# Energy and Low Carbon Technologies: Fuel Cells

## Abstract

One of the ways of protecting the environment from further effects of global warming, is to use low carbon energy sources. One such technology is as fuel cell. The paper has discussed how fuel cell technology work, types of fuel cell, its benefits, and hinderances to its application. It has been found out that the major types of fuel cells include: Alkaline Fuel Cell; Proton Exchange Membrane Fuel Cells; Phosphoric Acid Fuel Cells; Solid Oxide Fuel Cells; Molten Carbonate Fuel Cells; Direct Carbon Fuel Cells; and Unitized regenerative Fuel Cells. The major advantage of fuel cell is that it significantly contributes towards reduction of CO2 being released into the atmosphere hence helping to avert effects of global warm. The hinderance to its use as source of energy is high cost capital.

## Table of Contents

[1. Introduction 4](#_heading=h.gjdgxs)

[2. Fuel cell technology 4](#_heading=h.30j0zll)

[2.1 How Fuel cell work 4](#_heading=h.1fob9te)

[3. Types of Fuel cell 5](#_heading=h.3znysh7)

[3.1 Proton Exchange Membrane Fuel Cells 5](#_heading=h.2et92p0)

[3.2 Phosphoric Acid Fuel Cells 6](#_heading=h.tyjcwt)

[3.3 Solid Oxide Fuel Cells 7](#_heading=h.3dy6vkm)

[4. Fuel Cells and reduction of CO2 emissions 7](#_heading=h.1t3h5sf)

[5. Major inhibitors of application of Fuel cell technologies 8](#_heading=h.2s8eyo1)

[5.1 High capital cost (High initial investment) 8](#_heading=h.17dp8vu)

[5.6 Carbon emission associated with Fuel cell production 8](#_heading=h.3rdcrjn)

[6. Conclusion 8](#_heading=h.26in1rg)

[7. References 10](#_heading=h.lnxbz9)

## 1. Introduction

Fossil fuels such as natural gas, petroleum and coal are the major sources of energy in the world today. These sources of energies are responsible for the largest of composition of electricity, heat and fuel people use across the global. In 2005 for example, more than 85% of energy produced and used in the globe came from combustion of fossil fuel [1]. Unfortunately, the use of fossil fuels for production of energy has contributed significantly towards climate change through global warming. In United States, fossil fuels contribute to more than 80% of the total greenhouse emissions [1]. They are also responsible for more than 98% of carbon dioxide (CO2) emissions in United States [1]. Even though some of these CO2 are absorbed by natural processes such as photosynthesis, approximately 4.1 billion metric tons of carbon dioxide find its way into the atmosphere every year [1]. This number is expected rise since as the number of years go by, energy demands also increase.

In order to protect the environment from further effects of global warming, renewable energy technologies should replace the fossil fuels technologies as the major of sources of energy. One such source of renewable energy technology is low carbon energy technologies such as fuel cell. Many countries such as Japan, Korea, United Sates, and so on are already using fuel cells to power a number of operations. To understand the benefits of fuel cells with regard to low carbon emissions, this research paper will discuss how fuel cell technology work, types of fuel cell, its benefits, hinderances to its application, and so on.

## 2. Fuel cell technology

Fuel cells normally use the chemical energy stored in hydrogen or any other fuel to produce clean and electric and heat energies. If hydrogen is used as the source fuel cell, the only by products include: electricity, heat and electricity which are harmless to the environment with regard to greenhouse emissions [2]. These energy sources are quite versatile. They can provide large quantities of power (electric energy) just as a utility power plant [2]. They can also provide small quantities of power. For example, they can supply power to energize a single laptop computer [2].

## 2.1 How Fuel cell work

Fuel cell generates electric energy through a chemical reaction. The cell has two electrodes: anode and cathode. It is in these electrodes that the chemical reaction takes place [3]. A fuel cell also has an electrolyte. The purpose an electrolyte in a fuel cell is to carry the charged particles (protons and electrons) from one electrode to another. A fuel cell requires both oxygen and hydrogen to work. Hydrogen is fed into the system via the cell’s anode electrode and oxygen is supplied via the cathode electrode [4]. The chemical reaction removes electrons from hydrogen molecules and in the process the hydrogen atoms become ionized into H+ [3]. The negatively charged electrons flow through wires (cables) as electric energy. As oxygen (usually in form of air) enters through the system, it combines with the positively charged hydrogen atoms (H+) to form water which is expelled out of the system as a waste product [5] [3]. The electrolyte alloys only appropriate ions to flow between the electrodes (between anode and cathode) [6]. If inappropriate ions flow between the electrodes, the chemical reaction which is responsible for production of electric current may be disrupted [6]. The chemical reaction that normally takes place in a fuel cell is as shown below.

