Fuel Cell: Fundamental, Classification, Application, and Environmental Impact

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Abstract In this chapter, an outline of fuel cell technology is being discussed with its advantages, disadvantages, and classification. The application of fuel cell is being done in comprehensive areas such as stationary electrical energy generation, fuel cell energy for transportation, and portable electrical energy generation. Fuel cell environmental impact based on stationary power generation, transportation system is discussed.

Keywords Fuel cell · Environmental · Portable power · Transportation system Stationary power

1 Introduction

Fuel cell (FC) is a standing device in which electrochemical cell transforms chemical energy into electrical energy (Wilberforce et al. 2016). It produces electricity within the cell through chemical reactions between a hydrogen fuel and an oxidant, activated with electrolyte (Wang et al. 2017). The wandering of reactants in the cell, the response yields drift out, while the electrolyte remnants inside. Fuel cells operate until essential reactant and oxidant flows are sustained. For automotive applications cleaner source of energy has a wide range of operations, and the fuel

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A. Sharma et al. (eds.), *Low Carbon Energy Supply*, Green Energy and Technology,
https://doi.org/10.1007/978-981-10-7326-7_17

cell has sophisticated energy storage capability (Fuel cell Today 2012). In advanced countries, R&D on fuel cell is being funded for more than half a century initially to combat the rise in oil prices and later to combat the global warming. Billions of dollars have been spent in most of these countries. It is difficult to get the exact figures from the earliest years. However, some data are available for the more recent years (WEFORUM 2017). For example, USA announced $41.9 million (2009, DOE) in Recovery Act funding to quicken fuel cell commercialization and arrangement with diligence subsidizing another ~$54 million (totaling ~$96 million) with the definite objective of instantaneous disposition of up to 1,000 fuel cell systems in backup electrical power, material supervision, and combined heat and power uses. The bulk of the currency has been spent on fuel cell deployment. As expected, the level of research funding in India has been abysmally low even though fuel cell research has been continuing in this country for more than 25 years Jürgen (Garche and Jörissen 2017). India's policy on fuel cells and financial support are driven largely by four agencies, viz., MNRE, DST, DAE, and CSIR. Under its NMITLI program, CSIR has provided a total budgetary support of about Rs. 20 Crore during 2004–2013 for the development of different fuel cell technologies. MNRE is a major supporter of hydrogen and fuel cell research in the country for some epochs (MNRE 2017). It has supported nearly Rs. 5.0 crores during Eleventh Five Year Plan (2007–2012) and Rs. 1.00 crores during Twelfth Five Year Plan(2012–2017) for developing these technologies. MNRE guidelines state that financial assistance for R&D projects counting the skill authentication and parade projects that include an organization with industry/civil society administrations should habitually be partial to 50% of the project charge. However, for any suggestion from educational institutions, government/non-profit exploration administrations, and NGOs, the ministry may provide up to 100% funding. Private educational institutions should adhere to positive situations for availing project grants from the ministry (MNRE 2017).

1.1 Fuel Cell Principle

Fuel cell works on the principle of energy but is not at all like a battery; an energy unit does not rundown or requires reviving. It delivers energy as power and warmth insofar as fuel is provided (Wikipedia 2017). It comprises of an anode and a cathode with electrolyte sandwiched between them (USDE 2014). Oxygen disregards one cathode and hydrogen over the other, producing electrical energy, a limited amount of thermal energy, and water. Figure 1 shows the basic principle of the fuel cell.

1. Separation into a proton and an electron, till a hydrogen particle (from the fuel source) is in contact with the negative anode catalyst layer.
2. The conservative proton passes through the electrolyte.

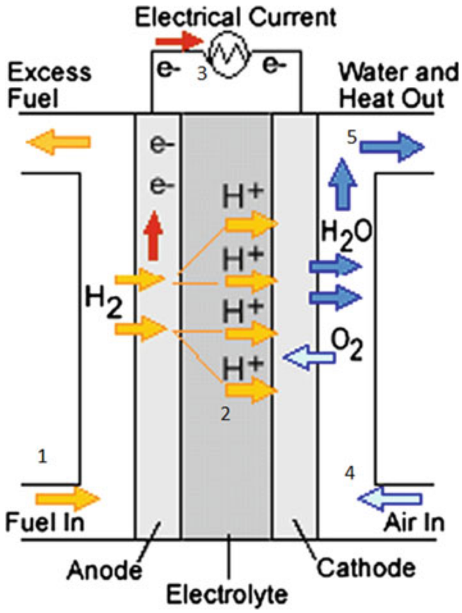

Fig. 1 Fuel cell principle (Wanga et al. 2011)

3. The FC current through the external circuit, electron passes.
4. The circuit allocations the electrons to the positive cross of the electrolyte coating tie and assembly an oxygen section.
5. Generating water and an inadequate extent of thermal energy in the positive cathode ingredient varnish.

1.2 Advantages of Fuel Cells

Fuel cells possess advantages over conventional power sources such as internal combustion engines or batteries (The next galaxy 2017 and Your article library 2017). Although fuel cells' characteristics are valid for some applications and rest are common.

1. No harmful gas emission—no emission except water at the tailpipe as no fossil fuels are used by the vehicle on fire.
2. Zero Pollution Lifelong—As hydrogen is derived from a renewable source and the automobiles can be made completely from renewable resources just as any other automobile can be.
3. No oil mandatory—in any of the components of a fuel cell vehicle as electric vehicle at its core.

