IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
IJARSCT
Impact Factor: 6.252
Volume 2, Issue 1, December 2022

Review on Recent Trends in Hydrogen Fuel Cell

Manoj Bauskar[1], Adinath Aher[2], Abhijit Dahagaonkar[3]
Assistant Professor, Department of Mechanical Engineering[1]
Students, Department of Mechanical Engineering[2,3]
All India Shri Shivaji Memorial Society's College of Engineering, Pune, Maharashtra, India

Abstract: *This research review major goal is to show how the growing need for industrial decarbonization and sustainable energy efficiency is driving academics from various fields to look for new, more efficient ways to achieve these objectives. A hydrogen economy built on fuel cell and hydrogen technology is a realistic and viable solution to meet India's energy goals and raise social standards while ensuring independence and security of the country's energy supply. Rapid adoption of environmentally friendly technologies necessitates comprehensive policy changes and cooperative efforts from all Member States. This article provides an overview of fuel cell and hydrogen technology. This examination covers the principles and technical components of several fuel cell systems. The study examines all fuel cells in-depth, looking at the many types of fuel cells and how they function. Numerous industries, including the automotive industry and stationary power generation, can benefit from the use of fuel cells. To compare the various fuel cell types, the most effective and environmentally friendly fuel cell is investigated..*

Keywords: FCV, Molten Carbonate, alkaline

I. INTRODUCTION

A fuel cell is an electrochemical device that uses two redox processes[1] to transform the chemical energy of a fuel (typically hydrogen) and an oxidizing agent (commonly oxygen [2]) into electricity. In contrast to most batteries, which typically rely on metals and their ions or oxides [3] that are typically already present in the battery, fuel cells need on a constant stream of fuel and oxygen (generally from air) to support the chemical reaction. Fuel cells can continually generate power if fuel and oxygen are available. If fuel and oxygen are available, fuel cells can constantly create electricity. Fuel cells have the potential to be used in a variety of applications, including major electrical plants, stationary electricity generation, portable power, and vehicle propulsion [4,5]. The classification of fuel cells depends on a variety of factors, including operating circumstances (pressure, humidity and Temperature), fuel cell structure (application system and size), and the color of the polymer electrolyte used in fuel cells [6].

This study examines recent developments in hydrogen fuel cells to explore the possibility of using hydrogen as a primary fuel in transportation systems.

II. HYDROGEN

2.1 Properties of Hydrogen

Hydrogen is an odorless gas which is very light in weight. At room temperature it remains in gaseous state. It has the density of 0.08375 kg/m3 at standard temperature and pressure.

2.2 Methods of Producing Hydrogen

There are numbers of methods for producing H2 from fossil sources. The hydrocarbon steam reforming method is very popular right now. Other hydrogen producing techniques Partial oxidation, plasma reforming, petroleum coke, and coal are all methods of producing hydrogen from fossil fuels. Electrolysis, radiolysis, photocatalytic water splitting, and electrolysis are all methods for producing hydrogen from water.[7]

III. FUEL CELL

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used.

3.1 Working Principles

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell.

At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons.

The positive ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products.[8] In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40 and 60%; however, if waste heat is captured in a cogeneration scheme, efficiencies of up to 85% can be obtained. [9]

3.2 Parameters Considered In Determining An Efficient Fuel Cell

- Energy conversion efficiency (%): It is the ratio between the useful output of an energy conversion machine and the input, in energy terms. The input, as well as the useful output may be chemical, electric power, mechanical work, light (radiation), or heat. [10] [11]
- Cell Voltage (V)
- Lifespan (hours)
- Energy density (kWh/m3) is the amount of energy that can be stored in each mass of a substance or system.[12] The higher the energy density of a system or material, the greater the amount of energy stored in its mass. [13]
- Power density (kW/m3): It is the amount of power (time rate of energy transfer) per unit volume. [14]
- Specific Power/ Power-to-weight ratio: It is the power generated by the engine divided by the mass.
- Specific Energy (Wh/kg)
- Energy Cost ($/kWh)
- Power Cost ($/kW)
- Working Temperature (◦C)

3.3 Types of Fuel Cells

A. The Direct methanol Fuel Cells

Direct methanol fuel cells are a type of low- temperature system that, unlike most other technologies, directly use a fuel other than hydrogen.[15,33]When steam and pure methanol are added to the direct methanol FC at the anode, a reaction occurs that causes the methanol to change into CO2 and hydrogen ions.

