

# **A Review of Fuel Cell Types and Applications**

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## **Abstract**

A fuel cell is an energy conversion device that converts the chemical energy of a reaction into direct electricity with water and heat by-products. Without the use of a steam boiler or turbine, only the chemical reaction produces electrical energy. It is obtained by electrochemical reaction between hydrogen and oxygen. In this review article, the definition of fuel cell is made and the studies of fuel cell types in the literature are examined. Then, examples of fuel cell applications are given. As a result of the study, it has been observed that thanks to the modular structure of the fuel cells, it can easily adapt from very small scale applications to very large scale.

**Keywords:** Fuel cell classifications, Fuel cell applications, Hydrogen energy.

## **1.Introduction**

Along with the increasing population, energy consumption is increasing and fossil energy sources are also rapidly depleting. Therefore, there is a search for new and alternative energy source. Having the simplest atomic structure in nature and the highest energy content per weight of all conventional fuels, hydrogen is able to meet this energy need. There is more than 90% hydrogen in the universe. Hydrogen is regarded as the alternative energy carrier of the future due to the higher energy density on a mass basis, less environmental problems, its abundant presence in different forms in the universe, and its convertibility into electricity or useful chemicals [1].

One of the most effective ways to convert the chemical energy of hydrogen into electrical energy is fuel cells [2]. Fuel cells are very popular because they have many advantages such as high efficiency, low emission, compactness and modularity. Fuel cells are quite similar to heat machines. However, they are separated from the heat machines since their efficiency is not limited to Carnot efficiency. Because fuel cells are free from the high temperature limit imposed by materials on heat engines and less irreversibilities associated with heat rejection [3].

The basic physical structure or building block of most fuel cells consists of an electrolyte layer in contact with porous anode and cathode electrodes on either side. In the dual chamber fuel cell, a

fuel enters the anode and an oxidant enters the cathode. These are separated by a selectively conductive electrolyte. Conduction through the electrolyte can occur in either direction – anode to cathode or cathode to anode – depending on the fuel cell. The fuel cell can be designed so that select species conduct [4].

In this review paper, after giving brief information about the types of fuel cells, the application areas of fuel cells are written.

## **2.Fuel Cells Classifications**

Fuel cells may be classified in a variety of different ways, depending on the criteria used, which are typically the parameters related to fuel cell operation or construction. Fuel cell systems involve a vast number of variables, such as the type of electrolyte used, the type of ion transferred through the electrolyte, the type of reactants (e.g., primary fuels and oxidants), operating temperature and pressure, direct or indirect use of the primary fuels, and primary or regenerative systems. Because the choice of the electrolyte defines the properties of a fuel cell, including the operation principle, design and construction, as well as the materials that can be used for the cell and stack components, it is customary now that fuel cells are primarily named by the nature of their electrolyte used [5].

The fuel cells are classified in relation to their electrolytes and fuels used as follows [6]:

1.PEMFC (proton exchange membrane or polymer electrolyte membrane fuel cell) uses a water-based, acidic polymer membrane as the electrolyte and platinum-catalysed electrodes. It uses pure hydrogen, but also reformed natural gas, removing carbon monoxide. Its operative temperature is below 100 °C;

2.HT-PEMFC (high temperature PEMFC) is a PEMFC obtained by changing the electrolyte from a water-based to a mineral acid-based system. It operates up to 200 °C;

3.DMFC (direct methanol fuel cell) uses a polymer membrane as the electrolyte and the platinum–ruthenium catalyst on its anode uses the hydrogen from liquid methanol directly;

4.MCFC (molten carbonate fuel cell) uses a molten carbonate salt suspended in a porous ceramic matrix as the electrolyte with coal-derived fuel gas, methane or natural gas, operating at temperatures of about 650 °C;

5.PAFC (phosphoric acid fuel cell) consists of an anode and a cathode made of a finely dispersed platinum; catalyst on carbon and a silicon carbide structure that holds the phosphoric acid electrolyte. It operates up to 200 °C;

6.SOFC (solid oxide fuel cell) uses a solid ceramic electrolyte;

7.AFC (alkaline fuel cell) uses an alkaline electrolyte and is fuelled with pure hydrogen and oxygen.

## 2.1. Proton Exchange Membrane Fuel Cell

Typical PEMFC schematic with its chemical reaction is outlined in Fig. 1. The PEMFC system consists of two electrodes viz., a cathode, anode and a proton-conducting membrane as an electrolyte. Fuel input ( $H_2$  gas) on the anode side spread over the electrode until they reach the catalytic layer to form protons and electrons. The protons pass through the catalytic layer via electrolyte to the cathode; while the electron takes an external circuit generating electric power. The oxygen supplied at the catalytic layer of the cathode combines with electrons and hydrogen ions to form water. Advantages of PEMFC are highly efficient, more electricity per unit of fuel is produce, low  $CO_2$  emission, low operating temperature and quick startup.