4. Dispersed fuel making—is possible as it is relatively simple and much more economical than gasoline. It leads to less transportation, and more options for fuel sourcing are possible.
5. Higher efficiency—than either gasoline or diesel is conceivable with a hydrogen fuel cell in vehicles.
6. Silent process—means no noise pollution as an electric vehicle is without a burning producer.
7. Low heat options - for fuel cells are being traveled by the military for sensitive operations and stealth applications.
8. Longer range than the buck and weight than do current and anticipated battery technologies as pound-for-pound, cost-for-cost contrasts.
9. Almost zero maintenance, but occasional failure of a cell within a cell stack as fuel cells are built of modular units without moving portions.

1.3 Disadvantages of Fuel Cell

The fuel cell energy has estimable benefits, but not absolutely preferable, clean, and inexpensive energy source for most governments and companies, are volatile batteries in gaseous state (The next galaxy 2017; Your article library 2017). It is beneficial than other sources but has various risks and drawbacks also (CEF 2017). Some of the disadvantages of hydrogen energy include the following:

1. Affluent but these cells are being handmade and there are automakers (17 so far) who are excited to drip with mass manufactures as fuel cells are rather modest units that lend themselves to easy mechanization in production.
2. As hydrogen is created, complete reforming is not as unsurprisingly possible as other sources of fuel—specifically some biofuels and clean power.
3. When complete life succession of hydrogen as a fuel is painstaking electrolysis is inefficient and a net energy loss overall.
4. As associated to accusing battery EV batteries it takes moderately shorter time but longer to refuel and start compared to gas or diesel engines. Refilling a hydrogen fuel cell takes more time than impelling gasoline.
5. Hydrogen fuel cell although at highest efficiency, at an exact core temperature often “rise up” to get to heat before producing enough power flow to operate a vehicle.
6. On output ratio, FCs are higher than the batteries but density/mile ratio is minor.
7. The platinum catalyst makes this common fuel cell technology expensive, replacements are being searched.

2 Classification of Fuel Cells

The fuel cells are in developing phase (Fuel Cell Today 2012) and can be classified as

- Varied categories (types of fuel and oxidant)
- The type of electrolyte,
- The hotness of procedure,
- The reactants are nourished to the cell by interior or outside manifolds, etc. (USDE 2014; Tomczyk 2006).

The nethermost collective prearrangement of fuel cells founded on the type of electrolyte:

(1) Phosphoric acid fuel cell (PAFC)
(2) Solid oxide fuel cell (SOFC)
(3) Alkaline fuel cell (AFC)
(4) Proton-exchange membrane fuel cell (PEMFC or PEFC).
(5) Molten carbonate fuel cell (MCFC).

2.1 Phosphoric Acid (PAFC)

Figure 2a shows the PAFC that uses liquefied phosphoric acid as an electrolyte, the principal fuel cells to be commercialized have enhanced expressively in stability, performance, and cost (Chen et al. 2016). PAFCs produce energy more than 40% productivity and closely 85% of the vapor generated is used for cogeneration. Working system temperatures are in the range of 300–400 °F (150–200 °C). The liquid phosphoric acid soaked in a matrix is the electrolyte (Pareta et al.). PAFCs has a tolerance of about 1.5% a CO concentration that enhances the choice of fuel they can use (Chen et al. 2015). Sulfur should be removed in case of gasoline being used.

2.2 Proton Exchange Membrane Fuel Cell (PEMFC)

PEM fuel cells recognized as PEM and are shown in Fig. 2b. PEMFC is a type of FC being developed for stationary FC power generation, portable FC, and transport applications as well (Cheng and Liu 2015). Functioning at quite low temperatures (about 175 °F or 80 °C), at high power density, can differ their output to meet shifts in energy demand and are suited for applications in vehicles where quick startup is required (Eddine et al. 2014; Guerrero et al. 2015). Thin PEM is a plastic sheet that

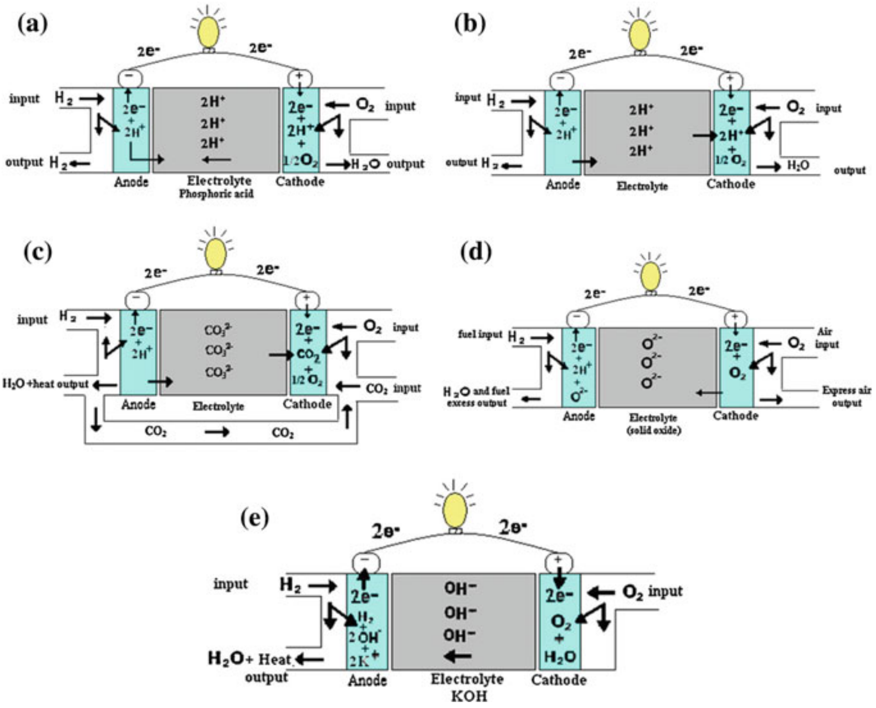

Fig. 2 Classification of fuel cell **a** PAFC **b** PEMFC **c** MCFC **d** SOFC **e** AFC (Mekhilefa et al. 2012)

allows hydrogen ions to pass through it. The solid organic polymer flour sulfonic acid is the electrolyte. The solid electrolyte has benefits because it reduces corrosion and management problems (Sutharssan et al. 2017).