(Anode Reaction) $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$ (i)

The protons are then transferred to the cathode through the electrolyte as the electrons flow back to the anode after passing through the external circuit to create the current. At the cathode, oxygen and the protons and electrons react to create water.

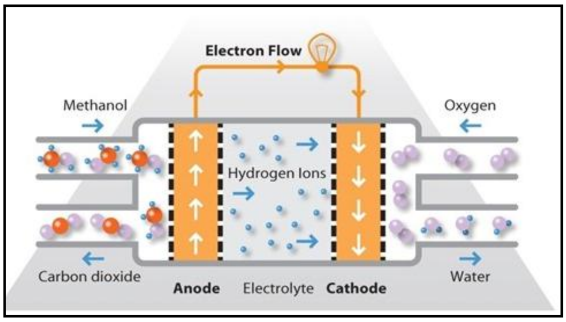
(Cathode Reaction) $^3/_2O_2 + 6H^+ + 6e^- \rightarrow 3\ H_2O$ (ii)

The anode, cathode and overall reactions in direct methanol FCs are described by Equations (i) (ii) &(iii) [16]

(Overall Reaction) $CH_3OH + ^3/_2O2 \rightarrow 2H_2O + CO_2$ (iii)

Although a DMFC's theoretical thermodynamic energy conversion efficiency is 97 percent [17], the actual energy conversion efficiency of operational cells can only reach 30 to 40 percent.[18-19]

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Impact Factor: 6.252
Volume 2, Issue 1, December 2022



Advantages: Methanol is a cost-effective, simple-to-produce substance that could be used directly in the functioning of a cell. They are used in low-weight battery alternatives for military and other applications because this enables simple cell structures and designs with comparatively low weights. The technique is suitable for portable electricity for laptops and mobile appliances, including small plants that are less than 5 kW; another advantage is that methanol is simple to store without the risk of explosions as in the case of hydrogen fuel.[18,16]

Disadvantage: The main drawback of direct methanol FCs is that they have the lowest efficiency of all FC technologies less than 40%. Additionally, methanol is derived from non-renewable fossil fuels, is very flammable, and has a mild poisonous effect.[16]

B. Molten Carbonate Fuel Cell

Carbonate salts are used as the electrolyte in molten carbonate fuel cells, a high temperature technology with an operating temperature of 650 °C [19,20]. The primary mechanism of the reaction is the migration of carbonate ions from the cathode to the anode, where they combine with hydrogen to produce water, CO2, and electrons.

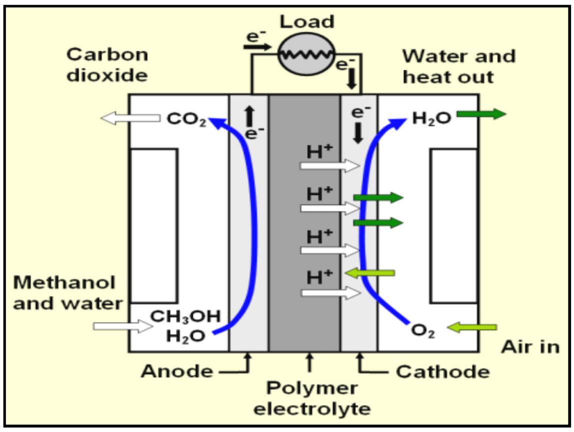
(Anode Reaction) $H_2 + CO_3^{2-} - \rightarrow H_2O + CO_2 + 2e$- (iv)

Carbonate ions are generated at high temperatures from carbonate salts.[19] Electric current is created when these electrons are moved from the anode to the cathode of an external circuit.

(Cathode Reaction) $^1/_2\, O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$ (v)

The interaction of oxygen and CO2 at the cathode [17] replaces the carbonate ion depleted from the electrolyte.

