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A Review: Fuel Cells Types and their Applications

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Abstract

Due to the environment issues and fluctuation in oil price market, the world since 1981 began to search seriously for an alternative sustainable energy resource, fuel cells as one of solutions has been studied thoroughly. This review paper shows the principle, size, type, the advantages and disadvantages for each type of fuel cells, application and fuel cell market forecast. It is expected that during the next two decades, the dependence on energy produced from fuel cells will be equivalent to a quarter of global power consumption.

Keywords: *Fuel cell, Applications, Sustainable Energy, Advantages and Disadvantages.*

1. Introduction

Pollutants are discharged directly into the air as a result of industrial processes, vehicle engine emissions, energy power production facilities, and other sources. Pollutant components include, but are not limited to: Metals (lead, mercury, cadmium) and Carbon oxides, Sulphur oxides, Ammonia, Light hydrocarbons, Volatile organic chemicals, and Metals (lead, mercury, and cadmium) [1].

The carbon overloading of the atmosphere and ocean waters is evidence of air pollution and climate change, which are the most pressing environmental challenges confronting our world. Warmer air, soils, and ocean surface waters result from atmospheric CO2 absorption and re-emission of infrared-wavelength radiation, which is beneficial (The planet would be frozen solid without this).

Unfortunately, there is currently an excessive amount of carbon in the atmosphere. CO2 concentrations in the atmosphere have risen from 280 parts per million (ppm) 200 years ago to around 400 ppm now, thanks to the burning of fossil fuels, deforestation for agriculture, and industrial activity. That's a record-breaking increase in both size and speed. As a result, the climate is disrupted.

Carbon overloading is just one type of pollution generated by coal, oil, gas, and wood combustion. According to the World Health Organization, one out of every nine fatalities in 2012 was caused by illnesses induced by carcinogens and other toxins in contaminated air [2].

Hydrogen and fuel cells are regarded key technologies for the twenty-first century in the United States and Japan, and are critical for economic growth. These nations have a lot of investment and industrial activity in the hydrogen and fuel cell space[3,4].Carbon-free or carbon-neutral energy sources, as well as fossil fuels with CO2 collection and storage, can all be used to create hydrogen (sequestration). As a result, the use of hydrogen in the energy industry might eventually eradicate greenhouse gas emissions. Fuel cells generate power efficiently and cleanly from a variety of fuels. They can also be placed close to the point of use, allowing the heat created in the process to be used, as indicated in the diagrams below [5,6].

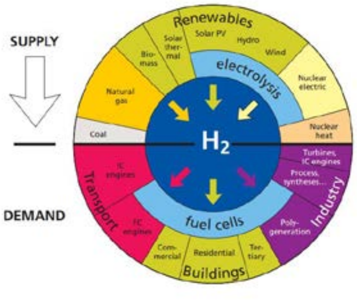


Figure 1: Hydrogen: primary energy sources, energy converters and applications
NB: Size of "sectors" has no connection with current or expected markets.

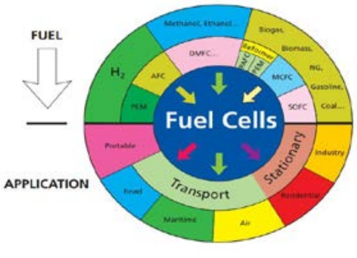


Figure 2: Fuel cell technologies, possible fuels and applications
*NB: Size of "sectors" has no connection with current or expected markets.**
** PEM = Proton Exchange Membrane Fuel Cell; AFC = Alkaline Fuel Cells;*
DMFC = Direct Methanol Fuel Cell; PAFC = Phosphoric Acid Fuel Cell;
MCFC = Molten Carbonate Fuel Cell; SOFC = Solid Oxide Fuel Cell

In 2019, primary energy usage increased by 2.9 percent. This is about double the previous decade's average of 1.5 percent each year[5]. Organization for Economic Co-operation and Development (OECD) nations utilize more than half of all transportation energy [6]. World governments have determined that new inventive technologies are the key to addressing climate change; as a result, large corporations have begun to fund research for new renewable energy sources, such as modifying fuel cell technology, which began in 1981. In many ways, this implies in the domains of decarbonization, power, the environment, health, and safety[7].Many people consider fuel cells to be a vital answer for the twenty-first century, since they allow for the clean and efficient production of electricity and heat from a variety of basic energy sources. Fuel cells are electrochemical devices that create electricity and heat by combining hydrogen (H2) or H2-rich fuels with oxygen from the air. However, depending on the kind of Fuel Cell and the fuel utilized, there are several variations of this fundamental process[8]. Micro power generators, auxiliary power generators, fixed power generators, distributed power generators, and portable power generators for transportation, military projects, and the automotive sector are all potential uses for this technology[9]. All of these applications will be employed in a wide range of businesses and settings across the world[10].

2.Fuel Cell

A fuel cell is an electrochemical device that transforms chemical energy from a fuel and an oxidant into electrical energy directly[11]. As illustrated in figure, a single cell's fundamental physical structure consists of an electrolyte layer in contact with a porous anode and cathode on both sides (1). Gaseous fuels are constantly supplied to the anode (negative electrode) compartment, and an oxidant (i.e., oxygen from air) is continuously fed to the cathode (positive electrode); electrochemical reactions occur at the electrodes to create an electric current (Fig. 3)[12]. Despite having comparable components and properties to a conventional battery, it varies in key ways [13]. An external supply of reactants is constantly provided [14].