2.3 *Molten Carbonate Fuel Cell (MCFC)*

The MCFC uses a watery solution of lithium saturated in a medium for an electrolyte and, sodium and/or potassium carbonates, Fig. 2c (Goo et al. 2016). The high efficiencies of fuel-to-electricity operating at 1200 °F or 650 °C with 85% cogeneration are around 60%. Because of this high temperature required for enough conductivity, moral metallic catalysts for the cell's electrochemical corrosion and decrease methods are not required (Discepoli and Desideri 2014). MCFCs have been worked on hydrogen, natural gas, propane, CO, landfill gas, nautical diesel, and replicated coal gasification yields (Devianto et al. 2016; Chiodo et al. 2016). 10–2 MW MCFCs have been tested for electric service applications. The high working temperatures are advantageous for flouting of carbon bonds due to higher efficiency an in larger hydrocarbon fuels as the higher adeptness and tractability to use more fuels and inexpensive catalysts are increased (Verda and Sciacovelli 2012).

2.4 Solid Oxide Fuel Cell (SOFC)

The FC with high energy procedures for industrial and large-scale essential energy generating plant SOFC are used as shown in Fig. 2d (Andrea et al. 2017). A solid oxide system utilizes hard ceramic material of solid zirconium oxide, at 1800 °F or 1000 °C, making efficacies up to 60 and 85% cogeneration and production up to 100 kW. SOFC utilization in motor vehicles are being established as fuel cell auxiliary power units (APUs) in Europe. Solid oxide fuel cells operate at 80–100 °C of all fuel cell systems (Cebollero et al. 2017; Cinti and Desideri 2015). These high temperatures abridge scheme formation. As the electrolyte is solid the cell can be molded in an assortment of arrangements by approving interior reforming easing the growth of cogeneration systems along with mixture energy systems as coating rounds for gas turbines and/or steam cycles (Chatrattanawet et al. 2017). As shown in Fig. 2, the electrolyte, yttria-stabilized zirconia is supported by the cathode constructed from lanthanum manganite surrounded by the anode, nickel cermet's. Fuel gas enters from the outer surface of the tube and air enters the cell from the inner surface (Dimitrova and Mar 2017). The prime focus is on reducing industrial cost, refining system integration, and dropping the working temperature to the range of 55–75 °C. The lower working temperature would unmoving deliver the compensations of internal reforming while reducing the physical problems related with the very high-temperature process. Systems based on SOFCs are being measured for a variety of purposes ranging from small applications such as housing energy systems and automobile supplementary energy units, where the basic gasoline dispensation requirements related with SOFCs are appealing to large utility-scale uses, which benefit from the high efficiencies obtained by assembly SOFC systems with vapor turbines and/or steam cycles (Emı et al. 2017). To form a fuel cell system tools labeled must be coupled with a variety of support subsystems, which yield useful energy from willingly obtainable fuels.

2.5 Alkaline Fuel Cell (AFC)

The AFC, also known as the bacon FC is one of the most established FC machineries as shown in Fig. 2e (Ariyanfar et al. 2011). AFCs chomp hydrogen and clean oxygen creating clean water, heat, and power. NASA has used AFC in Apollo-series missions, and on the space shuttle on space missions, these cells can realize energy generating productivities of up to 70%. Their working temperature is 150–200 °C (300–400 °F) using an aqueous solution of alkaline potassium

Table 1 Electrochemical reactions in fuel cells (Devianto et al. 2016; Chatrattanawet et al. 2017; Fuel cell Today 2012)

Fuel cell	Anode reaction	Cathode reaction	Overall reaction
PAFC	$H_2 \rightarrow 2H + 2e^-$	$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$H_2 + 1/2\,O_2 \rightarrow H_2O$
PEMFC	$H_2 \rightarrow 2H + 2e^-$	$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$H_2 + 1/2O_2 \rightarrow H_2O$
MCFC	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$	$1/2O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$H_2 + 1/2\,O_2 + CO_2(\text{cathode}) \rightarrow H_2O + CO_2(\text{anode})$
SOFC	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$	$1/2\,O_2 + 2e^- \rightarrow O^{2-}$	$H_2 + 1/2\,O_2 \rightarrow H_2O$
AFC	$H_2 + 2OH^- + 2e^- \rightarrow 2H_2O + 2e^-$	$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$	$2H_2 + O_2 \rightarrow 2H_2O$

Table 2 Comparison of different types of fuel cells (USDE 2014; Tomczyk 2006)