(Overall Reaction) $H2 + 1/\,2\ O2 \rightarrow H2O$ (vi)



These fuel cells are mostly employed in hospitals, military bases, small business locations, and local communities when rated power output requirements are considerable, typically greater than 200 kW.[21]

Advantage: the low cost of the catalyst, the great electric efficiency, and the superb regenerative capacity brought on by internal reforming. Along with these benefits, the cell offers fuel flexibility because virtually any hydrocarbon, biogas, etc. can be used, as well as improved pollutant tolerance due to high system temperatures. It also has an approximate 12–37.6 W/Kg specific power. The cell's lifespan is between 7000 and 8000 hours, and its voltage ranges from 0.7 to 1.0 V. Around 146–175 cents per kWh, the cost of energy is low. [22]

Disadvantage: The breakdown of cell components, loss from evaporation, dissolving of the catalyst, and sluggish startup time are other effects of the high temperatures. It also has a poor power density, only 1.05 to 1.67 kW/m3, compared to Polymer Electrolyte Membrane FCs, which have a power density of 4.2 to 35.0 kW/m3.[23]

C. Solid Oxide Fuel Cell

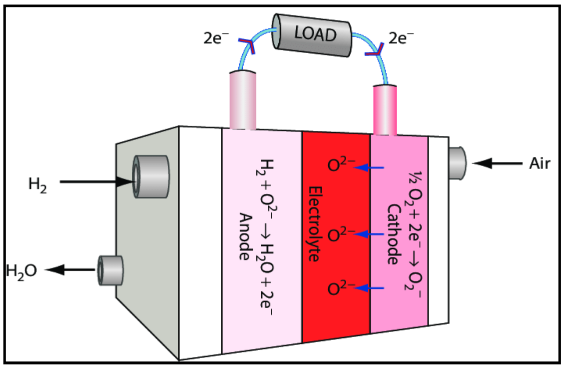
Another high temperature fuel cell is the solid oxide fuel cell. It operates between 800 and 1000 °C and uses nonporous zirconium oxide stabilized with yttrium oxide as an electrolyte.[19] The electrolyte's oxygen ions can easily travel in the direction of the hydrogen gas near the anode. When hydrogen and oxygen ions react at the anode, steam is produced.[20]

(Anode Reaction) $H_2 + O_2^- \rightarrow H_2O + 2e^-$ (vii)

(Cathode Reaction) $^1/_2\, O_2 + 2e^- \rightarrow O_2^-$ (viii)

(Overall Reaction) $H_2 + {^1/_2}\, O2 \rightarrow H2O$ (ix)

With the help of these cells, dynamic power and cooling generation for domestic use has been accomplished.[24]



Advantage: Long-term stability, excellent power efficiency, and fuel adaptability are all strengths of this cell. Operations at high temperatures don't need a catalyst to increase kinetics, are very contaminant-tolerant, and have the potential for internal reforming.[25]The cell has a lifespan of greater than 10,000 hours and cell voltage between 0.8 - 1.0 V.[28] The energy cost is low around 180 - 333 $/kWh and energy density for the cell is high in the range of 172.0 - 462.0 kWh/m3 which is comparable to the energy density of Polymer Electrolyte Membrane FC.[26]

Disadvantage: As the functionality is highly dependent on high temperature operations it leads to many drawbacks including corrosion, sintering of electrodes and mechanical and thermal stress. Long start-up time and strict material requirements are some other issues faced with this cell.[27]

D. Reversible Fuel Cell

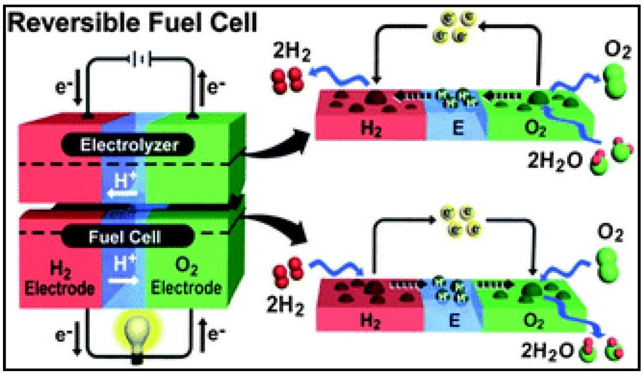
Here, water is split into hydrogen and oxygen using the electrolysis technique, which uses electricity generated by solar or wind energy. Reversible fuel cells can be used to generate electricity from hydrogen and oxygen, producing water as a byproduct, much like any other type of fuel cell.Equations (x) and (xi) illustrate the general reactions that take place during the two modes of operation:[29]

(Conventional Fuel Mode) $4H^+ + O_2 + 4e^- \rightarrow 2H_2O$ (x)

(Water Electrolyser Mode) $2H_2O \rightarrow 4H + +O_2 + 4e^-$(xi)

