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Sustainable Future of Transport and Stationary Applications Using Hydrogen Fuel Cell Technology

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ABSTRACT: The climate changes that are becoming visible today are a challenge for the global research community. The stationary application sector is one of the most important consumers of energy. Currently, the use of the potential of renewable energy is being considered worldwide to find alternatives for obtaining energy using technologies that offer maximum efficiency and minimum pollution. In this context, new energy production technologies are needed that would generate low carbon emissions and also identify, plan and implement directions for exploiting the potential of renewable energy sources. Hydrogen fuel cell technology represents one of the alternative solutions for future clean energy systems. This article summarizes the specific properties of hydrogen energy that recommend it as a clean energy for powering stationary applications. The aim of the review was to provide an overview of the elements of sustainability and the potential of using hydrogen as an alternative source of energy for stationary applications, or to identify possibilities for increasing the share of hydrogen energy in stationary applications. A SWOT analysis was used as a study method, after which a number of strategies were recommended that could be adopted in order to increase the utilization rate of hydrogen energy as an alternative to conventional energy for stationary applications. The SWOT analysis carried out in this study highlights that the implementation of the hydrogen economy crucially depends on the following main factors: legislative framework, energy decision-makers, information and interest from end-users, potential investors and the existence of specialists in the field.

Keywords: Alternative Energy,Energy Efficiency,Fuel cell,Hydrogen Energy,Stationary Application

I. INTRODUCTION

Non-conventional energy sources have gained and will continue to gain an ever-increasing share in energy systems worldwide, both due to the research and policy efforts associated with their development, and due to the increase in the price of energy obtained by traditional methods. Primary energy sources, generally called renewable, are resources found in the natural environment, available in practically unlimited quantities, or regenerated by natural processes faster than they are consumed. Officially recognized renewable energies come from the sun's rays, the Earth's internal temperature, or the gravitational interactions of the Sun and Moon with the oceans. The processes and methods of producing or capturing these types of alternative energy are in the process of being perfected, the lower cost of infrastructure investment and the improved efficiency of the conversion processes have meant that renewable energy sources cover a small part of the planet's energy needs. scale. More optimistic forecasts estimate that renewable energy production will have a 30-50% share of the total energy market around 2050, but this depends on reducing production costs and finding massive energy storage options. Furthermore, none of these forms of energy can also provide fuels in sufficient quantities for use in various stationary, mobile or industrial applications.

In this context, we are currently looking for alternatives to obtaining energy using technologies that offer maximum efficiency, high reliability and minimum pollution. Such technology, which is currently considered the cleanest, thanks to which sustainable energy can be obtained, is based on fuel cells. With the development of fuel cells, hydrogen-based energy production has become a reality. The future hydrogen economy presents hydrogen as an energy

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carrier within a secure and sustainable energy system. 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. Energy could be produced by sources with virtually zero pollution. Hydrogen can be considered as a synthetic fuel, carrying secondary energy in the future post-fossil fuel economy.

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

II. MATERIALS AND METHODS

The documentation for the study is based on the scientific literature, journal articles, papers presented at conferences on the topic of hydrogen applications and online scientific databases and websites, including Google Academic, Google Scholar, MDPI, Science Direct, Scopus and research platforms or subject-specific websites. In addition, this paper uses and analyzes a large number of reports, information related to strategic hydrogen and fuel cell research and documents published by the European Union (EU), the United Nations (UN), the International Energy Agency (IEA) and other important research and development data. institutions relevant to the hydrogen economy, including E4Tech, International Association for Hydrogen Energy (IAHE), National Research and Development Institute for Cryogenic and Isotope Technologies (ICSI) Ramnicu Valcea, Romania.The tool used in this contribution to verify and analyze the overall situation with regard to the state of general acceptance of the use of the energy potential of hydrogen technology and its use as an alternative source of energy for stationary applications is a SWOT analysis.

A SWOT analysis provides an overview of the characteristics specific to the objective/domain of the analysis and the environment in which it will be implemented. The SWOT analysis acts as an X-ray of the concept of implementing hydrogen energy in stationary applications, while evaluating the internal and external influencing factors of the concept as well as its position in the usability environment in order to highlight the strengths and weaknesses of the concept in relation to the opportunities and threats that currently exist.The steps to perform a SWOT analysis are schematically illustrated in the diagram in Fig. 1 in order to identify the characteristics of the strengths, weaknesses, opportunities and threats of the hydrogen energy concept for stationary applications.

Fig 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. 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 and advantages regarding the use of hydrogen energy in stationary applications, research/implementation/solutions/market status and possible changes, challenges, perspectives, and improvements.