Fuel cell ➡	AFC	PEMFC	PAFC	MCFC	SOFC
Electrolyte	Aqueous potassium hydroxide	Sulphonated organic polymer	Phosphoric acid	Molten lithium/sodium potassium carbonate	Yttria-stabilized zirconia (YSZ)
Operating temperature	60–90 °C	70–100 °C	150–220 °C	600–700 °C	650–1000 °C
Charge carrier	OH^-	H^+	H^+	CO_3^{2-}	O^{2-}
Anode	Nickel or precious metal	Platinum	Platinum	Nickel/Chromium Oxide	Nickel/Yttria-stabilized zirconia
Cathode	Platinum (Pt) or Lithiated NiO	Platinum	Platinum	Nickel Oxide (NiO)	Strontium doped lanthanum manganite
Co-generation heat	None	Low quality	Acceptable for many applications	High	High
Electrical efficiency	60	40–45	40–45	50–60	50–60
Fuel sources	H_2	H_2	H_2	H_{2}–, CO Natural gas	H_{2}–, CO Natural gas
Application	• Military • Space	• Backup power • Portable power • Distributed generation •Transportation • Specialty vehicles	• Distributed generation	• Electric utility • Distributed generation	• Auxiliary power • Electric utility • Distributed generation
Advantages	• Cathode reaction earlier in alkaline electrolyte, clues to high enactment • Low price mechanisms	• Solid electrolyte decreases weathering and electrolyte organization problems • Low temperature • Fast start-up	• Sophisticated temperature enables CHP • Increased acceptance to fuel impurities	• High efficiency • Fuel suppleness • Can use a variety of catalysts • Appropriate for CHP	• Extraordinary efficiency • Fuel flexibility • Can use a variety of catalysts • Hard electrolyte • Appropriate for CHP & CHHP • Hybrid/GT cycle
Disadvantages	• Sensitive to CO_2 in fuel and air • Electrolyte management	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat	• Pt catalyst • Long start-up time • Low current and power	• High-temperature corrosion and breakdown of cell mechanisms • Stretched start-up time • Low power density	• High-temperature corrosion and failure of cell components • High-temperature operation needs long start-up time and limits

hydroxide saturated in a matrix as the electrolyte (Song and Zhang 2014). The cathode reaction is quicker in the alkaline electrolyte which is beneficial and some enterprises are examining ways to reduce costs and improve operating flexibility (An et al. 2013). They typically have a cell output from 300–5 kW. Table 1 shows the anode, cathode, and overall electrochemical reaction of different types of fuel cells. Table 2 shows the comparison of different types of fuel cells.

3 Mathematical Modeling of Fuel Cell (FC)

The conversion of chemical energy of a fuel (hydrogen) and an oxidant (air or oxygen) into electrical power is through a fuel cell (Tanni and Iqbal 2014). The model shown in Fig. 3 characterizes working at insignificant circumstances of temperature and pressure. The corresponding circuit can be modified varying limitations of based on the polarization curve. The movement of negative current into the stack is vetoed by using anode (Mathworks 2017).

The fuel cell voltage is given by

$$V_{\mathrm{hfc}} = E_{\mathrm{op}} - \left\{ N_{\mathrm{hfc}} \times A \times \ln\left(\frac{i_{\mathrm{hfc}}}{i_0}\right) \times \frac{1}{\frac{\mathrm{ST_d}}{3} + 1} \right\} - \left(R_{\mathrm{int}} \times i_{\mathrm{hfc}}\right) \tag{1}$$

where V_{hfc} is the FC voltage (V) i_{hfc} is the FC current (A), E_{op} is the FC open circuit voltage (V), A is the FC Tafel slope (V), N_{hfc} is the number of FCs, i_0 is the exchange current (A), $\mathrm{ST_d}$ is the FC reply time at 95% of the final value (s), and R_{int} is the FC internal resistance (ohm) (Singh et al. 2017).

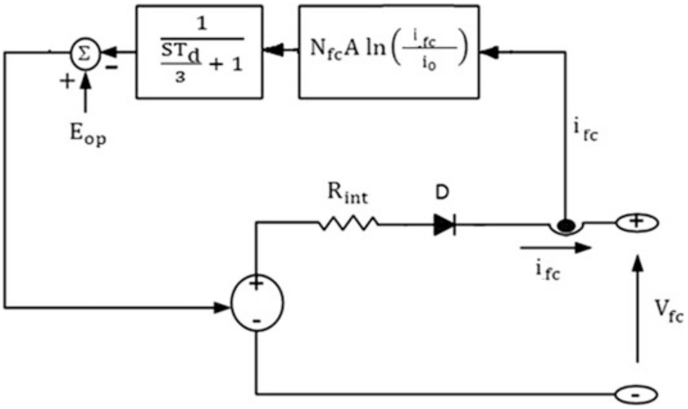

Fig. 3 Electrical circuit diagram of fuel cell (Souleman et al. 2009)

$$E_{\mathrm{op}} = K_{\mathrm{c}} \times E_{\mathrm{nerst}} \tag{2}$$

where E_{nerst} is the Nernst voltage (V) K_{c} is the voltage constant at the nominal condition.

$$i_{\mathrm{o}} = \frac{z \times F \times k \times (P_{\mathrm{H}_2} + P_{\mathrm{O}_2})}{R \times h} \times \mathrm{e}^{\left(\frac{-\Delta G}{R \times T}\right)} \tag{3}$$

where R is the gas constant [8.3145 J/(mol K)], F is the Faraday constant [96485 an s/mol], z is the amount of moving electrons ($z = 2$), ΔG is the start energy barrier (J), T is the temperature of process (K), h is the Planck's constant (6.626×10^{-34} Js), P_{O_2} is the FC air partial pressure (atm), P_{H_2} is the FC fuel partial pressure (atm), and k is the Boltzmann's constant (1.38×10^{-23} J/K).

$$A = \frac{R \times T}{z \times \alpha \times F} \tag{4}$$

where α is the coefficient of charge transfer (Mathworks 2017)?

$$\mathrm{UtH}_2 = \frac{60000 \times R \times T \times i_{\mathrm{hfc}}}{z \times F \times P_{\mathrm{ffuel}} \times V_{\mathrm{ffuel}} \times x\%} \tag{5}$$

where UtH_2 is the FC utilization of hydrogen, P_{ffuel} is the FC supply pressure of fuel (atm), V_{ffuel} is the FC fuel flow rate (l/min), $x\%$ is the percentage of hydrogen in the fuel (%).

$$\mathrm{UtO}_2 = \frac{60000 \times R \times T \times i_{\mathrm{hfc}}}{z \times F \times P_{\mathrm{fair}} \times V_{\mathrm{fair}} \times y\%} \tag{6}$$

In the above equation, UtO_2 is the utilization of oxygen, P_{fair} is the supply pressure of air (atm), V_{fair} is the airflow rate (l/min), $y\%$ is the percentage of oxygen in the oxidant (%).