Advantage: Reversible fuel cells have the advantage of being able to store energy in the form of hydrogen during periods of high energy output from other technologies, such as solar, wind, and others.[29]

Disadvantage: These reversible fuel cells can eliminate the main issue with fuel cell portability, and significant research is being done to make them commercially viable.[30]



E. Alkaline Fuel Cells (AFC)

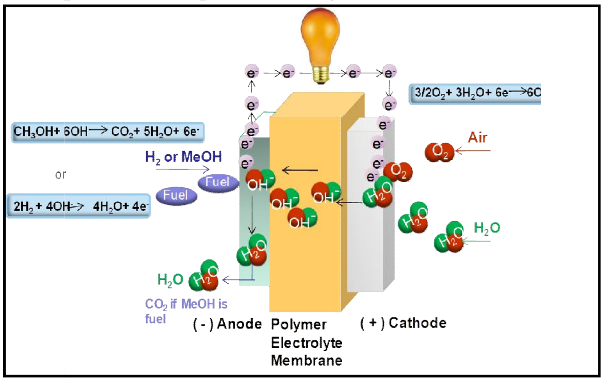
To conduct ions between electrodes, AFCs employ an aqueous solution of potassium hydroxide (KOH) as the electrolyte. Because the electrolyte is alkaline, PEMFCs' ion conduction mechanism is not applicable. The hydroxide ion (OH), which is carried by the alkaline electrolyte, has an impact on several other features of the FC.

Oxidation: $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$(xii)

Reduction: $O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$(xiii)

Water management is a significant problem that can occasionally be overcome by utilizing waterproof electrodes and maintaining the water in the electrolyte because water is required at the cathode for the oxygen reduction process.

The anode reaction rejects the water it produces, whereas the cathode reaction takes the water from the electrolyte. Outside the stack, the extra water (2 mol per reaction) evaporates. From 0.22 to 4.5 MPa and 80 to 230 C, respectively, AFCs may function over a broad temperature and pressure range.



Additionally, high-temperature AFCs use an electrolyte that is so concentrated that the ion transport mechanism switches from an aqueous solution to molten salt.[31]

Advantage: In some situations, they provide reasonably high efficiency of up to 60%. Depending on the system design, a single alkaline FC can produce a voltage output of 0.5 to 0.9 V with an efficiency of up to 65%, according to Alhassan et al. Alkaline FCs can also produce electrical output between 5 and 150 kW, and more recent systems can allow operation at temperatures as low as 70 C. This suggests that they can function across a larger temperature range.[19,33]

Disadvantage: the technology is that the electrolyte (KOH) is corrosive and that, due to its liquid form, sealing the anode and cathode gases is much more challenging than when using an electrolyte that is solid.Another difficulty is the carbon dioxide "poisoning" of the electrolyte, which occurs when the KOH adsorbs the gas and lowers the electrolyte's conduction power.[33,20]

IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 1, December 2022

F. Phosphoric Acid Fuel Cell

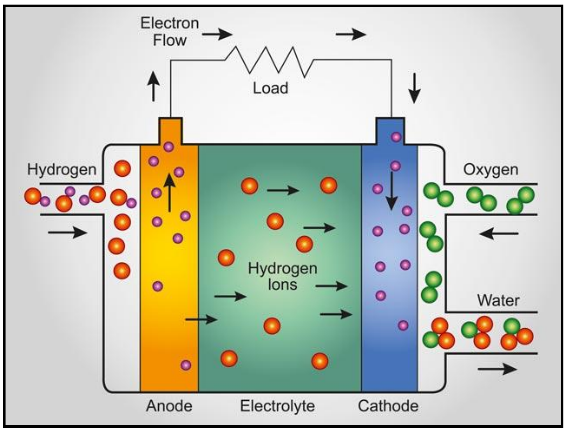
PAFCs rely on an acidic electrolyte, as with PEMFCs, to conduct hydrogen ions. The reactions in the anode and the cathode are the same as the PEMFC reactions. Phosphoric acid (H3PO4) is a viscous liquid that is contained by capillarity in the FC in a porous silicon carbide matrix. PAFCs are medium temperature fuel cells that conduct hydrogen ions, thus they are not as fuel-flexible as the high-temperature fuel cells that conduct oxidizing ions (e.g., O^-, CO_3^-). While PAFCs are predominantly used for stationary power, they have also been implemented in some large-scale vehicles, such as public buses. The overall reaction can be characterized as follows:[32]