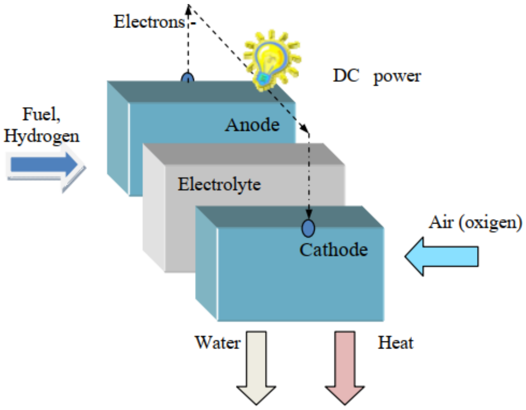


Fig. 3 fuel cell concept.

C. F. Schönbein, a German physicist, established the fuel cell idea in 1838[15]. In 1839, Welsh scientist Sir W.R. Grove showed the first fuel cell based on this research. F.T. Bacon, a British engineer, created a 5 kW stationary fuel cell in 1939. W.T. Grubb, a scientist at the General Electric (GE) Company in the United States, improved the initial fuel cell concept in 1955 by utilizing a sulphonated polystyrene ion-exchange membrane as the electrolyte. L. Niedrach, a GE chemist, devised a method of depositing platinum onto the membrane, which acted as a catalyst for the required hydrogen oxidation and oxygen reduction reactions[16,17].

went on to work with NASA to improve this technology, which was later used in Project Gemini. This was the first time a fuel cell was used in a business setting. H. Ihrig headed a team that developed a 15 kW fuel cell tractor for Allis-Chalmers in 1959, which was displayed at state fairs around the United States[18]. The electrolyte was potassium hydroxide, while the reactants were compressed hydrogen and oxygen. Pratt & Whitney licensed Bacon's US patents for use in the US space program in the 1960s to deliver power and drinking water (hydrogen and oxygen were easily accessible from the spaceship tanks)[19]. For the Apollo space missions, International Fuel Cells (IFC, subsequently UTC Power) developed a 1.5 kW alkaline fuel cell (AFC). For the remainder of their mission, the astronauts relied on the fuel cell for both electrical power and drinking water[20]. Following that, IFC built a 12 kW AFC, which was utilized to supply onboard power on all space shuttle missions. GM had previously experimented with their hydrogen fuel cell-powered Electrovan, which was equipped with a Union Carbide fuel cell[21]. Shell has been active in the development of direct methanol fuel cells (DMFC) since the mid-1960s, when the use of liquid fuel was seen as a significant benefit for automotive applications[22]. In the 1970s, a number of German, Japanese, and American automakers and their partners began experimenting with FCEVs, improving the power density of PEMFC stacks and creating hydrogen fuel storage systems[23]. As a result of these early initiatives, all of the world's major carmakers had active FCEV demonstration fleets by the end of the century. By that time, the focus had turned back to pure hydrogen fuel, which emits no hazardous emissions from the tailpipe[24]. Concerns about energy shortages and rising oil costs prompted several national governments and big corporations to launch research programs in the 1970s to create more efficient types of energy generation[25]. As a result, significant advancements in phosphoric acid fuel cell (PAFC) technology, particularly in terms of stability and performance, have been made. During the 1970s, there were several field demonstrations of huge permanent PAFC units providing prime, off-grid electricity, including one built by IFC[26]. Developments in molten carbonates fuel cell (MCFC) technology, such as internal natural gas reforming to hydrogen, were made possible thanks to funding from the US military and electric utilities. A significant benefit in developing fuel cells for large stationary prime power applications was the utilization of an established natural gas infrastructure. In the 1980s, significant technological and economic progress was made, particularly in the field of PAFC[27]. Around this period, it was commonly believed that the technology would have a bright future in stationary applications and buses. Ambitious conceptual designs for municipal utility power plant applications with outputs up to 100 MW have been published[28]. It was predicted that tens of thousands of units would be operational by the end of the century, but only a few hundred would actually appear by that time. Several large experimental stationary PAFC facilities were developed, but commercialization was slow in the 1980s[29]. PAFC were put out in greater numbers for large-scale combined heat and power applications over two decades later, with to advances in membrane durability and system performance [30]. Ballard, a Canadian company that began researching fuel cells in 1983 and went on to become a major player in the manufacture of stacks and systems for stationary and transportation applications in later years, was a major player in the manufacture of stacks and systems for stationary and transport applications in later years. In the 1990s, the polymer electrolyte membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC) technologies received a lot of attention, especially for small stationary applications [31]. Due to the lower cost per unit and wider variety of possible applications - such as backup power for telecommunications installations and domestic micro-CHP - they were viewed as having a more immediate economic potential. Significant government money has begun to be committed to developing PEMFC and SOFC technologies for domestic micro-CHP applications in Germany, Japan, and the United Kingdom [32].

As it emerges from a period of recession and completes the transition from R&D to commercialization, the fuel cell sector has encountered and continues to confront obstacles. It has, on the whole, persevered in the face of adversity [33]. Although many fuel cell firms are still in the early stages of profitability, the prospects for future development are quite encouraging. Because of the recent success of some application sectors, there has been a push to combine certain technologies into a common reference design for a specific type of fuel cell. As a result, fuel cells are rapidly being developed as scalable energy solutions that can serve a variety of market sectors, whether as APUs or to power devices like Unmanned Aerial Vehicles (UAVs)[34].