50% oxygen utilization by the fuel cell is the nominal condition (Milewski and Lewandowski 2014). The partial pressures of hydrogen, oxygen, and water vapor are determined as follows as in (7), (8), and (9):

$$P_{\mathrm{H}_2} = (1 - \mathrm{UtH}_2) \times x\% \times P_{\mathrm{ffuel}} \tag{7}$$

$$P_{\mathrm{O}_2} = (1 - \mathrm{UtO}_2) \times y\% \times P_{\mathrm{fair}} \tag{8}$$

$$P_{\mathrm{H}_2\mathrm{O}} = \{w + (2 \times y\% \times \mathrm{UtO}_2)\} \times P_{\mathrm{fair}} \tag{9}$$

$$w = \text{Percentage of water vapor in the oxidant}(\%)$$

Knowing the partial pressures of gases, the Nernst voltage equation is given as

$$E_{\text{nernst}} = 1.229 + \left\{(T - 298) \times \frac{-44.43}{zF}\right\} + \left\{\frac{RT}{zF} \times \ln\left(P_{\text{H}_2} \times \sqrt{P_{\text{O}_2}}\right)\right\} \tag{10}$$

For $T > 373$ K

$$E_{\text{nernst}} = 1.229 + \left\{(T - 298) \times \frac{-44.43}{zF}\right\} + \left\{\frac{RT}{zF} \times \ln\left(\frac{P_{\text{H}_2} \times \sqrt{P_{\text{O}_2}}}{P_{\text{H}_2\text{O}}}\right)\right\} \tag{11}$$

where

$$P_{\text{H}_2\text{O}} = \text{Partial pressure of water vapor (atm)}$$

The stack output voltage is represented by the following equation:

$$V = E_{\text{oc}} - \{N_{\text{fc}} \times A \times \ln(i_0)\} - R_{\text{int}} \tag{12}$$

4 Review Analysis of Fuel Cell Energy System

The fuel cell (FC) technology is another conventional energy unit due to its higher efficiency, hygienic process, and cost-effective supply of energy required by the consumers (Wang et al. 2005). The legalized models through experiments were approved on a 500-W Avista Labs SR-12 PEM fuel cell stack. Finished model results shown by the models can predict the energy response of the fuel cell stack below steady state as well as at momentary conditions. The temperature response of the fuel cell stack forecasts the use of fuel cell control-related studies.

Wolfgang Fried et al. (2004) present the governing equations of the transient behavior of a PEM and its influence of the operating conditions along with current density on internal parameters, especially the ohmic resistance.

(Pasricha and Shaw 2006) provide a relatively simple, physically motivated, dynamic model of a fuel cell. The dynamic model is obtained by extending a stationary current–voltage depiction to comprise temperature dependence, and by dynamically showing the temperature of the membrane. They validated model performance using investigational data collected from a 500-W fuel cell (Chiu et al. 2004). In this paper, an effort is defined to mend the small-signal modeling of a PEM fuel cell's dynamic presentation as an preliminary step toward examining internal design modifications and/or external controller strategies to improve its transient response. They recognized from the simulation results that the model significantly improves the transient response of PEMFC. Bucci et al. (2007) developed an automatic testing system and performed both the static and dynamic representation of PEMFC stack and the data obtained is used for the amalgamation of a dynamic model of a stack of PEMFC, which has been endorsed through experimental measures.

Na and Gou (2008) deliberate a dynamic PEMFC model and a design for a nonlinear control for PEMFCs by feedback linearization to delay the cell stack life. The feedback linearization is practical to the PEMFC arrangement so that the deviation can be kept as small as conceivable during turbulences or load distinctions. The nonlinear control strategy has been prompted in MATLAB. According to the results, the nonlinear controller has better transient responses than the linear controller under load deviations.

Tanrioven and Alam (2006) author presented the modeling, control, and simulation of 5 kW PEMFC-based energy supply system for residential applications, also a proportional–integral (PI)-type controller is proposed to satisfy the system desires for voltage and power. They concluded from simulation results that suitable dynamic responses are obtained from the proposed control structure. They inveterate by the power-quality estimation that the bus voltage harmonics meet the IEEE-519 requests for all home uses.

Andújar et al. (2011), in this work, constructed and verified a hybrid system involvinga fuel cell and a battery. They determined that the whole system works efficiently under changed load power values such as 12 V-DC, 48 V-DC, and 230 V-AC. Hua et al. (2007) established a dynamic model and then made a 600 W prototype hybrid power generation scheme consisting of fuel cells, lead-acid batteries, and a DC/DC converter. They applied a digital signal processor (DSP) for the system control and verified the results through experiments. They concluded that the hybrid power system increases the peak power capacity and provides a stable output with the addition of a power converter and appropriate controls.