$H2 + {}^1/_2\, O_2 \rightarrow H_2O$ (xiv)

The half reaction associated with the phosphoric acid fuel cell is as follows:

Oxidation reaction: $H_2 \rightarrow 2H^+ + 2e^-$(xv)

Reduction reaction: ${}^1/_2\, O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (xvi)



Advantage: Simple structure designs, less prone to electrolyte volatility and carbon monoxide poisoning, and used in small- to medium-sized plants between 50 kW and 11 MW. The evacuated water can be converted to steam for air and water heating at an operational temperature range of 150 to 200 °C. This might enable efficiency gains of up to 70%. Because PAFCs are CO2-tolerant and can withstand a CO concentration of roughly 1.5%, the range of fuels they can use is increased. Their cost, performance, and stability have all greatly improved. The PAFC is an excellent contender for early stationary applications because of these qualities.[34,35]

Disadvantage: Low power density, i.e., it provides less power when compared to fuel cells of comparable weight and volume. Additionally, it is a hostile electrolyte. Another drawback is the rise in system costs brought on by the necessity of integrating corrosion-resistant parts to lessen the impact of acid on the electrolyte.

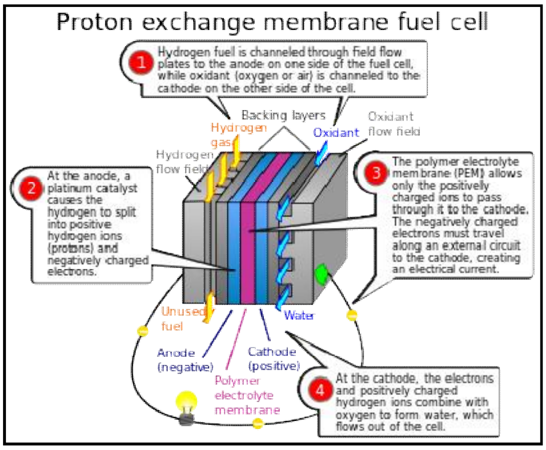
G. Polymer Electrolyte Membrane Fuel Cell (PEM FCS)

A thin, permeable polymeric membrane is used as a solid electrolyte in the Polymeric Electrolyte Membrane Fuel Cells, a low-temperature technology that essentially belongs to the low-temperature systems family. These fuel cells are often referred to as proton membrane exchangers.[36] The device uses platinum materials on one or two sides of the permeable membrane and operates at a temperature of about 80 °C with a short warm-up period. This is possible because the membrane is thin, light, and requires catalysts.[19] At the anode of this technology, hydrogen ions are provided, which are subsequently split into protons and electrons. While the electrons are forced to flow via the external circuit to produce direct current, the protons migrate to the cathode over the electrolyte.[19] When oxygen air and hydrogen ions interact at the cathode, water is created. The reactions at the anode and cathode are described by equations (xvii), (xviii), and (xix). [33]

(Anode Reaction) $H2 \rightarrow 2H^+ + 2e^-$ (xvii)

(Cathode Reaction) $1/2\ O2 + 2H^{+} + 2e^{-} \rightarrow H2O$(xviii)

(Overall Reaction) $H2 + 1/2\ O2 \rightarrow H2O$(xix)



Advantage: The Polymeric Electrolyte Membrane Fcs Has the Capability To Vary The System Output To Balance Load Demand Patterns And Achieve A Range Of Efficiencies Between 40% And 60%. The Innovation Can Discharge Electrical. A Compact and Lightweight Structure with Power inthe 5 to 250 Kw Range [19, 33]. This technology has a high-power density; the literature reported a value of more than 1000 W/kg [37].Fuel cell systems are less expensive to manufacture than some other technologies because a solid electrolyte is used in this technology, making it easier to seal gases at the anode and cathode terminals.

Additionally, the technology is less prone to corrosion. However, in some cases, a low working temperature of 80 C may not be sufficient to achieve useful combined heat and power (Chp) purposes, and a noble metal catalyst will be required to separate the hydrogen protons and electrons [19,20]. Costs are further raised by this technology's use of a platinum catalyst.