Table 1. SWOT Analysis Matrix

	Strengths (Internal)	**Weaknesses**(internal)
Opportunities(External)	**S&O**	**W&O**
Threats(External)	**S&T**	**W&T**

III. CONSIDERATIONS REGARDING HYDROGEN FUEL CELLTECHNOLOGY

Table 2. 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
Specific heat	kJ/kg K	14.89
Ignition limits in air	% (volume)	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
Air/fuel stoichiometry	kg/kg	34.30/1
Burning speed	cm/s	2.75
Power reserve factor	-	1.00

Table 3. Comparison between the main properties of hydrogen and other fuels

Fuel Type	**Unit (J/kg)**	**Unit (J/m^3)**	**Factor**	**Specific (kgC/kgFuel)**
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	-
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

Analysing the tabular information, it can be concluded that the main arguments in favor of using hydrogen as a synthetic fuel obtained from renewable sources are the following: it has the highest energy/mass unit of all fuel types; it is environmentally friendly because only water vapor is produced when it is burned, which indicates that hydrogen has zero carbon emissions; it has the highest energy reserve factor, i.e. the biggest conversion factor into electricity, and for this reason it is considered the best of the presented fuels and the energy efficiency is very high. Hydrogen is expected to play an important role infuture energy scenarios globally.

The advantages that favour it as an energy vector over other forms of energy are:

• Hydrogen can be transported remotely by pipeline under safe conditions.

• Hydrogen is a non-toxic energy carrier with a high specific energy per unit mass (eg the energy obtained from 9.5 kg of hydrogen is equivalent to the energy from 25 kg of petrol).

• Hydrogen can be produced from a variety of energy sources, including renewables.

• Compared to electricity or heat, hydrogen can be stored for a relatively long time.

• Hydrogen can be advantageously used in all sectors of the economy (as a raw material in industry, as a fuel for cars and as an energy carrier in sustainable energy systems to produce electricity and heat through fuel cells

Obstacles to overcome are related to the issues:

• Hydrogen burns in the presence of air, which can cause operational safety issues.

•Storing hydrogen in liquid form is difficult because very low temperatures are required to liquefy hydrogen.

• High cost 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 end consumers requires expensive investments.

IV. 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 security.

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

4.1 Fuel cell

Fuel cells are now increasingly being researched because they are revolutionizing the way energy is produced. They use hydrogen as fuel and at the same time ensure the possibility of producing clean energy while protecting and even improving environmental parameters.

A fuel cell is, by definition, an electrical cell that, unlike battery cells, can be continuously supplied with fuel, so that the electrical output from the output of that electrical cell can be sustained indefinitely. A fuel cell therefore converts hydrogen or hydrogen-based fuels directly into electricity and heat through the electrochemical reaction of hydrogen with oxygen. The process performed at the fuel cell level is the opposite of electrolysis:

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

where the chemical energy of the fuel (hydrogen) and oxidant (oxygen) is converted into continuous current, heat and water as reaction products. Since in the fuel cell hydrogen and oxygen are converted by an electrochemical reaction to water, this has significant advantages compared to thermal engines: higher efficiency, practically silent operation, lack of pollutant emissions, where the fuel is even hydrogen, and if the hydrogen is produced from renewable sources of energy, the electrical energy obtained in this way is truly sustainable.

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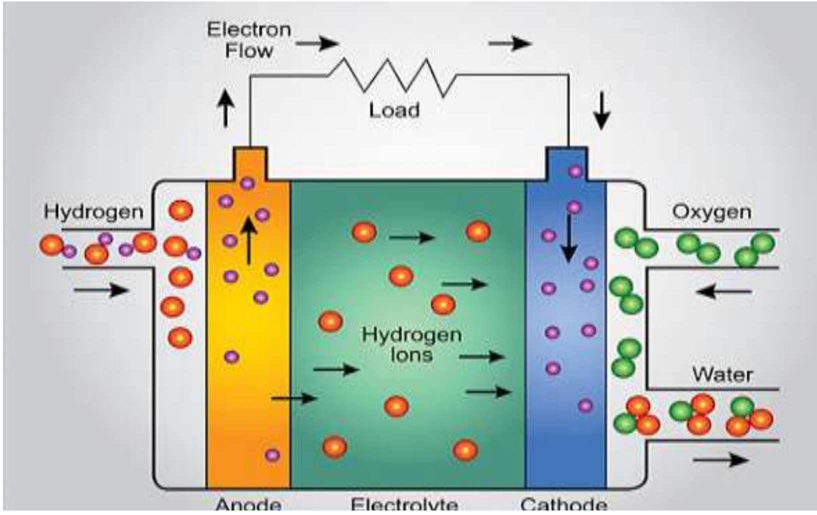

Fig 2. Components of the fuel cell

4.2 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.

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. The schematic in Fig 3 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.