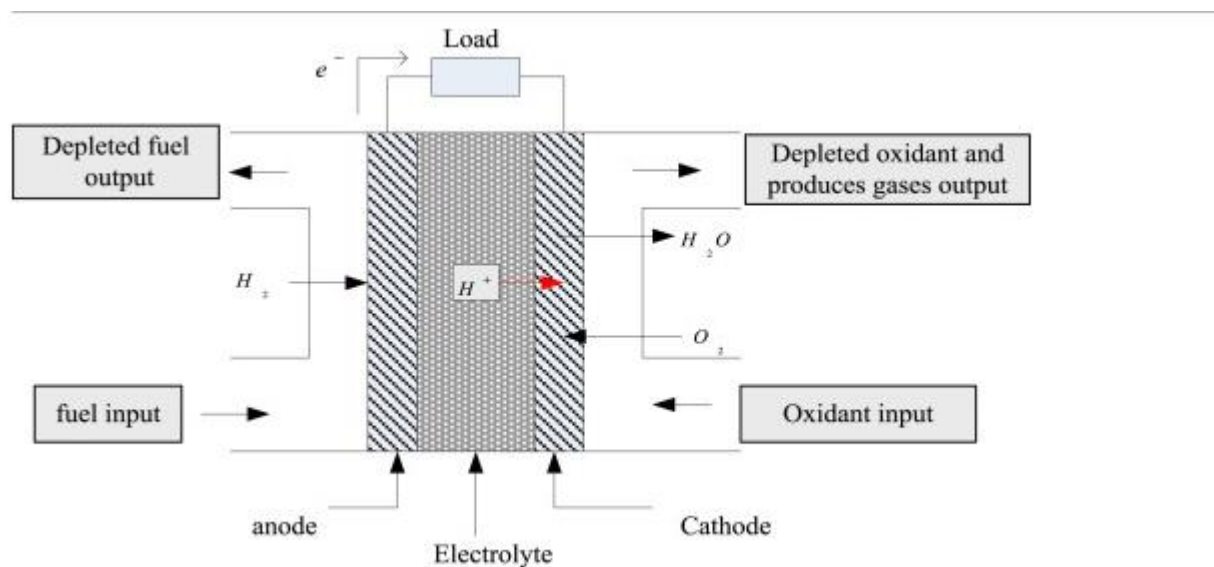


Fig.1 Schematic diagram of the PEMFC [7].

## 2.2. High Temperature Proton Exchange Fuel Cell

PEMFC can be classified into two categories by its range of working temperature. The low temperature PEMFC operated around 60–80 °C while the high temperature PEMFC (HT-PEMFC) operated above 120 °C up to 200 °C. The temperature within the range of 120–180 °C is regarded as a potential solution to problems faced by typical PEMFC operations. The lower boundary temperature of 120 °C is recommended to avoid the formation of liquid water while the upper boundary level of 180 °C is to avoid furious degradation. However, there are significant effects of charge transfer and proton transfer with temperature; the resistance of the transfers is reduced as the temperature increases, which will result in a more effective kinetic reaction in the fuel cell [8].

## 2.3. Direct Methanol Fuel Cell

In the DMFC (Fig. 2), energy is converted when liquid methanol is directly catalytically oxidized at the anode and produces protons and electrons. Protons diffuse through a polymer electrolyte membrane (PEM) to the cathode, where they combine with electrons to produce electrical energy with water and carbon dioxide as byproducts. In Fig. 2, the anode catalyst/PEM/cathode catalyst composite is referred to as a membrane electrode assembly (MEA). Catalyst is usually adhered to the membrane and carbon fiber cloth, or gas diffusion layer (GDL), is placed on each side of the MEA during PEM fuel cell tests.

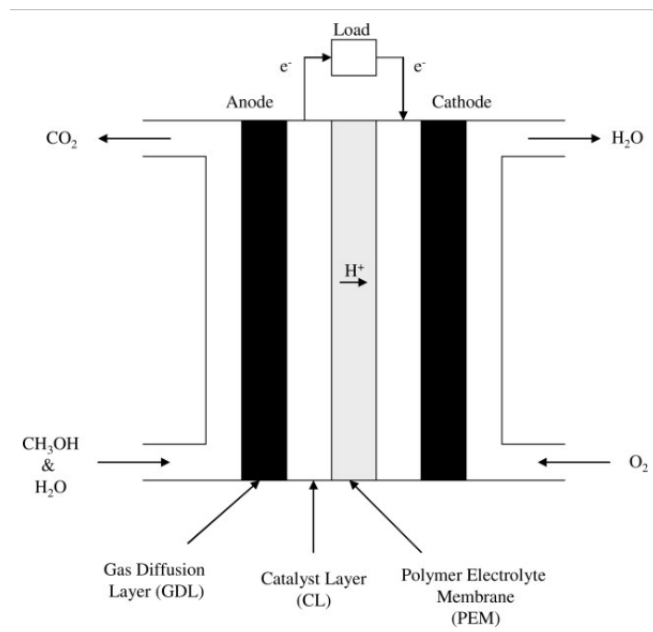


Fig.2. Schematic diagram of the DMFC [9].