Disadvantage: Due to its compactness, the Pem Fuel Cell is widely used and a top candidate for applications in vehicles and mobile devices. However, a few problems have arisen.Data for 2016 to 2021 have been collected directly from fuel cell manufacturers and integrators where they were able to share it. For those who were not able to share primary data, and to sense check our numbers, we have collected and cross-referenced data from publicly available sources such as company statements and statutory reports, press releases, and demonstration and roll-out programmes, in addition to discussions with other parties in the supply chain

IV. SUMMARY

In comparison to solid oxide fuel cells and other systems, which have a value of 1.05-1.67 w/kg, the study indicates that polymer electrolyte membrane fuel cells have a reasonably high specific power of >1000 w/kg. The PEM fuel cell is well known for this characteristic, which has led to several uses for them in the transportation sector, the automotive industry, stationary fuel cell systems, and portable fuel cell systems.

Although the efficiencies of the polymer electrolyte membrane, solid oxide, phosphoric acid, alkaline, and molten carbonate fuel cells range from 35 to 45 percent, 50 to 70 percent, 37 to 45 percent, 35 to 60 percent, and >50 percent, respectively, the literature indicates that the direct methanol fuel cells have the lowest efficiency of all the technologies, at around 35 percent. Additionally, solid oxide and molten carbonate fuel cells, which are high-temperature technologies, operate at temperatures between 800°C and 1000 °C and 600°C and 800°C, respectively, in contrast to proton exchange membrane, phosphoric acid, alkaline, and direct methanol fuel cells, which operate at temperatures between 50°C and 100 °C, 150°C and 220°C,

IJARSCT

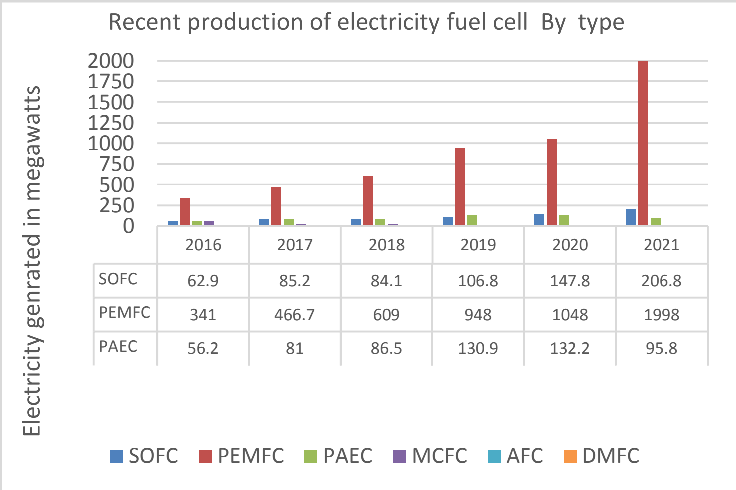
ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Volume 2, Issue 1, December 2022

Impact Factor: 6.252

60°C and 120°C, and 70°C and 100°C, respectively. The PEM fuel cell stands out from its rivals for having a high efficiency at a low working temperature, making them the most robust, transportable, and flexible and active fuel cell technology.



This review article gave a detailed investigation of the various fuel cell technologies from high temperature systems like molten carbonate and solid oxide fuel cells to low temperature technologies namely alkaline, direct methanol, polymer electrolyte membrane and phosphoric acid fuel cells. The paper also presented a detailed review of the catalysts and support material being used in the polymer electrolyte membrane fuel cell while also discussing about its performance and weaknesses.

Fuel Cell Name	Electrolyte	Qualified Power (W)	Working Temp. (°C)	Efficiency (%)		Status (Note)	Cost (USD/W)
				Cell	System		
Direct formic acid fuel cell (DFAFC)	Polymer membrane (ionomer)	< 50 W	< 40			C / R	
Regenerative fuel cell	Polymer membrane (ionomer)		< 50			C / R	
Alkaline fuel cell	Aqueous alkaline solution	10~200 kW	< 80	60~70	62	C / R	
Direct methanol fuel cell	Polymer membrane (ionomer)	100 mW~1 kW	90 ~ 120	20~30	10~25	C / R	125
Reformed methanol fuel cell	Polymer membrane (ionomer)	5 W~100 kW	250~300 (Reformer) 125~200 (PBI)	50~60	25~40	C / R	
Direct-ethanol fuel cell	Polymer membrane (ionomer)	< 140 mW/cm²	> 25 ? 90–120			R	
Proton-exchange membrane fuel cell	Polymer membrane (ionomer)	1 W~500 kW	50~100 (Nafion) 120~200 (PBI)	50~70	30~50	C / R	50 ~ 100
Redox fuel cell (RFC)	Liquid electrolytes with redox shuttle and polymer membrane (ionomer)	1 kW~10 MW				R	
Phosphoric acid fuel cell	Molten phosphoric acid (H3PO4)	< 10 MW	150~200	55%	40 (Co-gen: 90)	C / R	4 ~ 5
Solid acid fuel cell	H+-conducting oxyanion salt (solid acid)	10 W~1 kW	200~300	55~60	40~45	C / R	
Molten carbonate fuel cell	Molten alkaline carbonate	100 MW	600~650	55%	45~55	C / R	
Tubular solid oxide fuel cell (TSOFC)	O2−-conducting ceramic oxide	< 100 MW	850~1100	60~65	55~60	C / R	
Planar solid oxide fuel cell	O2−-conducting ceramic oxide	< 100 MW	500~1100	60~65	55~60	C / R	