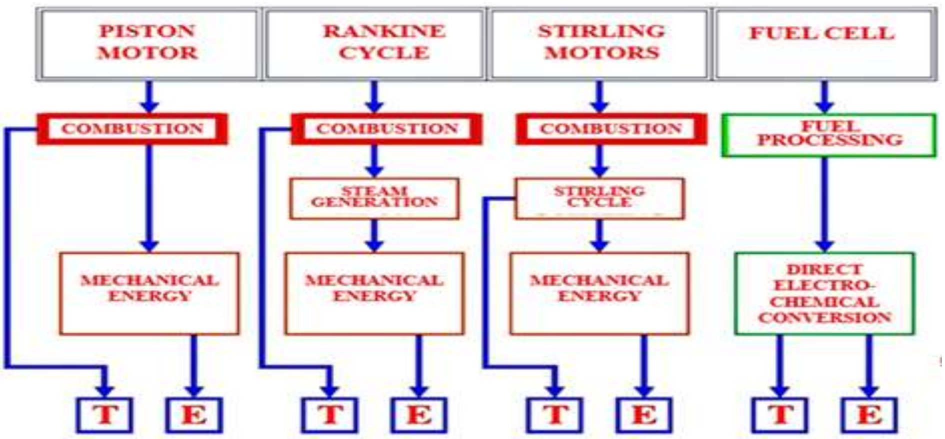

Fig 3. Fuel conversion process. Comparison of the operation principles of various technologies.

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.

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:

acid electrolyte: $H_2 \rightarrow 2H^+ + 2e^-$ (2)

alkaline electrolyte: $H_2 + 2OH^- \rightarrow 2H_2 + 2e^-$ (3)

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

acid electrolyte: $1\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (4)

alkaline electrolyte: $1\ O_2 + H_2O + 2e^- \rightarrow 2OH^-$ (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.

4.3 The Main Types of Fuel Cell

Table 4. The main types of fuel cell

Fuel Cell	**Temperature**
Alkaline fuel cells (AFCs)	70°C
Direct methanol fuel cells (DMFCs)	60–130°C
Molten carbon fuel cells (MCFCs)	650°C
Phosphoric acid fuel cells (PAFCs)	180–200°C
Protonexchangemembranefuelcells (PEMFCs)	150 °C to 200°C
Solid oxide fuel cells (SOFCs)	800–1000°C

4.4 Practical Applications of the FuelCell

Based on the literature, especially the most recent reports compiled from 2018-2022 by Fuel Cell Today, the leading source of information, studies and analysis covering the global fuel cell market, and the Fuel Cells and Hydrogen Joint Undertaking - New Energy World, representing the organization , whose main objective is hydrogen and its technology at the level of the European Union, aspects of the latest information of the last five years, regional and global developments regarding the implementation of these devices have been synthesized.

In commercial markets, fuel cells for the stationary sector show an increasing trend of technology transfer from the producer to the final consumer Fig. 4, which is currently considered a feasible option compared to conventional technologies such as generators, internal combustion engines or batteries. At the level of 2018, this technology transfer reached the value of 395,000 units delivered to the stationary area of fuel cell equipment and increased to 575,000 units for 2022, which is possible due to the increased use of fuel cells as a practical application in which they play the role of energy backup (backup system) but also due to the success of the residential fuel cell program "ENE-FARM" developed in Japan.

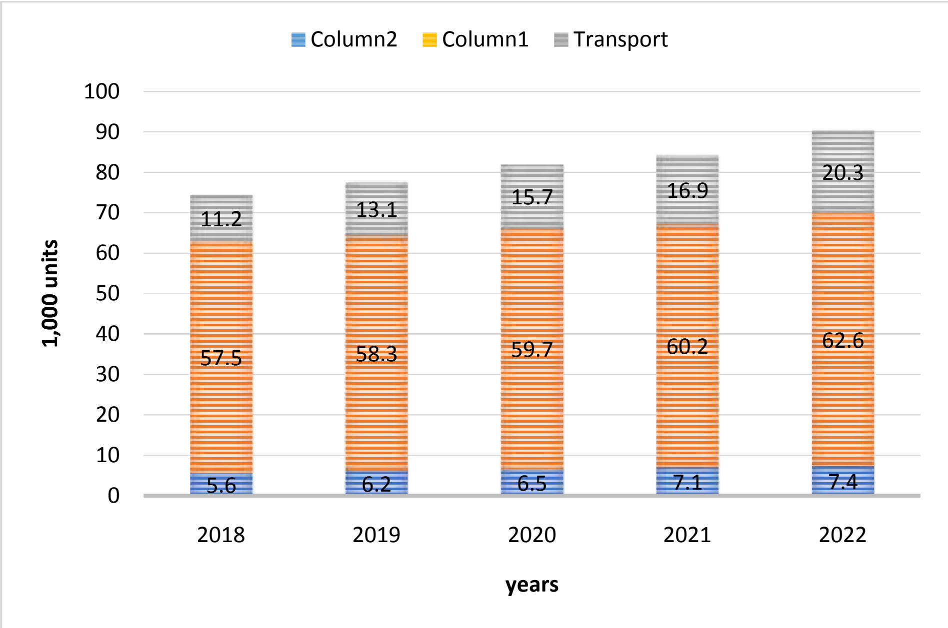

Fig 4. Shipments by Application

When analyzing the value data reported over the last five years regarding the distribution of the technological transfer according to the fuel cell typology Fig 5, 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.