## 2.4. Molten Carbonate Fuel Cell

Molten carbonate fuel cells (MCFCs) are high-temperature fuel cells that use as an electrolyte a molten carbonate salt mixture suspended in a porous, chemically inert ceramic matrix of beta-alumina. MCFC consists of a porous nickel (containing dispersed aluminum or chromium to provide strength and sintering resistance) anode (fuel electrode), a porous, lithium-doped, nickel oxide cathode (oxidant electrode), and a lithium aluminate matrix filled with lithium and potassium carbonates as the electrolyte. The cell is operated at a temperature of about 650 °C and at a pressure of 1–10 atm; the fuel gas is a humidified mixture of H<sub>2</sub> and CO, and the oxidant is a mixture of O<sub>2</sub> and CO<sub>2</sub> which may contain water vapor [10].

## 2.5. Phosphoric Acid Fuel Cell

Phosphoric acid fuel cell, developed for commercial applications in the 1960s, has an acidic and high density liquid electrolyte. It has an operating temperature of approximately 160-220 °C. Since the phosphoric acid used as the electrolyte is a stable acid, only platinum and / or platinum alloys can be used as the electrode. In this fuel cell, while the hydrogen ions move from the anode to the cathode through the electrolyte, the current created by the electrons formed in the anode is collected through an external circuit. On the cathode, hydrogen ions and oxygen combine to form water. Fig. 3 shows the working principle of the phosphoric acid fuel cell.

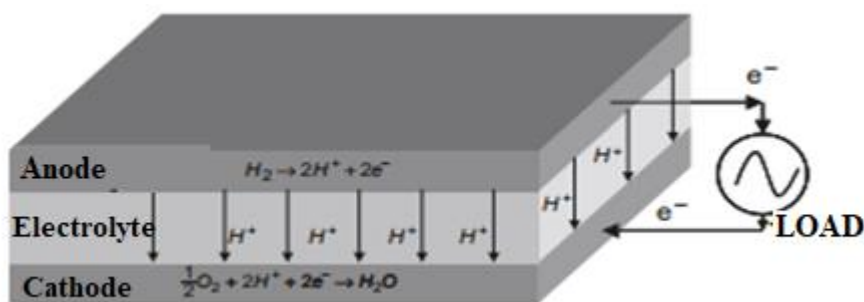


Fig.3. Working principle of the phosphoric acid fuel cell [11]

## 2.6. Solid Oxide Fuel Cell

Solid oxide fuel cells are high temperature fuel cell systems that use solid ceramic electrolytes. Although it is said that it can work at about 500 °C with the developing technology, it usually

works between 800-1000 ° C. The advantage of solid oxide fuel cells is that the high temperature heat released during the reaction can be used again as another process heat [12]. In this fuel cell, negatively charged oxygen ions pass through the electrolyte to the anode side. The electrons produced in the anode are collected through an external circuit as in other fuel cells. The efficiency of solid oxide fuel cells are about 60%. Fig. 4 shows the working principle of the solid oxide fuel cell.