Anode reaction (oxidation reaction):

2H2 => 4H++ 4e-

Cathode reaction (reduction reaction):

O2 + 4H+ + 4e- => 2H2O

Net reaction (Redox reaction

2H2 + O2 => 2H2O

Typically, a single of fuel cell can produce about 0.7 volts of electronic energy [6]. This means that a number of fuel cells are usually connected to form a fuel cell system that can now be used in a number of applications [6].

## 3. Types of Fuel cell

Fuel cells are generally classified according to the electrolyte used. This because the type of electrolyte determines the fuel to be used, type of chemical reaction to take place, the type of catalyst to be used and optimum operating temperature [7]. The major types of fuel cell include: Alkaline Fuel Cell; Proton Exchange Membrane Fuel Cells; Phosphoric Acid Fuel Cells; Solid Oxide Fuel Cells; Molten Carbonate Fuel Cells; Direct Carbon Fuel Cells; and Unitized regenerative Fuel Cells [7].

## 3.1 Proton Exchange Membrane Fuel Cells

This fuel cell can be used in automotive industry, stationary fuel cell applications (Combined heat and power applications and back-up power units), and small portable fuel cell applications such as a small potable electric power source. When substantial amounts of hydrogen are available such as from chlorine related industrial plants large scale stationary Proton Exchange Membrane Fuel Cells (PEMFCs) can be used as source of both electric and heat energy [7].

This type of fuel cell (stationary Proton Exchange Membrane Fuel Cells) consist of state-of-the art electrolytes which are based on perfluorosulfonic acid polymers such as Nafion [7]. The fuel cell also consists of an electrode which also doubles up as a catalyst layer. The electrode is normally divided into two layers: catalyst layer (active layer) and gas diffusion layer. The active layer is located next to the Proton Exchange Membrane where the chemical reaction responsible for flow of electric current (electrochemical reaction) takes place [8]. The gas diffusion layer is responsible for distribution of gas and management of water. Proton Exchange Membrane Fuel Cells also have Bipolar plates. These plates may made of graphite, metal alloys, stainless steel and graphite alloys [7]. The Bipolar plates (also known as flow plate materials) must resistant to: oxidation, acid corrosion, hydrogen embrittlement, and so on. The normally make up the greatest composition of the cell weight and volume. Usually it accounts for more than 80% of the cell weight [7].

The Proton Exchange Membrane Fuel Cells are considered the most developed fuel cell technologies [9]. They consist of more than 90% fuel cell powered components to date [9].They are most widely applied in form of stack technology to power fuel cell vehicles. They are also used for heating residential houses such as the Japanese ‘EneFarm’ program [9]. In this application (residential heating application), they are cable of producing 1-3 kW of thermal power [9]. Currently they these types of fuel cell durable, highly efficient, and reliable. Their costs have also gone down as result of mass production [9].

### 3.2 Phosphoric Acid Fuel Cells

These types of fuel cells employ concentrated liquid phosphoric acid as the electrolyte (the acid concentration is usually approximately 100%). This acid is normally contained inside silicon carbide matrix bonded by Polytetrafluoroethylene (PTFE) [7]. Porous carbon electrodes which contain platinum catalysts are used as electrodes (both the anode and the cathode). The temperature in which these cells operate ranges between 150o and 220o [7]. They are typically used as stationary power generators. However, some have been used to power large vehicles such as buses (city and institution buses) [7].

### 3.3 Solid Oxide Fuel Cells

These types of Fuel cells were developed to operate at temperatures above 900o C. As a result, ceramic oxides are used as the electrolytes [7]. The fuel cell typically consists of metal ceramic or porous ceramic electrodes, and dense ceramic electronic electrolyte. All these components are in solid state [7]. When operating at low temperatures (temperatures less than 600o C), less expensive metals such bipolar plates may be used as main component. The main materials in Solid Oxide Fuel Cells include: Scandia or yttria stabilized zirconia as an electrolyte; Ni-cermet as electrode; and perovskites (which can conduct electrical energy) such as La-Sr-manganites, and so on.

## 4. Fuel Cells and reduction of CO2 emissions

Fossil fuels such as natural gas, petroleum and coal are the major sources of energy. When these types of fuels are used to generate electricity, they are often referred to as high-carbon electricity systems. This is because when compared to other technologies they produce substantial amounts of carbon related emissions which are then released into the atmosphere. These carbon emissions are responsible for global warming since they contribute significantly towards destruction (depletion) of the ozone layer.

A modern gas fired boiler normally produce heat with an intensity of approximately 215 gCO2/kWh [9]. This carbon emission even worse in most modern electricity generating systems around the world. In United Kingdom, for example, the carbon emission was estimated to be 441 gCO2/kWh in 2011, and 503 gCO2/kWh in United States in the same year [9]. In Germany, the amount of CO2 emission was 477 gCO2/kWh in 2011 [9]. Fuel cells on the other hand produce 10–20 gCO2/kWh of electric power or 8–16 gCO2/kWh of heat energy [9]. This is even lower than nuclear fission power plants and solar PV [9]. The nuclear fission power plants produce 10–30 gCO2/kWh while solar PV produce 80 gCO2/kWh [7].