The fuel cell (FC) is an energy conversion device that may potentially produce electrical energy as long as the electrodes are supplied with fuel and oxidant [28]. The practical operational life of fuel cells is limited by degradation, usually corrosion, or component failure. FC is essentially a device that converts the chemical energy of fuels into power directly, without the need of intermediary energy forms, through a reaction between fuel and oxygen O2 [35]. In FCs, the fuel and oxygen react electrochemically, creating electrical energy, CO2, H2O, and some waste heat that is far less than that produced by traditional combustion [36]. An FC has two electrodes: an anode and a cathode. While oxygen flows at the cathode, a fuel travels via the anode bipolar plates into the FC [37].

Although all fuel cells have the same fundamental design of an electrolyte and two electrodes, they are classified into several kinds based on the electrolyte they employ as shown in figure 4.

There are several fuel and oxidant combinations that can be used. The fuel may be diesel or methanol, and the oxidants could be air, chlorine, or chlorine dioxide. The ingredients used in most modern fuel cells, on the other hand, are hydrogen and oxygen.

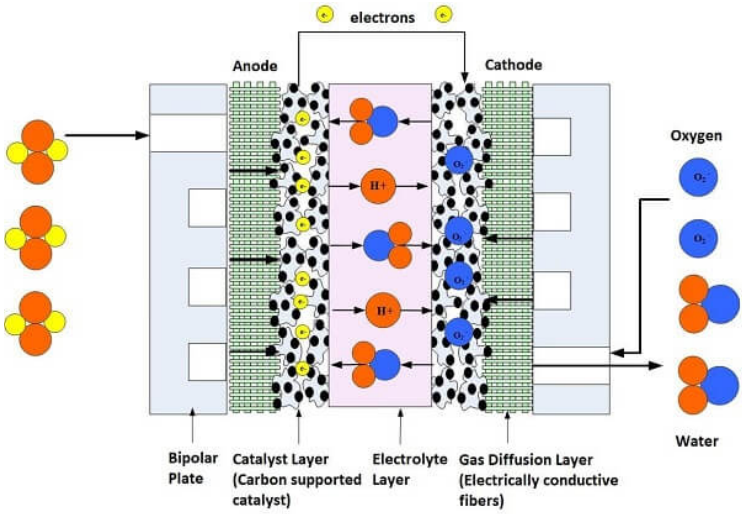


Fig. 4 fuel cell fundemantal design

2.1 Common types of fuel cells

Thousands of automobiles are driven on the streets of the world every day, releasing massive amounts of pollution into the environment. As a result, experts are striving to find a new source of power generation. Long-lasting and environmentally friendly[11]. Companies make electric cars as an alternative to engine cars, but the disadvantage of those cars is that they use batteries that have a short working cycle life of less than (2-3) years and are very expensive. As a result, fuel cells were the best choice to be investigated and modified as research, then commercialized worldwide prediction to meet global needs[12]. Reduced prices and increased dependability for commercial usage are two significant problems in energy delivery systems[13]. Fuel cells are now being researched as a potential green energy source in various energy development sectors. Fuel cells provided portable and micro-scale electronics with reliable power production, transportation, and traction[14]. Over the last 20 years, many types of fuel cells with various possible uses and designs have been described.

Table 1: type of fuel with energy

Fuel Type	Energy/Mass Unit (J/kg)	Energy/Volume Unit (J/m3)	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
Methanol	22.30	18.10	0.23	0.50
Ethanol	29.90	23.60	0.37	0.50

Fuel cells are different according to their operating temperature, efficiency, applications and costs. They are classified based on the choice of fuel and electrolyte into 6 major groups - Alkaline fuel cell (AFC) - Phosphoric acid fuel cell (PAFC) - Solid oxide fuel cell (SOFC) - Molten carbonate fuel cell (MCFC) - Proton exchange membrane fuel cell (PEMFC) - Direct methanol fuel cell (DMFC) as shown in table2.

2.1.1 FUEL CELLS WITH POLYMERIC ELECTROLYTE MEMBRANE (PEMFCS)

The anode and cathode of a polymeric electrolyte membrane fuel cell (PEMFC) are connected by an electrolyte that permits protons, or H+, to flow from the anode to the cathode[15]. This electrolyte or membrane is a solid polymer with a working temperature of 70–90 °C and a pressure of 1–2 bar. For a single-cell stack, the average cell stack voltage is 1.1 V, and it rises proportionally with the number of cells in the stack[16]. The electrochemical processes in a hydrogen FC as a typical PEMFC are summarized in Eqs. (1-3).

Anode: $H_{2\,(g)} \rightarrow 2H^+ + 2e^-$ (1)
Cathode: $1/2O_{2\,(g)} + 2H^+ + 2e^- \rightarrow H_2O$ (2)
Overall: $1/2O_{2\,(g)} + H_{2\,(g)} \rightarrow H_2O$+ electricity + heat (3)

Bipolar plates (typically graphite) serve as the anode and cathode, with flow channels allowing reactants to flow into the FC[17]. As a result, the bipolar plate geometry's design has a major impact on overall performance. It also controls the cell's heat and water management. To absorb excess heat created in the FC, some FCs feature cooling plates positioned between the various cells in the stack [18]. Because of the high cost of gasoline, it is critical to optimize the FC. Only by optimizing various cell components can this be accomplished. The design of FCs varies based on the output voltage required [19]. To compete with alternative energy storage or conversion devices, the final design must be simple to build and inexpensive [20].