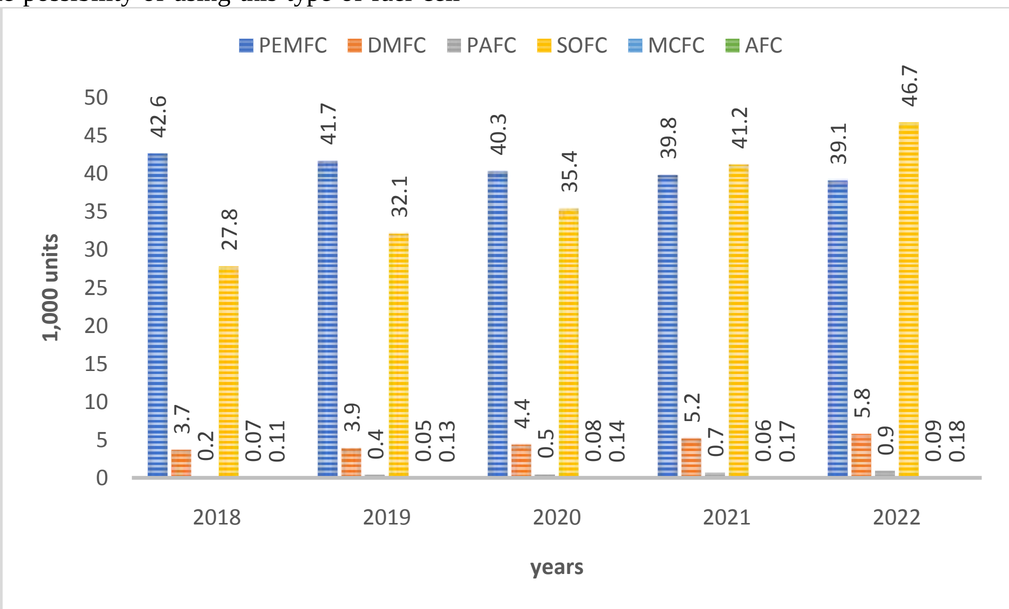

Fig 5. Shipments by fuel cell type.

It should be noted that with the development and widespread use of PEMFC, other types of fuel cells, such as DMFC, MCFC and PAFC, have seen little upward or downward variation during the five years, but this is also because most types of cells are integrated into projects and programs, which are in the pilot phase where the results are verified.

With regard to SOFC technology, there has also been a significant increase in the number of units converted to practical applications since 2020, thanks to the stationary space moves that are

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the subject of the Japanese Ene-Farm project and scheme. If in 2018, approx. 3,200 units were reported, with a significant increase to 28,700 SOFC units converted to their practical applications in 2022.

Based on the number of units converted to practical applications, Fuel Cell Today performed a calculation regarding the sum of the fuel cell capacities that have been installed to support these applications. The total obtained capacity is shown schematically in Fig. 6.

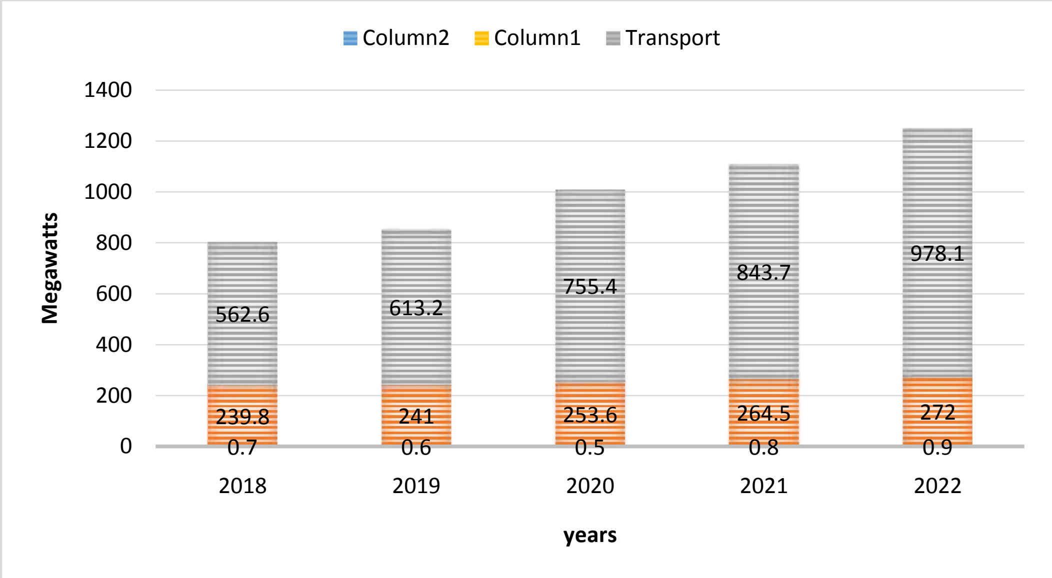

Fig 6. Megawatts by Application.