Fuel cells technology, which is a form of low carbon technology, when used to generate electricity or even source of heat, can reduce amount of carbon relate emissions released into the atmosphere. For example, in UK it has been estimated each 0.7 to 1 kW fuel cell system saves 1.3 – 1.9 tCO2 per year in a household of 4 people [9]. This approximately 35% to 50% reduction in carbon dioxide emissions per year [9]. For larger applications, fuel cells can save up to 3 tCO2 per year [9]. This means that Fuel cell micro-CHP (combined heat and power) produces lower CO2 emissions when compared to the other sources of electricity and heat.

## 5. Major inhibitors of application of Fuel cell technologies

Even though fuel cell technologies are alternative sources of fuel and can significantly reduce greenhouse gas emission, it has not been widely adopted as the major source of fuel. This because of a number of reasons some of which have been discussed below.

### 5.1 High capital cost (High initial investment)

The initial investment (upfront capital investment) is the major hinderance to adoption of fuel cell as a source of energy in the modern world. Even with subsidies currently being offered in countries like United Kingdom and Japan, most fuel cell micro-CHP systems applied in residential settings are unable to recover their initial investment within the expected lifetime. However, as production expands, their capital costs have continued to fall relatively in the recent years; though they are still expensive. As of 2014, a 0.7 kW Proton Exchange Membrane Fuel Cells or Solid Oxide Fuel Cells for residential setting was approximately £16000 in Japan. A 1.5 kW Solid Oxide Fuel Cells was approximately £20,000 in Australia and £26,000 in European countries. Because of economies of scale, commercial Molten Carbonate Fuel Cells   
(MCFC) and Phosphoric Acid Fuel Cells (PAFC) systems are generally cheaper per power output. Consequently, cost approximately £2500–3500 per kW in Europe.

### 5.6 Carbon emission associated with Fuel cell production

Generally, fuel cells are much heavier and large compared to gas boilers of equivalent capacity. In addition, they require catalysts such as platinum and nickel which are require large quantities of energy to produce. Production of these catalysts as well as production of the cells themselves leads to carbon emission. For example, producing 1 kW CHP that can be used in a residential setting results into 0.5–1 tCO2 emission while production of a 100kW CHP commercial system may result in 25–100 tCO2 emission. In order to offset this disadvantage low carbon energy technologies such as solar and nuclear may be used as sources of energy for producing fuel cells.

## 6. Conclusion

Fossil fuels such as natural gas, petroleum and coal are the major sources of energy in the world today. These sources of energies are responsible for the largest of composition of electricity, heat and fuel people use across the global. Unfortunately, the use of fossil fuels for production of energy has contributed significantly towards climate change. One of the ways of protecting the environment from further effects of global warming, is to use low carbon energy sources. One such technology is as fuel cell. There are a number of types of fuel cell they include: Alkaline Fuel Cell; Proton Exchange Membrane Fuel Cells; Phosphoric Acid Fuel Cells; Solid Oxide Fuel Cells; Molten Carbonate Fuel Cells; Direct Carbon Fuel Cells; and Unitized regenerative Fuel Cells. The major advantage of fuel cell is that it significantly contributes towards reduction of CO2 being released into the atmosphere hence helping to avert effects of global warm. The hinderance to its use as source of energy is high cost capital.

## 7. References

[1] Center for Biological Diversity, "Energy and Global Warming," Center for Biological Diversity, 2017.

[2] Energy Efficiency & Renewable Energy, "Fuel Cells," Energy Efficiency & Renewable Energy, 2017.

[3] B. Sørensen, Hydrogen and Fuel Cells: Emerging Technologies and Applications, Oxford: Academic Press, 2012.

[4] R. O'Hayre, S.-W. Cha and F. B. Prinz, , Fuel Cell Fundamentals, New Jersey: John Wiley & Sons, 2016.

[5] J. K. Nørskov, . J. Rossmeisl, A. Logadottir and L. Lindqvist, "Origin of the Overpotential for Oxygen Reduction at a Fuel-Cell Cathode," J. Phys. Chem., vol. 108, no. 46, p. 17886–17892, 2004.

[6] Bluffton University, "How Fuel Cells Work," Bluffton University, 18 04 2002. [Online].

[7] I. Cerri, F. Lefebvre-Joud, . P. Holtappels, K. Honegger, T. Stubos and . P. Millet, "Hydrogen and Fuel Cells," European Union, Luxembourg, 2012.

[8] J. Larminie and A. Dicks, Fuel Cell Systems Explained, West Sussex: John Wiley & Sons, 2003.

[9] P. E. Dodds, I. Staffell, A. D. Hawkes , F. L. Li, P. Gru¨newald, W. McDowall and P. Ekins, "Hydrogen and fuel cell technologies for heating: A review," *International Journal of Hydrogen Energy*, vol. 40, no. 5, pp. 2065-2083, 2015.