The electro catalyst layer is crucial since it affects the fuel cell's total cost. Pt is commonly used as a catalyst in PEMFCs to speed up the chemical process. A tiny quantity of Nafion (Sulfonated Polytetrafluoroethylene) holds these catalysts together [21]. Electrons go from the anode to the cathode through an externally linked circuit in the FC. At the same time, protons travel through the electrolyte to reach the cathode [22]. The electrons, protons, and oxygen finally make their way to the cathode, where they are reduced. These types of FC [23] have benefits such as quick start-up, strong mechanical construction, a broad range of power output from mW to kW scale, and simple scale-up. Slow oxygen reduction kinetics, poor heat and water management, CO poisoning, and the necessity for high quality hydrogen as a fuel are among drawbacks of PEMFCs. Regardless, PEMFC is a viable contender for replacing gasoline engines in automobiles and aircraft [24].

2.1.2 Alkaline Fuel Cells (AFC)

The alkaline fuel cell (AFC) runs at low temperatures of 23–70 °C and employs an alkaline-based solution such as NaOH or KOH as an electrolyte. Unlike PEMFCs, an AFC is an anion exchange membrane fuel cell (AEMFC), which is the earliest form of FC. In comparison to other alkaline solutions, KOH is the most often utilized electrolyte due to its high conductivity. High efficiency, better heat management, faster start-up, increased activity, cheaper cost, and fast kinetics of oxygen reduction are the primary advantages of AFCs [25]. At the anode of AFCs, platinum Pt might be replaced by nickel Ni or its alloys, or other transition metals. AFCs may survive CO poisoning to a considerable extent due to their greater activity than PEMFCs. The inability of AFCs to withstand CO2, which is a primary reaction product with hydrocarbon fuels, is one of their major drawbacks. CO2 eats the electrolyte, resulting in the formation of carbonate salt [26]. The carbonate salt causes the electrolyte's ionic conductivity to decrease, lowering overall performance and efficiency [27]. The electrochemical reactions of AFC may be summarized in the following way, with an overall response comparable to that of PEMFC.

Anode: $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ (4)
Cathode: $1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$ (5)

2.1.3 Direct Alcohol Fuel Cell (DAFC)

Direct alcohol fuel cells (DAFCs) similarly function at low temperatures, typically below 100 °C, and are mostly utilized for portable power applications requiring less than 250 watts[28]. Methanol and ethanol are utilized as fuels in direct methanol/ethanol fuel cells (DMFC) and direct methanol/ethanol fuel cells (DEFC)[29]. The DAFC catalyst layer should preferably be composed of Pt and ruthenium Ru, as Ru prevents Pt from CO poisoning. DAFCs have a number of benefits, including a quick start-up time, the use of waste resources as a source of fuel (methanol or ethanol from waste), a high energy density, fuel that is easy to use and carry, and lastly, cost-effectiveness[30]. The major issue with DAFCs is fuel crossover, which occurs when fuel flows from the anode to the cathode owing to a change in concentration, resulting in mixed potential, which reduces overall performance and poisons the cathode[31]. As a result, the alcohol content is reduced, lowering the energy density. Furthermore, alcohols are very flammable and can be poisonous, as in the case of methanol. Furthermore, the catalysts employed in DAFCs are made of precious and expensive metals such as Pt and Ru[32]. In a DAFC, the most important electrochemical processes are:

Anode: $CH_3\,OH + H_2O \rightarrow 6H^+ + 6e^- + CO_2$ (6)
Cathode: $6H^+ + 6e^- + 3/2\,O_2 \rightarrow 3H_2O$ (7)
Overall: $CH_3\,OH + 3/2\,O_2 \rightarrow 2H_2O + CO_2$ +electricity + heat (8)

2.1.4 Phosphoric acid fuel cells (PAFC)

The phosphoric acid fuel cell (PAFC) is a medium-temperature fuel cell that runs between 150 and 220 degrees Celsius, with an optimal cell temperature of about 180 degrees Celsius [33]. The cell's electrolyte is phosphoric acid H3PO4, therefore the name PAFCs. PAFC is the most widely used FC for commercial reasons, and it is more mature than other FCs [34]. PAFCs offer several advantages over PEMFCs, including better tolerance to CO poisoning and reduced Pt catalyst requirement due to increased activity, lowering cost. They also enable for the use of waste heat [35]. PAFCs are a particularly appealing alternative in combined heat and power (CHP) applications since they function at greater temperatures than PEMFCs. PAFCs have several drawbacks, including a high cost owing to the usage of a Pt catalyst, a slow start-up time, and poor ionic conductivity [36]. Because it's an intermediate-temperature FC, the material options are restricted, and materials should have similar thermal expansion to avoid cracking the membrane electrode assembly (MEA). PAFCs have electrochemical processes that are comparable to PEMFCs [37].