If one looks at the aspect of the total installed capacity in relation to the fuel cell typology Fig 7 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 2018 to 2022. Considering the validation and demonstration of the large size capabilities of many PAFC and SOFC units implemented in the stationary field starting with 2018, there is an increasing trend in the use and implementation in stationary applications of these types of fuel cells.

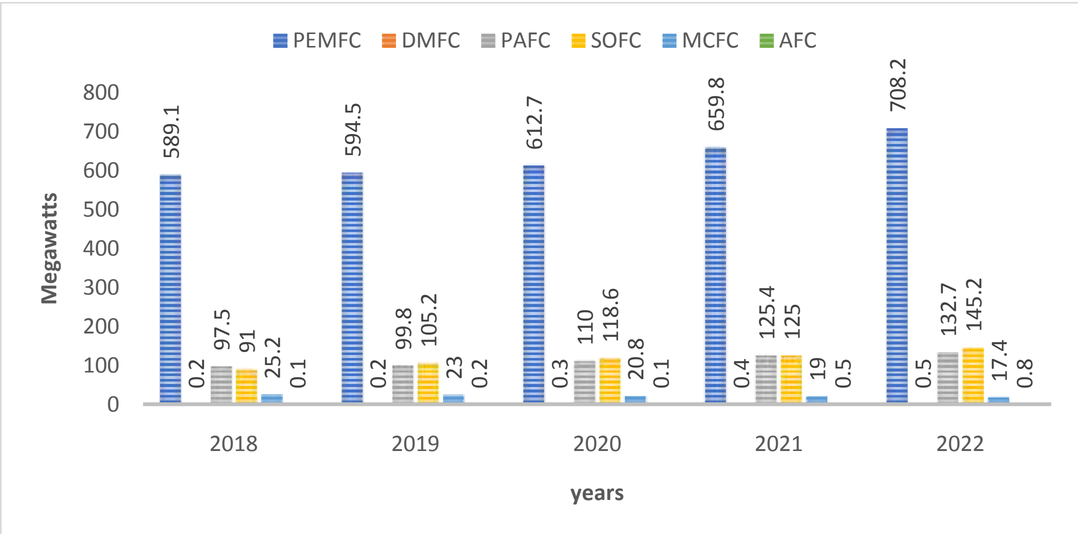

Fig 7. Megawatts by fuel cell type.

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From a sustainability perspective, reducing carbon dioxide emissions in all areas of activity using fuel cells and hydrogen production from renewable electricity is advantageous for reducing the level of carbon dioxide emissions in the electricity industry. In order to stabilize the electricity distribution network, hydrogen power plants will contribute to their balance and locally ensure the necessary energy supply near the renewable energy production sites.

At the global and regional level, a number of major plans targeting this segment are announced, and governments and partner organizations specialized in hydrogen and fuel cells are making a concerted effort to provide centralized production, storage and distribution infrastructure and supply hydrogen to end users. and a wide range of technical, financial and managerial issues are also reviewed to develop a future hydrogen-based economy.

The main arguments worth noting regarding fuel cell power generation systems in stationary applications are as follows:

• By using hydrogen technology in electricity production, 100% autonomy can be achieved compared to the national centralized electricity supply network.

• Hydrogen and fuel cells meet 100% of the consumer's energy needs with no unmet energy demand.

• Renewable resources can be better used by completely eliminating the disadvantages related to their meteorological volatility, but also the problems associated with storage in batteries, while completely eliminating the losses associated with these disadvantages of hydrogen technologies, especially hydrogen-based electrolytic production. on renewable energies and storage using hydrogen, a secondary energy carrier that can release this stored energy through an electrochemical transformation carried out by a fuel cell.

• Excess energy resulting from the operation of the systems can be used with hydrogen either as green energy exported to the centralized electricity grid or as a useful fuel for other types of applications.

• The electrolytic production of hydrogen is directly affected by the availability of renewable energy sources with a variable character over time, which implicitly affects the production of electricity of the fuel cell, which is also directly proportional to the availability of hydrogen.

• Carbon dioxide emissions for fuel cell power systems are much lower and have seen an average reduction of more than 80% compared to conventional power systems that support off-the-shelf applications.

• In the diagram of the total costs of these systems, the costs of the equipment components of the energy systems with respect to hydrogen technology and the costs of purchasing hydrogen fuel have a great influence, but the technology of electricity generation based on hydrogen or methods of production, storage and distribution of hydrogen are the subject of constant research and development, and over time, a number of pilot projects in this area will be verified, which will influence and determine cost reductions in the near future, and this device, as well as hydrogen fuel, will be competitive with classical technologies in areas of energy production and storage.

