications in stationary, transport and portable domains; - sustainable transportable energy source; - favorable research and development theme; - stimulates and creates new jobs; - hydrogen will become an energy center, just as electricity is now. **S4. Diversity in resources harnessing:** - hydrogen can be obtained from a wide range of primary energies; - various methods of obtaining hydrogen; - harnessing waste as it is possible to produce hydrogen from waste as a by-product; - can be used as a feedstock in other industries; - hydrogen has potential to integrate in the energy system of the intermittent renewable energies; - allows remote communities to manage their own energy supply; - decrease dependence to fossil classic fuels and increase alternative energy diversity.	**W1. Unavailability of an efficient hydrogen infrastructure:** - lack of points of hydrogen production; - lack of an efficient transport, distribution and storage systems; - incomplete hydrogen infrastructure; - limited access and availability (unavailability) of enough hydrogen refill stations; - necessity to change current distribution system in residential buildings; - lack of plans for the development and implementation of the hydrogen economy. **W2. Introduction risks:** - the complexity of the hydrogen economy; - the integration of hydrogen as energy carrier into the energy system is not tested on an industrial scale; - lack of effective instruments for introduction of hydrogen in the existing transmission and distribution natural gas networks; - development of support services assistance in the hydrogen energy domain is still very immature; - hydrogen burns in the presence of air, which can cause operational safety problems; - hydrogen energy as a new product presents uncertainties related to its public acceptance. **W3. Lack of support from the government:** - insufficient cooperation between political authorities and professional associations in the field of hydrogen energy and economic operators, producers of hydrogen fuel cell technologies. **W4. System integration:** - lack of codes, technical design regulations, implementation procedures, technical standards for hydrogen economy in general, stationary applications of hydrogen energy in particular; - lack of widespread awareness of capabilities and potential benefits of hydrogen fuel cell technologies used to supply clean energy for stationary applications; - weak development of hydrogen supply network; - uncertainties and lack of information related to problems of exploitation under conditions of stability and safety of hydrogen; - unavailability of clear marketing policies and strategies to promote hydrogen energy as clean energy for stationary applications; - unclear plans for a future economy based on hydrogen energy. **W5. High costs:** - high initial investment installation costs; - high production costs of hydrogen; - high production costs of fuel cell; - high production costs of systems based on hydrogen fuel cell technologies; - high price of energy generated by hydrogen-based energy systems; - high costs for hydrogen storage; - high costs for adaptation of the hydrogen economy; - lack of focused research and development works from major companies to develop the equipment and reduce costs.