2.1.5 Molten Carbonate Fuel Cell (MCFC)

The molten carbonate fuel cell (MCFC) is a high-temperature fuel cell that works between 550 and 700 degrees Celsius. Molten carbonate salt, primarily lithium and potassium carbonates, is used as the electrolyte/membrane in various sorts of FCs[38]. Both the anode and cathode of the MCFC are made of nickel-based powders. MCFCs may be made from a number of fuels, including natural gas with oxygen or carbon dioxide as oxidants[39]. MCFCs have a number of advantages, including great efficiency. They can also utilise CO2 as an oxidant, which makes them suitable for carbon capture and storage (CCS)[40]. Because MCFCs function at a higher temperature, noble metals are not required, making them more cost-effective. Because of its high working temperatures, long start-up times, restricted possibilities for building materials, and difficult handling of the molten carbonate liquid, MCFCs' major constraint is corrosion[41]. With an overall reaction comparable to that of PEMFC, the electrochemical reactions of MCFC may be described as follows:

Anode: $CO^{2-}{}_3 + H_2 \rightarrow H_2O + 2e^- + CO_2$ (9)
Cathode: $CO_2 + 2e^- + 1/2\,O_2 \rightarrow CO2^-{}_3$ (10)

2.1.6 Solid oxide fuel cell (SOFC)

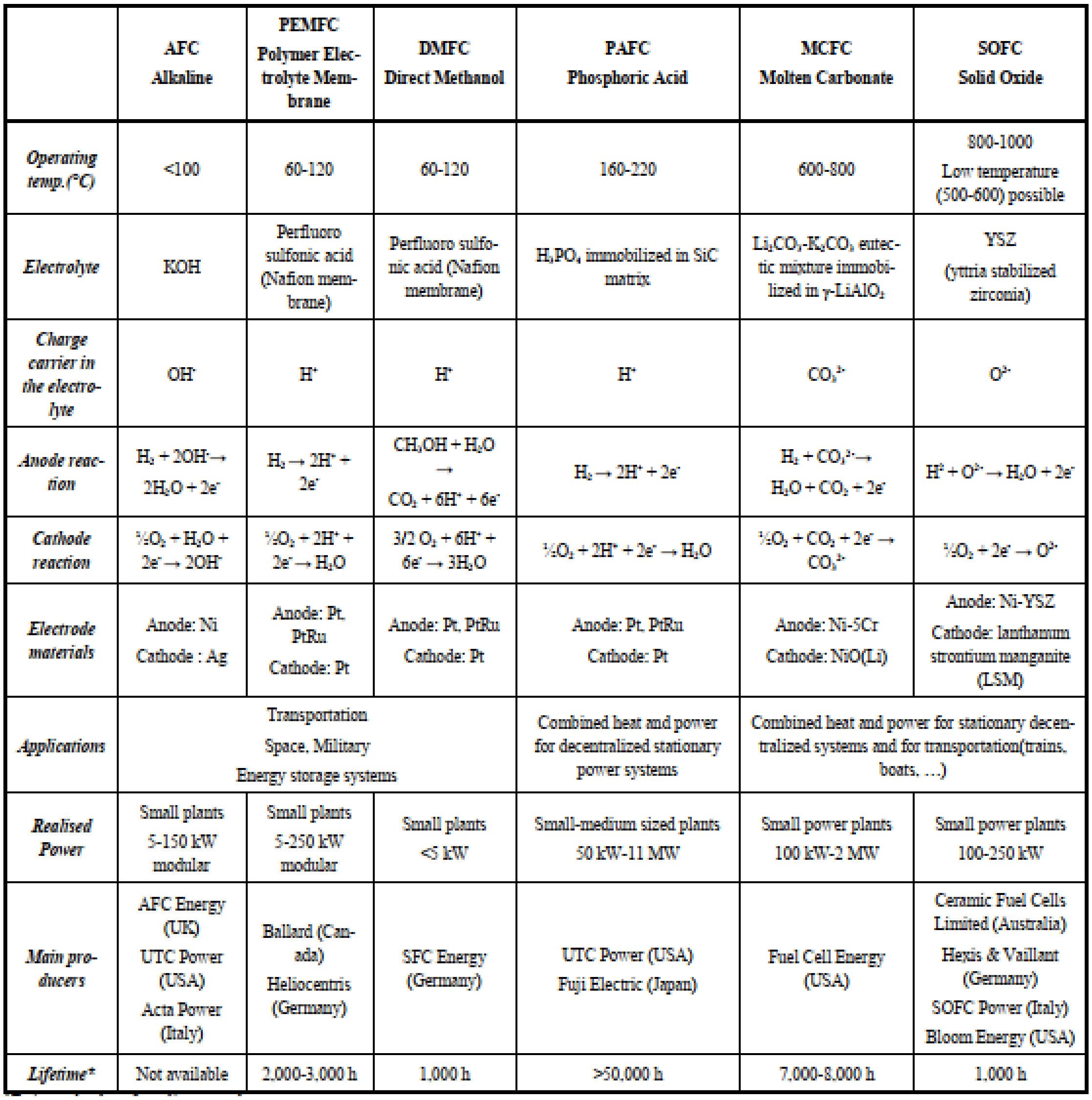
A solid oxide fuel cell (SOFC) is a high-temperature fuel cell that works between 600 and 1100 degrees Celsius[42]. Yttrium stabilized zirconia can be used as the solid electrolyte in SOFCs (YSZ). Thermal stability, steady ionic conductivity, and catalytic activity are all factors to consider when selecting a material for use as the cathode in SOFCs[43]. Lanthanum Strontium Manganite (LSM) MnO3 is one of the minerals that satisfies all of these criteria. As a result, it is frequently employed as the cathode in SOFCs; the anode can also be nickel-based YSZ, which accelerates the hydrogen oxidation reaction[44].