Thounthong et al. (2008) display a novel control algorithm for utilizing a PEMFC mainly for future electric automobile applications as a source and batteries as a balancing source for distributed power generation system. The structure used was FC system current, battery bank current, and battery SOC cascade control. The small-scale devices of a 500 W, 40-A PEMFC and a 48 V, 33 Ah battery bank were used for the offered control procedure during motor drive cycles and they showed excellent performances (Prema Kumar et al. 2012). In this work, the load behavior of SOFC was analyzed and it was observed that the fluctuations due to load distinctions occupied attention by the SOFC output voltages in the electrical energy system. The SOFC can supply power-preserving inverter voltage as desired, reducing effluence and the cost of energy.

Ariyanfar et al. (2011) offered a 100 W alkaline fuel cell with mobile electrolyte and its marginal apparatus was intended. The offered model uses GAMS codes to find optimum beliefs of the cost model, electrochemical and heat transfer equations. The electrolyte flow rate, inlet and outlet temperatures, pressure drop, heat exchanger areas as parameters that effect on cell concert and total cost. They found that running cost is more effective than the fixed cost.

5 Applications of Fuel Cells

Fuel cell is categorized into three comprehensive sectors: stationary electrical power generation, energy for transportation, and portable electrical power generation.

5.1 *Stationary Power Generation*

Stationary FC today is defined as a unit which provides electricity (and sometimes heat) without movement of the system. When the generation exceeds the demand, hydrogen can be stored via electrolysis on water (Blain 2007). During high load time, the demand exceeds generation, the stored hydrogen retained within the fuel cell can be used to meet the demand. A stationary power generation application of fuel cells focuses on two main markets shown in (Fig. 4). A fuel cell is used for dispersed generation. Keeping the fuel cell close to the assigned center, transmission and distribution cost could be avoided then reduced. To join on isolated websites certain as development sites, military camps yet short village well accepted than DG sets.

Emergency or auxiliary furnish at hospitals, academic establishments, and so on may stand met using a fuel cell. Combined heat and power (Wilberforce et al. 2016), energy produced from the fuels cells operating at high temperatures, like SOFC and MCFC, provide industrial process heat or generate extra energy retaining waste heat boilers and steam turbines. It is an important occasion to increase the efficiency of the electrical power plant.

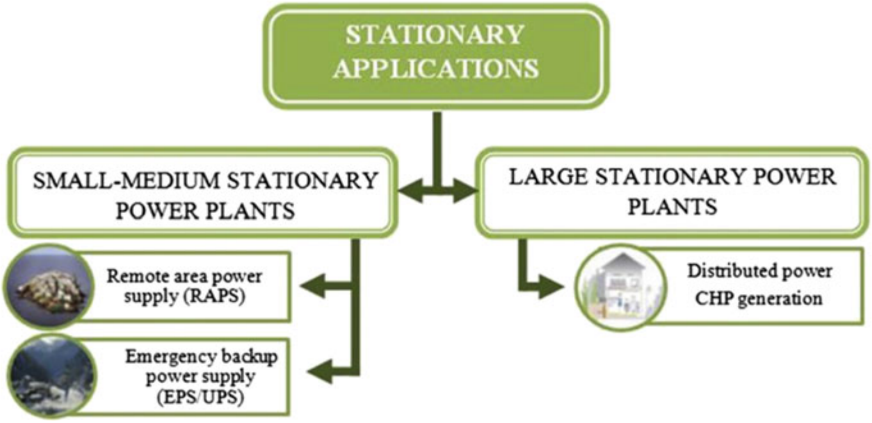

Fig. 4 Stationary applications for fuel cells (Wilberforce et al. 2016)

5.2 Transportation Power

Development of particular vehicles devours huge quantities of fossil fuel and their emissions significantly lower the air quality (Amjad et al. 2010). To discourse these difficulties, investigating alternative sources of power is done. Almost all of the major automobile manufacturers are designing and testing fuels being done by Mazda, Honda, Nissan, Volkswagen, Hyundai, Toyota, General Motors, Ford, Chrysler, BMW, and Suzuki shown in Fig. 5 (Gooeyrabinski 2017). Fuel cell-powered automobiles contain many scarcer parts to a variety of noise than in an IC engine that burns fuel, the only noise from a fuel cell-powered automobile is