Table 6. *Cont.*

Opportunities	Threats
O1. Development potential - hydrogen is a key element for a future green sustainable development of energy systems; - hydrogen energy can be considered as an object of innovations and technological development along the lines of energy efficiency; - hydrogen fuel cells technology enables investment in sustainable energy infrastructure; - encouraging the generation of green energy from indigenous unconventional sources; - hydrogen fuel cell technology can be considered next energy efficiency solution for supply energy in stationary applications; - developing social policies that respond to the challenges generated by the implementation of clean energy policies; - development of human capital in order to ensure the implementation of the energy strategy in a future hydrogen-based economy; - hydrogen and fuel cell technology stimulates research, innovation and development in the energy systems domain. **O2. Improve energy security** - hydrogen is expected to play an important role in global future energy scenarios; - an energy carrier helps to increase the stabilization of energy security and price, giving rise to competition between different energy sources; - increasing the energy efficiency through the efficient use of energy resources throughout the energy cycle - production, transport, storage, distribution and final consumption; - decarbonisation of the energy sector at minimum costs; - energy diversification; - integrating hydrogen into the energy mix that responds to the sustainable development desire and which ensures the reduction of energy import dependency. **O3. Increase cooperation** - opportunities for collaboration between academic institutions, research institutes on line of knowledge transfer to economic operators; - educational opportunity for universities with energetic and environmental learning profile to development of a new teaching discipline; - improve cooperation with governments, local authorities and make alliance with local political administrations or economic operators as investors in the implementation of green energy systems; - collaboration opportunities among line ministries, departments and other energy system actors; - international interconnection. **O4. New business opportunity** - emergence of hydrogen market; - emergence of a new commercialization plans; - emergence of potential suppliers, demanders and end-users; - involving several companies in the energy sector and setting up new ones; - emergence and development of new business models; - emergence of new jobs; - development of the blockchain model for hydrogen economy.	**T1. Technical** - low stimulation of hydrogen competitiveness in field of stationary applications regarding the generation of energy from alternative sources to the classical ones; - immaturity of some technologies for the conversion of hydrogen into electric and thermal energy despite the efforts stimulated on the one hand by the technical progress in the field of fuel cells, and on the other hand driven by the global concerns regarding energy security, efficiency, energy sustainability, reduction of greenhouse gases emissions and last but not least, the reduction of dependence on the use of fossil fuels; - lack of specialists and experts in the field regarding the implementation of hydrogen energy projects for stationary applications; - insufficient storage capacity in large quantities of hydrogen: Increasing production of fluctuating renewable energy intensifies the need for electricity storage to ensure network reliability and flexibility. Using hydrogen as a mean to store energy in the long run may in the future help address the challenge of grid balancing when large quantities of fluctuating renewable electricity are introduced in the energy mix; - immature solutions for massive hydrogen storage, which are not widely tested (e.g. underground hydrogen storage, potentially attractive solution, but still needs to be evaluated thoroughly from a technical, economic and societal standpoint); - limited practical experience in both producers and consumers; - lack technical information of potential investors regarding hydrogen new technologies for power generation and energy efficiency of fuel cell technology, which it generates a low degree of interest from them. **T2. Social** - negative influence from other energy actors; - public acceptance of the widespread use of hydrogen in stationary applications is unclear; - technical regulations, standards and procedures deficiencies for the applicability of hydrogen energy in stationary applications; - immaturity of the legislative framework; - weak support from authorities and government to shift to a hydrogen-based economy; - non-recognition of hydrogen-based power generation systems and hydrogen economy as strategic infrastructure; - the results of the research projects cannot be adequately replicated due to the various difficulties at the legislative level. **T3. Economic** - its were not developed sufficient fiscal instruments to support the investment programs in the energy efficiency sector and the use of hydrogen energy in stationary applications; - lack of potential suppliers, potential investors and demanders; - competitions with other renewable resources; - the difficulty to compete with the current fossil fuel market; - strong position of fossil fuel producers; - deficient organization and financing of the hydrogen economy.

This type of instrument/analysis method is validated by numerous studies carried out in the energy and the environment domain [85–87]. The objectives of the analysis were to highlight the strengths and weaknesses, in relation to the opportunities and threats existing or potential regarding the conditions of the implementation of hydrogen as the source of energy in stationary applications.

4.2. Strategies Proposed for the Use in Stationary Applications of Hydrogen Energy

In order to outline an overview of the possibilities of implementing hydrogen-based energy systems to power stationary applications, respectively to identify the possibilities for increasing the share of the use of hydrogen as alternative resource, a series of strategies have been proposed with a character of recommendation (Figure 14).

	Strengths	**Weaknesses**
Opportunities	**S&O1:** promote the utilization of hydrogen energy in stationary applications to make it more popular; **S&O2:** develop hydrogen economy with comprehensive legislation; **S&O3:** stimulate public acceptance.	**W&O1:** stimulate developments, innovations and research; **W&O2:** stimulate development in hydrogen infrastructure; **W&O3:** governmental and funding programmes.
Threats	**S&T1:** continued R&D funding to explore the potential applications; **S&T2:** strategies between hydrogen energy and other renewables to decrease competition between them; **S&T3:** cooperation between energy actors, R&D centers and politicians.	**W&T1:**promote regulated hydrogen economy; **W&T2:** absorb private and foreign investments to financially support hydrogen economy projects; **W&T3:** implementation of specific laws for safety and stability in use.

Figure 14. Established and recommended strategies.