SOFCs have a lot of advantages, which is why they're used in so many applications. These types of FCs have a high efficiency, and the surplus heat generated during the reaction may be utilized for cogeneration[45]. These FCs can work without noble metals, making them more cheap and providing a long operational duration of up to 80,000 hours. SOFCs, unlike other forms of FCs, allow for the utilization of a variety of fuels[46]. Methanol and biogas are two of these fuels. Because only a few number of materials are thermally, catalytically, and conductively stable at such high temperatures, the major drawback of SOFC is the high cell temperature[47]. The following are the electrochemical reactions of SOFC, with an overall reaction comparable to that of PEMFC:

Anode: $O^{2-} + H_2 \rightarrow H_2O + 2e^-$ (11)
Cathode: $2e^- + 1/2\,O_2 \rightarrow O2^-$ (12)

The interest in FCs as a promising high-efficiency direct energy con-version tool has attracted many research works, thereby developing a wide range of FC types and combinations. Given such a wide range of the different advantages and disadvantages of different FCs, it is imperative to compare the different aspects of FCs, emphasizing on their advantages and disadvantages

Table 1: comparison of different types of fuel cell



	AFC **Alkaline**	**PEMFC** **Polymer Electrolyte Membrane**	**DMFC** **Direct Methanol**	**PAFC** **Phosphoric Acid**	**MCFC** **Molten Carbonate**	**SOFC** **Solid Oxide**
Operating temp.(°C)	<100	60-120	60-120	160-220	600-800	800-1000 Low temperature (500-600) possible
Electrolyte	KOH	Perfluoro sulfonic acid (Nafion membrane)	Perfluoro sulfonic acid (Nafion membrane)	H_3PO_4 immobilized in SiC matrix	Li_2CO_3-K_2CO_3 eutectic mixture immobilized in γ-$LiAlO_2$	YSZ (yttria stabilized zirconia)
Charge carrier in the electrolyte	OH^-	H^+	H^+	H^+	CO_3^{2-}	O^{2-}
Anode reaction	$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$	$H^2 + O^{2-} \rightarrow H_2O + 2e^-$
Cathode reaction	$½O_2 + H_2O + 2e^- \rightarrow 2OH^-$	$½O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$	$½O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$½O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$½O_2 + 2e^- \rightarrow O^{2-}$
Electrode materials	Anode: Ni Cathode : Ag	Anode: Pt. PtRu Cathode: Pt	Anode: Pt. PtRu Cathode: Pt	Anode: Pt. PtRu Cathode: Pt	Anode: Ni-5Cr Cathode: NiO(Li)	Anode: Ni-YSZ Cathode: lanthanum strontium manganite (LSM)
Applications	Transportation Space, Military Energy storage systems			Combined heat and power for decentralized stationary power systems	Combined heat and power for stationary decentralized systems and for transportation(trains, boats, …)	
Realised Power	Small plants 5-150 kW modular	Small plants 5-250 kW modular	Small plants <5 kW	Small-medium sized plants 50 kW-11 MW	Small power plants 100 kW-2 MW	Small power plants 100-250 kW
Main producers	AFC Energy (UK) UTC Power (USA) Acta Power (Italy)	Ballard (Canada) Heliocentris (Germany)	SFC Energy (Germany)	UTC Power (USA) Fuji Electric (Japan)	Fuel Cell Energy (USA)	Ceramic Fuel Cells Limited (Australia) Hexis & Vaillant (Germany) SOFC Power (Italy) Bloom Energy (USA)
Lifetime*	Not available	2,000-3,000 h	1,000 h	>50,000 h	7,000-8,000 h	1,000 h

2.2 Main features of fuel cells

The electrolyte utilized, the operating circumstances, the necessary load, the available fuel, the starting time, and the application used to distinguish FCs [48]. FC electrolytes are available in a variety of solid and liquid forms. These electrolytes work in both hot and cold conditions. To speed up the chemical process in FCs that function at low temperatures, a platinum (Pt) catalyst is required [49]. Platinum Pt is the best catalyst for low-temperature FCs, although it adds substantially to the cost. Pt is not required to speed up the reaction in high-temperature FCs [50]. FCs may run on a variety of fuels, including gases like hydrogen and liquids like methanol and ethanol. Hydrogen's electrochemical reactivity is usually higher than that of other fuels [51].

The anode receives the fuel, whereas the cathode receives the oxygen. Only when the electrode, membrane, and cathode are linked do electrons flow. The passage of electrons via the electrodes produces solely thermal energy [52]. Only when the external circuit is linked, i.e. when the circuit is closed, may electrons travel. The flow of charge is enabled by the passage of ions over a membrane, which has a distinct connection to the membrane's conductivity [53]. The electrolyte is intended to enable only the movement of ions, not electrons, and to function as a barrier between the reactant and the electrodes while also physically supporting them [54].

The operating parameters of an FC, particularly temperature, are determined by the membrane. High-temperature FCs allow light hydrocarbon fuels to undergo reforming since their operational temperature range surpasses 600 °C [55]. Because the rate of reaction in high-temperature FCs is readily high, a catalyst is not required [56]. High-temperature fuel cells include solid oxide fuel cells (SOFC) and molten carbonate fuel cells (MCFC). Low-temperature FCs are those that operate at temperatures below 250 °C. These FCs are unable to conduct fuel reforming, necessitating the use of external fuel [57].