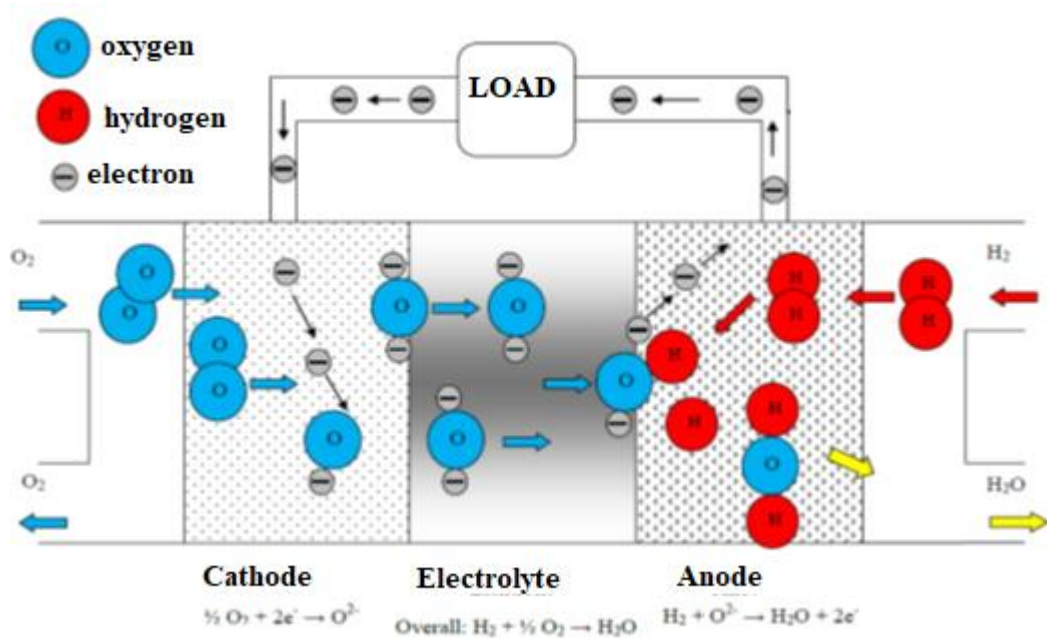


Fig.4. Working principle of the solid oxide fuel cell [13].

## 2.7. Alkaline Fuel Cell

Aqueous potassium hydroxide solution is used as electrolyte in the alkaline fuel cell and it is worked around 80 ° C. The most important advantages are low electrolyte material costs and high efficiency (up to 60% in spacecraft applications). However, in this fuel cell, which is very sensitive to carbon dioxide, the fuel used to prevent carbon dioxide poisoning should be pure hydrogen. While hydroxyl ions ( $OH^-$ ) move from cathode to anode in this fuel cell, it reacts with hydrogen at the anode and releases water and electrons.

## 3. Fuel Cell Applications

Fuel cells have the potential to replace existing power sources for many applications. The most likely consumer applications for fuel cells include portable (0–100-W), stationary (0–25-kW), and transportation (~100-kW) applications.

### **3.1. Portable Applications**

Perhaps where fuel cells show the most promise for ubiquitous near-term implementation is in portable power (0–100-W) applications, such as cell phones and laptop computers. Current battery technology has not yet provided the energy density required for long-term operation, and recharging is time consuming. Additionally, the cost of existing premium power battery systems is already on the same order as contemporary fuel cells, with additional development anticipated.

### **3.2 Stationary and Distributed Power Applications**

Stationary (1–500-kW) applications include power units for homes or auxiliary and backup power generation units. Stationary applications are designed for nearly continuous use and therefore must have far greater lifetime than automotive units, although operation at a near-continuous steady state is advantageous for durability. Distributed power plants are even larger than stationary systems and are designed for megawatt-level capacity.

### **3.3. Transportation Applications**

With fuel cell technology, although there are no moving parts such as pistons, cylinders and crankshafts in vehicles, silent operation of the vehicle, low emission and higher efficiency compared to otto or diesel engine make it inevitable to be used in cars. The power obtained from the fuel cells according to today's vehicle characteristics is on average 80–90 kW. When a 160-liter pure hydrogen is filled with a fuel cell vehicle, it travels an average of 400–430 km and the maximum speed it can reach is 160 km / h [14]. In addition, the energy needs of a house can be met as well as a cell phone charge is possible with fuel cells.

### **3.4. Other Applications**

Any application requiring electrical power could potentially operate on fuel cells, although not all make practical sense. The military has a need for fuel cells for battery replacement and transportation applications. The heavy weight and cost of primary batteries make fuel cells attractive, even just for training purposes. In a regenerative fuel cell powered by hydrogen and

oxygen, the closed fuel cell vessel actually operates as a battery, producing current from stored oxygen and hydrogen when in the power mode. In the power mode, product water is generated from the electrochemical reactions. In the regeneration mode, the water is electrolyzed back into oxygen and hydrogen by reversal of the hydrogen oxidation and oxidizer reduction reactions. Through this cycle, the fuel and oxidizer are continually recycled and reused, reducing the weight of reactants required to be put into orbit for a chosen duty cycle.

## Conclusions

The following results have been obtained in this review article:

- Energy consumption is increasing in the world and fossil fuel resources are running out. Therefore, alternative energy sources are researched.
- Hydrogen is an energy source that attracts attention with the amount of energy per unit volume.
- Fuel cells are electrochemical devices that convert the chemical energy of hydrogen (fuel) into electrical energy.
- There are different types of fuel cells depending on the operating temperature and the type of electrolyte used. Depending on the intended use, these fuel cells can generate energy from very small power densities to very large power densities.
- Fuel cells can be used in batteries, stationary and distributed power, transportation and military purposes.

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