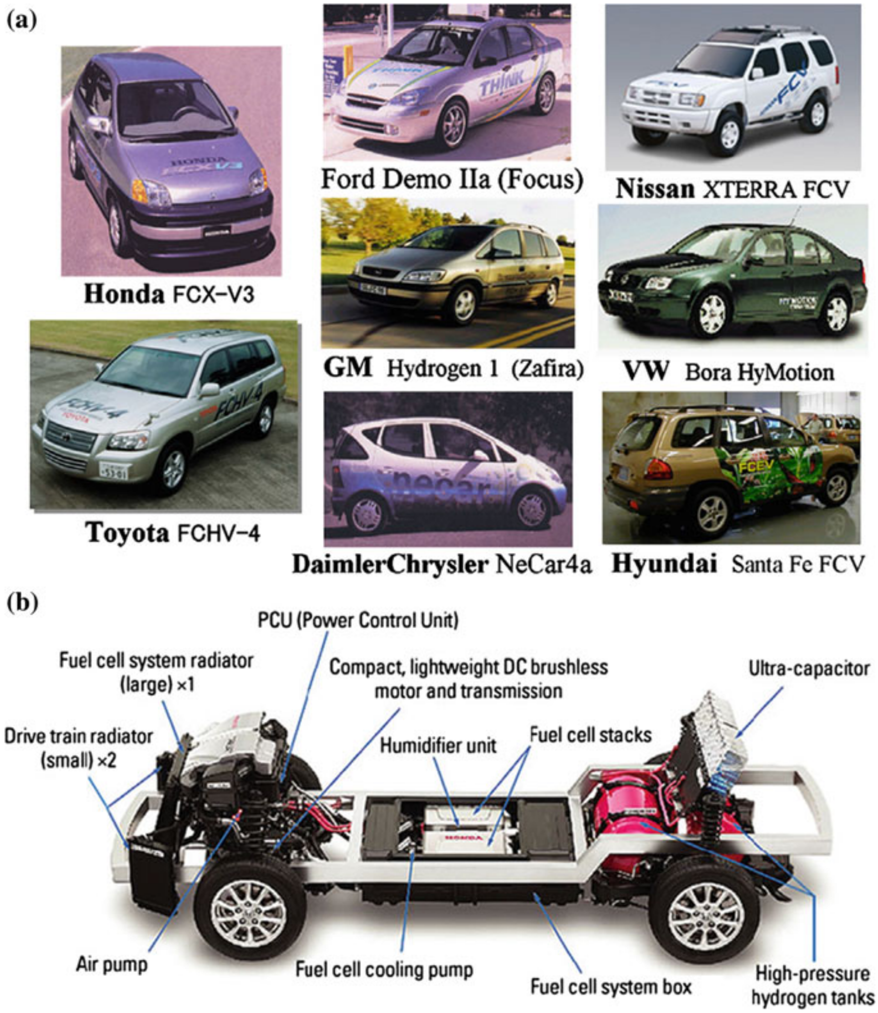

Fig. 5 Fuel cell car (**a**) and layout of the Honda FCX Powertrain (**b**) (Wanga et al. 2011)

from the compressor. Fuel cell-powered vehicles do not require any CI Engine (Aftabuzzaman and Mazloumi 2011). Less maintenance is required as there are no moving parts. Fuel cell automobiles are more reliable due to scarcer progressions to failure as shown in Fig. 6 (Greencarreports 2017). The biggest drawback is that water is needed to produce power and can freeze below 32 °F damaging the membrane and other components (Ahluwalia et al. 2011). Draining the water from the stack before shutting down the vehicle or using new coolant systems and/or block heaters are the solutions to this problem. Solutions to address this problem includes producing fuel cells commercially. The largest fuel cell uses their sixth-generation FC Velocity-HD6 modules power bus fleet in the world, which operates 20 buses (Ahluwalia et al. 2012). Greenhouse gas productions are compact by about 2000 tons per year. Many other nations use fuel cell-powered buses counting Brazil, Japan, Spain, Czech Republic, Australia, and the United States of America.

5.3 Portable Power

Fuel cell performance since ancient in the form of power portable electronic devices, (e.g., cellular phones, laptops yet other low power appliances, especially among military operations). It is used as a substitute for primary or rechargeable batteries. Instead of charging for long, a small cartridge of methanol can be replaced by an ink size cartridge of the printer. The efficiency of FC is always higher as

Fig. 6 Fuel cell bus (**a**); and one of the DaimlerChrysler fuel cell buses (**b**) (Wanga et al. 2011)

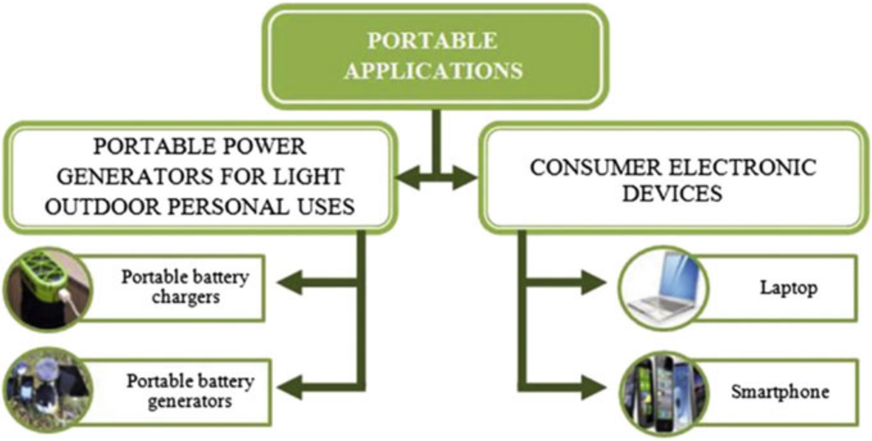

Fig. 7 Portable applications for fuel cells (Wilberforce et al. 2016)

linked with predictable electrical energy system and other distributed power generation systems as it is beneficial due to zero emanation, quick fitting and gives respectable opportunities for cogeneration processes as shown in Fig. 7.

6 Environmental Impact

Decrease in greenhouse gas emissions by fuel cells that use hydrogen, deliver high air feature (Suleman et al. 2015). The decrease of NO_X, SO_2, and CO_2 finished variation of coal, oil, and ordinary gas-fired producing capacity with Connecticut with a fuel cell as follows (Sharma and Strezov 2017).

This resources that for each megawatt of predictable fossil fuel generation ability substituted with capability from a fuel cell:

- Normal reductions of NO_X discharges would be compact by 11,213 lbs;
- SO_2 discharges would be compact by 9,373 lbs, and
- CO_2 discharges would be compact by approximately 7.2 million lbs.

At 40 MW, average reductions of NO_X discharges would be compact by 224 tons; SO_2 emissions would be compact by 187 tons, and CO_2 emissions would be condensed by roughly 144 thousand tons. With a CHP use and pretentious extra increased efficiency from abridged transmission line losses; these yearly emission decreases could be crumpled (Lee et al. 2015). Table 3 shows the Emission Declines by Fuel Cell Technology (lb/MWh) and Table 4 shows the Budding Average Annual Emissions Decline for each megawatt of predictable fossil fuel cohort replaced with volume from a fuel cell.