2.3 Advantage and Disadvantage of Fuel Cell

The Advantages and Disadvantages of Fuel Cells If compared with conventional fossil fuel propelled electric generators, the use of fuel cells brings about many advantages[58] :

2.3.1 Advantages

1-More Effectiveness

Fuel cells have a higher efficiency because they produce electric energy directly (chemically) from the fuel they use. As a result, the technology is unaffected by the Carnot thermic cycle's limitations, which plague all combustion-based electric generation systems[59].

2-Chemical, acoustic, and thermal emissions are minimal.

Fuel cells emit less carbon dioxide and nitrogen oxides per kilowatt of power generated due to higher efficiencies and lower fuel oxidation temperatures. Another feature is that noise and vibration are minimal because fuel cells have no moving components (except for auxiliary pumps, blowers, and transformers)[60].

3-Siting Flexibility and Modularity

A single fuel cell produces less than one volt of electrical potential, thus fuel cells are stacked on top of each other and linked in series to create larger voltages. Cell stacks are made up of multiple fuel cell units that each have an anode, cathode, electrolyte, and a bipolar separator plate [46]. The number of cells in a stack is determined by the required power output as well as the performance of each individual cell. The stacks range in size from a few hundred Watts to several hundred kilowatts [61].

4-Easy to Maintain

Due to the high modularity of generator systems, it is relatively easy to locate and replace a damaged or malfunctioning fuel cell contained within a stack for the same type of fuel cell. This feature, of course, results in decreased maintenance costs[62].

5-Fuel Versatility

However, fuel flexibility has been demonstrated in many technologies using natural gas, propane, landfill gas, anaerobic digester gas, military logistic fuels, and coal gas[63]. Hydrogen is the most commonly used fuel (especially for low temperature fuel cell technologies that require pure gasses to operate); however, fuel flexibility has been demonstrated in many technologies using natural gas, propane, landfill gas, anaerobic digester gas, military logistic fuels, and coal gas. This adaptability is mostly determined by the operating temperature range of the fuel cells employed (in principle, the higher the temperature the less pure the gas that the fuel cell can use). Even though they can offer a number of significant benefits, all fuel cell technologies are still in the early stages of development and are plagued by a number of issues that make their usage less comfortable than that of other technologies now in use[64].

2.3.2 Disadvantages

1-Fuel cell prices for stationary electric generating (€/Wh) are still too expensive, making them unsuitable for replacing fossil-fuel-based technologies [65].
2-Many fuel cell technologies' life cycles and deterioration times (particularly the high temperature technologies that are ideal for electric power production) are yet unknown [66].
3- Hydrogen, one of the major fuels for fuel cell technologies, is costly, and there is no network for its manufacture and distribution [67].
4-The use of low-temperature fuel cells in automobiles is constrained by the difficulty of containing a sufficient amount of hydrogen in small fuel containers, as well as the fact that hydrogen is a combustible and possibly explosive gas (particularly when compressed in small containers)[68].

These are the reasons why fuel cells are unable to replace many other technologies that are less efficient and have a larger environmental impact [69].

As a result, a significant amount of research and development is still required to make this technology accessible, particularly in terms of lowering energy production costs through the use of new materials and improving the conductivity mechanism in electrolytes, especially because the development of new materials is still ongoing [70].

2.4 Fuel cell Market Forecast

The electric vehicle market is anticipated to reach 350 million units by 2040, with 300 million of those being passenger cars[71]. As a result, electric vehicles would cover one-fourth of all passenger vehicle kilometers. By the end of the year, half of all new public and freight vehicles will be electric or hydrogen-powered. “Additional renewables, as well as more Carbon Capture, Utilization, and Storage (CCUS) in combination with natural gas and coal, would be required for decarbonization of the power industry [72].” However, according to the International Energy Agency (IEA), only around two-thirds of final energy usage has the technological capacity to be electrified, emphasizing the need for alternate lower-carbon types of energy (and energy carriers) for the remaining one-third. Hydrogen generated from decarbonized sources, bioenergy, and gas/coal/oil with CCUS are all examples of this [73].

2.5 Application of fuel cells

Fuel cells may be used effectively in a wide range of applications. These include everything from large-scale fixed power facilities to small portable power devices.

1- Power Plants (Stationary) A steady number of stationary power plant projects have been successfully constructed during the previous decade. The Ballard Generation Systems power plant, with a capacity of 250 kW, is now the biggest power plant in the world. Its PEM fuel cell is fuelled by natural gas and may successfully serve as a backup power supply for essential institutions (e.g. hospitals) or small neighborhoods[74]. Natural gas or other conventional fuels are widely used in stationary power plants, which are typically extremely efficient in operation. Unlike smaller portable systems, warm-up times are not an issue for these applications. Furthermore, these plants generate a lot of waste heat and hot water. These outputs are frequently used by the local population, which increases the system's efficiency [75].

2-Submarines are an interesting topic. Fuel cell systems are almost silent, and the hot water produced by them may be used by on-board reformers. Furthermore, the infrared fingerprints of fuel cells appeal to these sorts of military applications. In recent years, a large number of prototype systems have been successfully tested [76].