• Optimization of fuel cell systems to increase the overall efficiency of the hybrid.

power generation systems can be performed by nonlinear control, extreme search, and global optimization techniques.

4.5 Main methods of energy supply through hydrogen fuel cell technologies

The main types of fuel cell technologies mentioned above, which have different operational characteristics and principles, can serve different segments of the power generation market, whether in cogeneration or electricity generation. Each type of technology has advantages and disadvantages that motivate its end use in specific applications and domains. In summary, the applications for which different types of fuel cells are suitable, as well as their advantages and disadvantages, are shown in Table 5.

Table 5. Suitability in practical applications of the fuel cell types

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; Lowtemperature;	Sensitive toCO_2in fueland air;Electrolyte management(aque

				Quickly start-up.	ous);Electrolytec onductivity (polymer).
MCFC	50%	300-3000	Electricity utility; Distributed generation	Fuel flexibility; High efficiency; Suitable for hybrid/gas turbine cycle;	High temperature corrosion and breakdown of cell components; long start-up time; low power density.
PAFC	40%	5-400	Distributed generation	Increased tolerance to fuel	Expensive catalysts; Long start-up time; sulfur sensitivity.
PEMFC	60% direct H40% reformed fuel	1-100	Back-up power; Distributed generation, power to power	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;	Fuel flexibility; High efficiency; Solid electrolyte; Suitable for CHP; 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:

4.6 CHP With Fuel Cells in the Buildings Domain

Fuel cells are suitable for micro-CHP and co-generation because the technology inherently produces electricity and heat from a single fuel source, such as hydrogen, and the systems can also run-on traditional fuels such as natural gas. Currently, cogeneration units with fuel cells are installed in buildings, which are functional in individual modes, but such systems with low energy capacities are under development, projects with goals oriented towards the energy support of mass houses with several apartments.

In this type of application, a proton exchange membrane fuel cell is commonly used, which operates and supplies the energy demand both during the day when peaks are observed and at night. Solid oxide fuel cells can also be used in residential micro-CHP systems, which have relatively the same efficiency as PEMFCs. Because SOFCs use higher operating temperatures than PEMFCs, they are more tolerant of carbon monoxide in the fuel, allowing for some simplification in terms of system configuration.

All cogeneration technologies offer increased combined efficiency compared to traditional solutions for separate production of electricity and thermal energy. Fuel cell cogeneration can exceed the value of "traditional limits" in terms of energy efficiency due to the special performances achieved by this type of technology Table 6. PEMFCs and SOFCs are typically used for energy supply systems for small residential applications and SOFCs, PAFCs and MCFCs for systems, that power large commercial and industrial applications.

Table 6. A summary of the CHP performance of fuel cells

	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 a project started in the 1990s by the Japanese government, which supported research activities to develop a hydrogen system obtained from city gas that would generate both electricity and heat for individual residential buildings. developed a residential micro-cogeneration system recognized worldwide under the name Ene-Farm. At the end of 2022, it was reported that 300,000 PEMFC units had been implemented under the Ene-Farm project.

In the future, Japan plans to install a system similar to the one developed by the Ene-Farm project in mass apartment buildings. Ene-Farm's success has inspired various demonstration projects in other parts of the world, including Korea, Denmark, Germany, the US and the UK.

Back-up energy systems using renewable energy sources or waste-to-energy. This type of function involves storing and increasing the degree of utilization by avoiding losses associated with excess energy produced in power plants that operate using renewable energy sources.

Various concerns in this sector have laid the foundations for research and development projects of these systems, which are currently underway or the results obtained are being verified.

As an example: Solar to Hydrogen - MYRTE combines solar energy with electrolysis, hydrogen storage and the use of fuel cells, and the project was a partnership between the French Commission for Nuclear and Alternative Energy, the energy company AREVA and the University of Corsica.

The production of hydrogen by electrolysis of water leads to the consumption of water resources. In some areas this is not a problem, but in others it is a huge barrier to the implementation of hydrogen fuel cell technology.

For these reasons, a number of studies have been focused on methods of obtaining hydrogen from various wastes, examples of which can be cited. preparation and catalytic steam reforming of raw bioethanol obtained from fir wood, pyrolysis-catalytic steam reforming of agricultural biomass waste and biomass components for the production of hydrogen/syngas, methodology for handling biomass, coal, MSW/any types of waste and sewage sludge for the production of clean /improved materials for the production of hydrogen, energy and liquid fuel-chemicals, production of biohydrogen from solid waste, last but not least, technology for the production of carbohydrates for hydrogen. Table 7 lists the main hydrogen production methods in terms of efficiency and energy consumption.

Table 7. Hydrogen production methods-efficiency and energy consumption.