At EU level, there are a large number of projects [88] that are already facing some of the strategies highlighted in Figure 14. To assist and promote the EU's commitment to the "hydrogen challenge", it is worth highlighting some of these significant projects in the area of Hydrogen Fuel Cell Technology for sustainable future of Stationary Applications: TriSOFC—Durable Solid Oxide Fuel Cell Tri-generation system for low carbon Buildings [89]; C3SOFC—Cost Competitive Component Integration for Stationary Fuel Cell Power, application area: stationary power production and CHP [90]; STAGE-SOFC—Innovative SOFC system layout for stationary power and CHP applications [91]; Remote area Energy supply with Multiple Options for integrated hydrogen-based Technologies—demonstration of fuel cell-based energy storage solutions for isolated micro-grid or off-grid remote areas [92]; Demo4Grid—Demonstration of 4MW Pressurized Alkaline Electrolyser for Grid Balancing Services [93]; ELECTROU—MW Fuel Cell micro grid and district heating at King's Cross [94], ene.field—European-wide field trials for residential fuel cell micro-CHP [95], H2 Future-Hydrogen meeting future needs of low carbon manufacturing value chains [96].

Energy strategies in the context of sustainable development refer both to the present and to the future, as they define the vital interests and establish the lines of action to meet the present and future needs while managing the evolutions in the field. When discussing energy security, it must be viewed as a vital component and includes: security of energy sources, securing the existing energy routes, identifying alternative energy routes, identifying alternative energy sources, environment protection. As a result, the topics discussed and analyzed in the present article fall into the current national, european and international context, the importance of the problem being topical both from a scientific, technological, but also from a socio-economic or cultural point of view.

In this context, hydrogen, as an energy vector or environmentally friendly synthetic fuel, together with the fuel cell, its conversion technology, can play an important role in energy strategies regarding the efficiency and decarbonisation of energy generation systems in stationary applications. Technologies using low-carbon footprint hydrogen can be valuable in various end-use stationary applications.

5. Conclusions

Hydrogen and fuel cell technology have advanced considerably over the last fifteen years. At the global level, this area continues to face significant challenges—technical, commercial and infrastructure-related—that need to be overcome before fuel cells can realize the full potential of which they are capable. Policy makers have included hydrogen and fuel cell on the map of future energy strategies and have already taken into account the fact that fuel cells have great real potential and can successfully meet the technical, social, economic and environmental objectives in the context of the multidisciplinary concept of sustainable development.

In this paper, the review of literature and agencies' reports on specialized metrics in the domain of the hydrogen fuel cell technologies, highlights the essential considerations regarding stationary applications, as follows:

- More than 850 MW of large stationary fuel cell systems with a (> 200 kw) nominal power have been installed worldwide for power generation and CHP applications up until 2018.
- Worldwide, the use of three types of fuel cell technologies is prevalent: MCFC, SOFC and PAFC.
- AFC and PEMFC are relatively new technologies under development and implementation within stationary applications.
- The main modalities of integrating hydrogen fuel cell technology into stationary applications are in the form of CHP units with fuel cells for small individual residential buildings, back-up power systems and large capacity electric power stations or distributed generation systems.
- The key factors that influencing development include: energy and climate policies, fuel cell funding programmes, concurrent technologies, the attendance of fuel cell system producers and energy costs.

The SWOT analysis conducted in the present study highlights that the implementation of the hydrogen economy depends decisively on the following main factors: legislative framework, energy decision makers, information and interest from the end beneficiaries, potential investors, and existence of specialists in this field.

Author Contributions: conceptualization, R.-A.F.; methodology, R.-A.F. and E.C.; validation, E.C., M.S.R. and C.F.; formal analysis, C.N.T.; investigation, M.S.R. and E.C.; data curation, C.T.; writing—Original draft preparation, R.-A.F., M.S.R. and C.N.T.; writing—Review and editing, E.C. and C.F.; visualization, R.-A.F.; supervision, C.F.; project administration, R.-A.F. and E.C.

Acknowledgments: This work was supported by a grant from the Romanian Ministery of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0776/No. 36 PCCDI/15.03.2018, within PNCDI III.

Conflicts of Interest: The authors declare no conflict of interest.

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