3-Production of ammonia and iron Ammonia production methods are already extensively used, but direct reduced iron (DRI) production has just recently grown significantly. DRI worldwide output surpassed 100 million tons in 2018 owing to recent technological advancements in fuel cell technology. Beyond future renewable fuels, present hydrogen demand includes refineries, with a particular focus on hydrocracking (the refining of middle distillates) [77]. Power Supply for the Go In many compact/mobile applications, portable power systems may efficiently replace batteries. Commercial systems may now produce 1.2 kW (4100 Btu h) of electrical power [78].

2.6 Fuel cell technology in the automotive market

Toyota, Honda, and Hyundai were the first to launch mass-produced hydrogen automobiles, and other major companies quickly followed. Trucks and heavy-duty vehicles are also being manufactured to help decarbonize the transportation sector[79]. With current mass-production scaling, mid-size hydrogen FCEVs cost around 50% more than comparable ICE vehicles. Battery-electric cars are seeing quicker market growth and, as a result, are obtaining a bigger proportion of the passenger car industry, particularly for short-range and urban applications[80]. Instead, FCEVs want to

dominate the long-distance, heavy-duty transportation market. Several hundred hydrogen buses have already been deployed in most Chinese cities[81], and Europe is presently developing a wide range of hydrogen buses.
Higher fuel economy, longer driving range, and quick recharging of fuel cells are boosting the automotive industry for innovative fuel cell applications.
In the future decades, the passenger automobile category is expected to be the fastest-growing market for fuel cells. Some of the primary reasons for this forecast include the modularity of the systems, great efficiency, and enhanced driving range compared to older versions. Another important factor for this forecast is the projected rise in OEM focus in the industry [83].

Components such as the fuel stack, fuel processor, and power conditioner can be used to segment the fuel cell market. The fuel stack is projected to be the most popular component in the fuel cell industry, followed by the power conditioner section, which comprises all of the vehicle's electric systems. The automobile fuel cell market is divided into two categories based on power output: 100-200 kW and demand for more than 200 kW [84].

The worldwide automotive hydrogen and fuel cell market is expected to grow at a 25% CAGR through 2025, according to the 2019 Market Research Futures Report (MRFR) [85]. Increased government activities, stringent pollution regulations, and technological development investments are all needed to propel hydrogen automobiles forward.

3. Conclusions

This study shows after reviewing all information available about six fuel cell types are: may be used one of classification technique, type of anode, cathode, electrolyte solution, the material and operating condition of catalyst Specially operating temperature.
1- Fuel cells can be classified to three main categories:

- transportation: Solid Oxide Fuel Cell (SOFC), Molten Carbonate Fuel Cell (MCFC) both cells have high operating temperature (800-1000 °C), (600-800 °C) respectively, which normally used type of catalyst: SOFC (Ni-YSZ as anode and lanthanum strontium manganite (LSM) as cathode. The rated power of cells (5- 250 KW) , main producers Canada and Germany.
- Stationary (industrial, residential) : as PAFC which is the operating temperature around (160-220 C) , the anode made of Pt- Ru and cathode is made of Pt. the application of such cells for small to medium sized plants (50 kw – 11 MW) , main producers are USA and Japan electric companies.
- portables : Alkaline fuel cells (AFC) normally used in transportation, space, military and energy storage systems. Anode of cell is made of Ni and cathode is made of Ag. Rated power generated between (5- 150 KW) main producers are Italy and UK and USA

2- Fuel Cell Costs
The true costs associated with fuel cells are not yet clear—either from a capital or operating perspective. Present costs are well above conventional technologies in most areas, though this depends slightly on the type of fuel cell and the market area in which it may play a part.

The economics of fuel cell systems are also different in different market niches. The fuel cell has the potential to usurp many traditional technologies in a variety of markets, from very small batteries and sensors to multi-megawatt power plants. Each system has very different characteristics and will accept very different prices. For example, a laptop battery substitute that could run for 20 h instead of 2 h could command a high price, especially if it could be refueled in seconds from a canister rather than recharged over several hours. At the other end of the scale, the potential for building modular power plants in which maintenance can be carried out on each module without shutting down the system is worth a significant amount of money to the owner.
Traditional economic calculations have suggested that the fuel cell system for large-scale power generation needs to be less than $1500/Kw before it will be competitive, while the fuel cell system for automobiles and mass production must be competitive with the internal combustion engine at $50/Kw or below. That said, it must be remembered other drivers exist for the technology, including environmental benefits, and an issue of increasing strategic importance for many counties, namely a reduced reliance on oil. Some fuel cell systems will sell themselves at $10,000/kW, however, if they can be installed where there is currently no available technology capable of meeting requirements.

However, it is clear that all fuel cell costs at present—and these are estimated at anything between 500 and 10,000 dollars per kilowatt (a mature technology such as a gas turbine costs about $400/Kw are high because they are representative of an emerging technology. Once in mass production, recent estimates predict costs of $40 to $300/kW for PEMFCs for transport applications, depending on assumptions regarding technology development. It is clear that both further technical innovation as well as mass manufacture will be needed to compete solely on a cost basis with the internal combustion engine.

High-temperature systems tend to be more expensive as they require significant investment in associated balance of plant, but should still be able to be manufactured for close to $600 per kilowatt, not far from the current price for a gas turbine or gas engine.

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