	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 catalytic reforming of natural gas, appears to be ecologically irresponsible methods, especially due to the carbon emissions that qualify the processes as negative emission technologies. In this regard, concerted research efforts are being made to develop cleaner hydrogen production systems. A series of high-purity hydrogen production devices operating with carbon capture and storage (CCS) or post-combustion carbon capture (PCC) are thus demonstrated. The research activity supported by the Technical University of Graz, the Institute of Chemical Engineering and Environmental Technology in Austria by Bock, Zacharias and Hacker is noteworthy in this regard. They studied and demonstrated the production of high-purity hydrogen (99.997%) with co-production of pure nitrogen (98.5%) and carbon dioxide (99%) with feedstock utilization of up to 60% in the largest fixed-bed loops worldwide.

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V. PRODUCTION OF PRIMARY ENERGY LARGE-CAPACITY ELECTRIC POWER PLANTS

Several types of fuel cells find application in power generation for large stationary applications. AFC, PAFC, PEMFC, SOFC and MCFC systems are used worldwide to generate distributed electricity for local use. Giant. 8 shows the relative weight of different high-capacity fuel cell technologies installed by the end of 2022. It should be noted that three types of technologies dominate the sector, with MCFC having the highest weight, followed by SOFC and PAFC. To date, only a small number of large-capacity installations based on PEMFC and AFC technologies have been implemented.

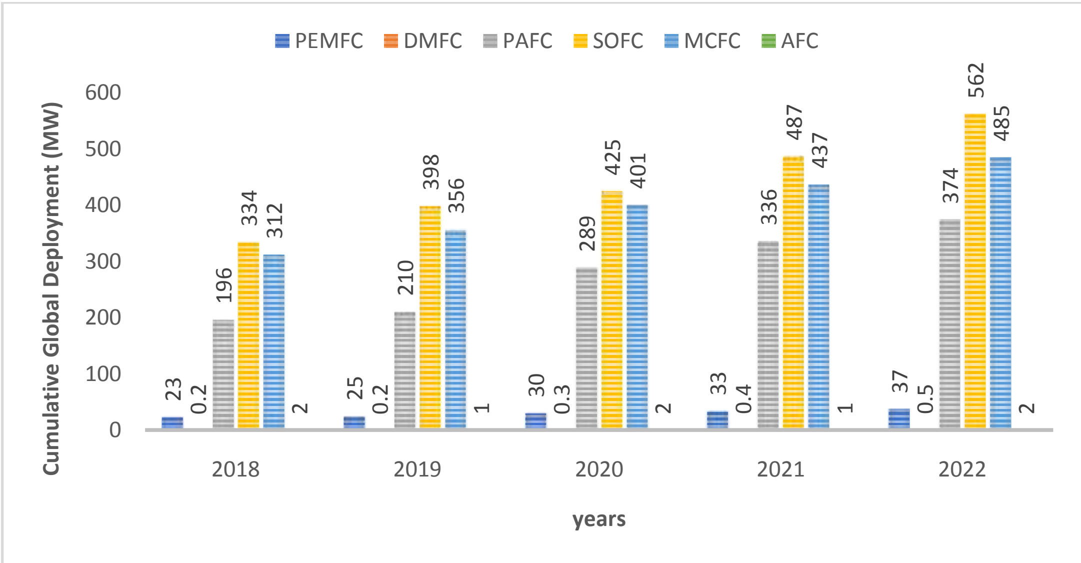

Fig 8. Large scale stationary fuel cells.

VI. RESULTS AND DISCUSSION

The important elements to be discussed regarding hydrogen fuel cell technology were schematically presented in Fig 9 being widely developed within the SWOT analysis and refer to technological, environmental, social, and economic factors.

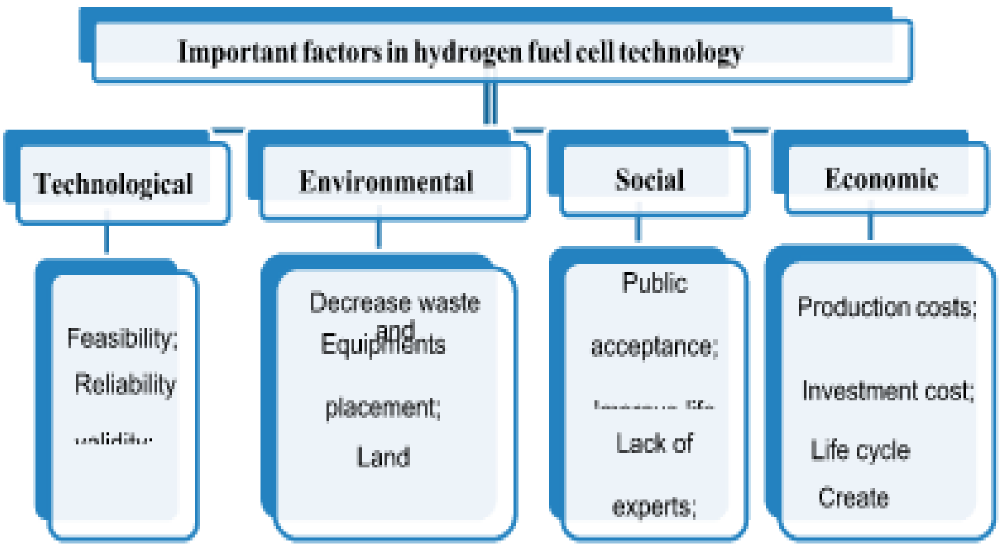

Fig 9. Hierarchy of important factors in hydrogen fuel cell technology.