Note: C: Commercial; R: Research

An analysis of fuel cell-based energy production using hydrogen is presented in this review paper. In comparison to batteries alone, FCs with effective control systems may prove to be the better option for applications in automobiles. Soon, hydrogen fuel cells will be widely used in the transportation sector. When fuel cells are manufactured in large quantities and put on the market, their price will drop. In the coming decades, it is likely that fuel cell-based vehicles, power plants, and electricity producers will gain popularity.

The ability to use heat and power from hydrogen fuel cells in addition to their high efficiency (between 40 and 70 percent) will significantly reduce air emissions. For instance, a fuel cell with a 60% efficiency would produce 80% less CO2 from hydrogen and 35–60% less CO2 from fossil fuels.

Future energy sources will need to be cleaner and more effective than existing ones, and fuel cells meet these criteria. An environmentally benign source of power is on the horizon, but there are still a number of obstacles to overcome before we will see widespread commercialization, primarily because of limitations with size, cost, reliability, and safety.

A potential replacement for the present auto fuels is hydrogen fuel cells. They essentially combine the clean, efficient operation of electric vehicles with the energy density and convenience of liquid fuels. Although some features of the technology, such as effective on-board storage, still need to be developed, there is no reason why hydrogen couldn't one day be as practical and appealing as today's diesel or gasoline as a transportation fuel.

REFERENCES

[1]. Saikia, Kaustav; Kakati, Biraj Kumar; Boro, Bibha; Verma, Anil (2018). "Current Advances and Applications of Fuel Cell Technologies". Recent Advancements in Biofuels and Bioenergy Utilization. Singapore: Springer. Pp. 303–337.
[2]. Khurmi, R. S. (2014). Material Science. S. Chand & Company.
[3]. Schmidt-Rohr, K. (2018). "How Batteries Store and Release Energy: Explaining Basic Electrochemistry", J. Chem. Educ., 95: 1801–1810.
[4]. Ajanovic A., Haas R. Economic Prospects and Policy Framework for Hydrogen as Fuel in The Transport Sector. Energy Policy. 2018; 123:280–288. Doi: 10.1016/J.Enpol.2018.08.063
[5]. Hames Y., Kaya K., Baltacioğlu E., Turksoy A. Analysis of the control strategies for fuel saving in the hydrogen fuel cell vehicles. Int. J. Hydrog. Energy. 2018; 43:10810–10821. doi: 10.1016/j.ijhydene.2017.12.150
[6]. Salleh M.T., Jaafar J., Mohamed M.A., Norddin M., Ismail A.F., Othman M., Rahman M.A., Yusof N., Aziz F.,
[7]. Salleh W.N.W. Stability of SPEEK/Cloisite®/TAP nanocomposite membrane under Fenton reagent condition fordirect methanol fuel cell application. Polym. Degrad. Stab. 2017;137:83–99.doi: 10.1016/j.polymdegradstab.2016.12.011
[8]. B. Parkinson, P. Balcombe, J.F. Speirs, A.D. Hawkes, K. Hellgardt, Levelized cost of CO2 mitigation from hydrogen production routes, Energy Environ. Sci. 12 (1) (2019) 19–40.
[9]. https://en.wikipedia.org/wiki/Fuel_cell#cite_note-1
[10]. "Types of Fuel Cells". Department of Energy EERE website
[11]. Energy Glossary, California Energy Commission
[12]. Efficiency, J.M.K.C. Donev et al. (2020). Energy Education - Efficiency
[13]. C. Dillon. (2009, October). How Far Will Energy Go? - An Energy Density Comparison [Online].
[14]. Uni. South Carolina. (2003, October). Description of Energy and Power [Online]
[15]. Jelley, N. A. (Nicholas Alfred), 1946-. A dictionary of energy science. [Oxford]
[16]. Umit B. Demirci (2007). "Review: Direct liquid-feed fuel cells: Thermodynamic and environmental concerns". Journal of Power Sources. 169.
[17]. Ibrahim Dincer, Calin Zamfirescu (2014). "4.4.7 Direct Methanol Fuel Cells". Advanced Power Generation Systems
[18]. Keith Scott, Lei Xing (2012). "3.1 Introduction". Fuel Cell Engineering. p. 147.
[19]. Zhong, J. et al. Synthesis and high electrocatalytic activity of Au-decorated Pd heterogeneous nanocube catalysts for ethanol electro-oxidation in alkaline media. Catal. Sci. Technol. 6, 5397–5404 (2016).
[20]. Adamson, K.A. Stationary Fuel Cells; Elsevier: Amsterdam, The Netherlands, 2007