Table 3 Emission declines by fuel cell technology (lb/MWh) (CHFCC 2017)

GHG emissions ↓	Coal power plant converted fuel cells plant	Oil-power plant converted fuel cells plant	Gas-power plant converted fuel cells plant	Average emissions reductions after fuel cell plant
NO_X	2.53	2.4	0.31	1.28
SO_2	1.79	4.12	0.021	1.07
CO_2	1,106–1,524	832–1,340	255–763	824

Table 4 Probable average annual emissions decline for every megawatt of predictable fossil fuel generation substituted with volume from a fuel cell (CHFCC 2017)

GHG emissions ↓	1 MW	40 MW
NO_X	11,213 lbs	224 tons
SO_2	9,373 lbs	187 tons
CO_2	7,218,240 lbs	144,365 tons

Table 5 Automobile emissions comparison (grams/mile) (CHFCC 2017)

GHG emissions ↓	Emissions after predictable gasoline-powered passenger cars	Emissions after predictable gasoline drove light trucks	Emissions after conventional diesel transit buses	Emissions after hydrogen fuel cells
NO_X	0.95	1.22	12.5	0
SO_2	0.007	0.0097	0.0214	0
CO_2	369	511	2,242.7	0

The use of fuel cells for transport applications will decrease emission for traveler automobiles and mass transportation as 61% of transport reliefs GHG emissions. These automobiles are responsible for 28% of all GHG emissions in Connecticut, likened to 22% nationwide (Ito 2017). Conventional diesel transport buses emit noteworthy amounts of GHG have the budding for the supreme energy investments using fuel cell applications associated with most other transport uses. A comparison of automobile emissions is shown in Tables 5 and 6. Figure 8 shows the conservational impact of fuel cell bus and Fig. 9 shows the well-to-wheels greenhouse gas emission.

Table 6 Automobile emissions evaluation (grams/mile) potential annual emission decreases per automobile using hydrogen fuel cell impulsion systems (pounds/year) (CHFCC 2017)

GHG emissions ↓	Possible emission decreases per year after replacement of a gasoline-fueled passenger car	Possible emission decreases per year after replacement of a gasoline-fueled light truck	Possible emission decreases per year after replacement of a predictable diesel transit bus
NO_X	26.2	37.7	1,019.9
SO_2	0.192	0.299	1.746
CO_2	10,169	15,772	182,984

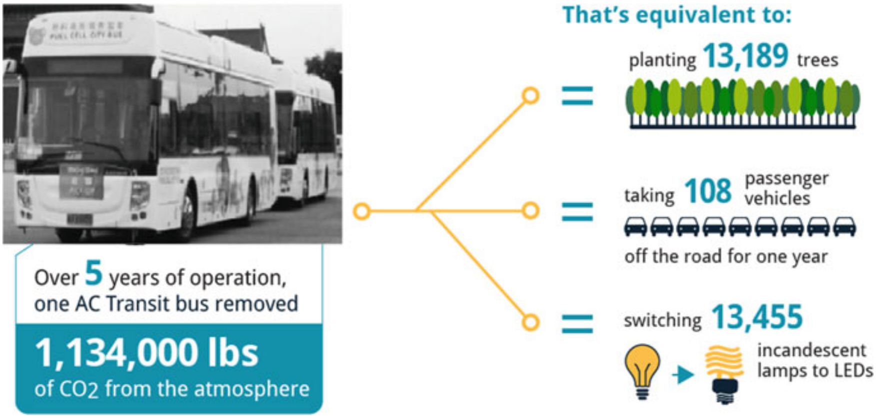

Fig. 8 Environmental impact of fuel cell bus (Liangfei et al. 2009)

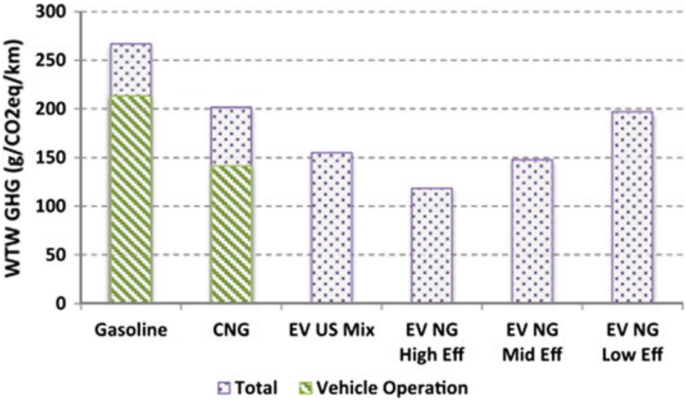

Fig. 9 Well-to-wheels greenhouse gas emission (Curran et al. 2014)

This accepts hydrogen-produced fuel cell automobiles running on hydrogen fashioned from renewable resources removing all GHG emissions associated to predictable fossil fuel-powered automobiles (Duclos et al. 2017). Supplementary of one traveler vehicle, light truck or transit bus can result in yearly emission decreases shown in the following tables.

7 Conclusion

This chapter presents a basic overview of the fuel cell technology along with advantage, disadvantages, applications, classification, and review of the fuel cell. The classification of fuel cell such as PAFC, PEMFC, AFC, MCFC, and SOFC is described. Fuel cell is categorized on the basis of stationary power generation, power for transportation, and portable power generation. The usage of fuel cells particularly that employ hydrogen, better-quality air and concentrated GHG emissions is explained Replacement of coal, oil, and natural gas-fired producing capability by fuel cell (fueled by natural gas) technology would result in the decrease of NO_X, SO_2, and CO_2, Fuel cell with other energy sources offers more advantages such as high energy efficiency, zero emission, quick installation, and delivers for cogeneration processes.

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