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6.1 Strengths–Weaknesses–Opportunities–Threats (SWOT)Analysis

Based on the data from the specialized literature collected, studied, analyzed critically, the SWOT matrix was developed Table 8 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 8. Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis.

Strengths	Weaknesses
S1. Technical strengths: -hydrogen has thehighestenergy /mass unit of all fuel types. -1kgofhydrogencontainsasmuchenergyas2.1 kg of natural gas or 2.8 kg ofoil. -fuel cell technology has anoverallefficiencyof 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'splace -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 transportationinfrastructure. **S2. Environmental strengths:** -it is an inexhaustible source, if it is obtained by electrolysis of water, hydrogen production and consumption is a closedcycle. -theburningofhydrogenisalmostentirely devoid of pollutantemissions. -hydrogen is a non-toxic energy transport operator. -environmentally friendly and reduces the amount of GHG emissions from the energysystem. -low noise pollution compared to other energy production methods. **S3. Sustainable development strengths:** -consequentenergysupplyandenergysecurity (hydrogencouldbeconsideredasanever-ending source ofenergy); -hydrogen as a non-polluting energy carrier. -huge development potential. -possibility of production on site for stand-	**W1. Unavailability of an efficient hydrogen infrastructure:** -lack of points of hydrogen production. -lack ofanefficient transport, distribution,and storagesystems. -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. -lackofeffective instruments for introduction of hydrogen in the existing transmission and distribution natural gasnetworks. -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:** -efficient cooperation between political authoritiesandprofessionalassociationsinthe field of hydrogen energy and economic operators, producers of hydrogenfuelcell technologies. **W4. System integration:** -lack of codes, technical design regulations, implementation procedures, technical standards for hydrogen economy in general, stationary applications of hydrogen energy. -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

aloneapplications and remoteareas. -hydrogencanbeobtainedfromawiderangeof primary renewableenergies. -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 primaryenergies. -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 renewableenergies. -allowsremotecommunitiestomanagetheirown energy supply. -decrease dependence to fossil classic fuels and increase alternative energy diversity.	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.

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.	**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 andthermal energy despite the efforts stimulated onthe one hand by the technical progress in the field of fuel cells, and on the other hand drivenby the global concerns regarding energy security, efficiency, energy sustainability, reduction of greenhouse gases emissions and last but not least, the reduction of dependenceon the use of fossil fuels. -lack of specialists and experts in the field regarding the implementation of hydrogen energy projects for stationary applications. -efficient 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

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. -decarbonization 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 online 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.	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 investorsregarding 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:** -it'swere not developed sufficient fiscal instruments to support the investment programs in the energy efficiency sector and the use of hydrogen energy instationary 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. 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.

6.2 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 Table 9.

Table 9. Established and recommended strategies.

	Strengths	**Weaknesses**
Opportunities	**S&O1:** promote the utilization of hydrogen energy in stationary applicationstomakeitmorepopular; **S&O2:** develop hydrogen economy with comprehensive legislation. **S&O3:** stimulate publicacceptance.	**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 inuse.

At EU level, there are a large number of projectsthat are already facing some of the strategies highlighted in Table 9.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; C3SOFC—Cost Competitive Component Integration for Stationary Fuel Cell Power, application are a:stationary power production and CHP; STAGE-SOFC—Innovative SOFC system layout for stationary power and CHP applications;

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; Demo4Grid—Demonstration of 4MW Pressurized Alkaline Electrolyser for Grid Balancing Services; ELECTROU—MW Fuel Cell micro grid and district heating at King's Cross, ene.field—European-wide field trials for residential fuel cell micro-CHP,H2 Future-Hydrogen meeting future needs of low carbon manufacturing value chains.

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 decarbonization of energy generation systems in stationary applications. Technologies using low-carbon footprint hydrogen can be valuable in various end-use stationary applications.

VII. 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 950 MW of large stationary fuel cell systems with a (> 200 kw) nominal power have been installed worldwide for power generation and CHP applications up until2022.
- Worldwide, the use of three types of fuel cell technologies is prevalent: MCFC, SOFC andPAFC.
- AFC and PEMFC are relatively new technologies under development and implementation within stationary applications.
- The main modal it ies 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-uppower 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.

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