[21]. Office of Renewable Energy. Types of Fuel Cells|Department of Energy; U.S. Office of Energy Efficiency andRenewable Energy: Washington, DC, USA, 2017.
[22]. Kirubakaran, A.; Jain, S.; Nema, R.K. A review on fuel cell technologies and power electronic interface. Renew.Sustain. Energy Rev. 2009, 13, 2430–2440.
[23]. US DOE (Energy Efficiency & Renewable). Comparison of Fuel Cell TechnologiesAvailableonline:https://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf , Accessed on 27August 2021.
[24]. Sabihuddin, S.; Kiprakis, A.E.; Mueller, M. A numerical and graphical review of energy storage technologies.Energies 2015, 8, 172–216.
[25]. Asghari, M.; Brouwer, J. Integration of a solid oxide fuel cell with an organic rankine cycle and absorption chiller for dynamic generation of power and cooling for a residential application. Fuel Cells 2019, 19, 361–373
[26]. Sammes, N.; Smirnova, A.; Vasylyev, O. Fuel Cell Technologies: State and Perspectives; Springer: Dordrecht, The Netherlands, 2005.
[27]. Sabihuddin, S.; Kiprakis, A.E.; Mueller, M. A numerical and graphical review of energy storage technologies.Energies 2015, 8, 172–216.
[28]. Chen, Y.; Nie, X.; Wang, B.; Xia, C.; Dong, W.; Wang, X.; Wang, B.Z. Tuning La0.6Sr0.4Co0.2Fe0.8O3 -δ perovskite cathode as functional electrolytes for advanced low-temperature SOFCs. Catal.
[29]. Mahato, N.; Banerjee, A.; Gupta, A.; Omar, S.; Balani, K. Progress in material selection for solid oxide fuel cell technology: A review. Prog. Mater. Sci. 2015, 72, 141–337.
[30]. Sebastian Altmann, Till Kaz, Kaspar Andreas Friedrich, Bifunctional electrodes for unitised regenerative fuel cells,Electrochimica Acta 56 (2011) 4287–4293
[31]. F. Barbir, T. Molter, L. Dalton, Int. J. Hydrogen Energy 30 (2005) 351.
[32]. Garche, J.; Jörissen, L. Applications of Fuel Cell Technology: Status and Perspectives. Electrochem. Soc. Interface 2015, 24, 39–43. [CrossRef]
[33]. Yamarone, R. The Trader’s Guide to Key Economic Indicators; Bloomberg Press: Hoboken, NJ, USA, 2004;ISBN 1576601390.
[34]. Giorgi, L. Fuel cells: Technologies and applications. Open Fuel Cells J. 2013, 6
[35]. Fuel Cells Archived November 23, 2010, at the Wayback Machine
[36]. http://energy.gov/eere/fuelcells/types-fuel-cells#phosphoric, Accessed on 28 August 2021.
[37]. Bagotsky, V.S. Fuel Cells: Problems and Solutions; John Wiley & Sons: Hoboken, NJ, USA, 2008.
[38]. Li, X. Fuel cells. In Energy Conversion, 2nd ed.; CRR Press: Boca Raton, FL, USA, 2017.