

Green Fuel Cells

for

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1.0 Historical Development



1801

Humphry Davy described the principle of what was to become a fuel cell [5]



1842

William Grove invented “gas voltaic battery” – prototype of first fuel cell [7]



1932

Francis Bacon developed the alkaline fuel cell – AFC [9]



1960s

NASA first used fuel cells in space missions [11]



1970s

The oil crisis prompted the development of alternative energy technologies [14]



1990s

The small stationary fuel cells developed for commercial locations [16]

2014

Toyota introduced the first commercial fuel cell car [18]



1838

Christian Schönbein published a paper about the reactions in fuel cell [6]



1889

Charles Langer and Ludwig Mond developed Grove’s invention and name the fuel cell [8]



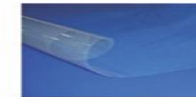
1959

General Electric invented the proton exchange membrane fuel cell – PEMFC [10]



1960s

DuPont developed Nafion® [12]



1966

General Motors used fuel cell technology in production of the Electrovan [13]



The United States Navy used the fuel cells in submarines [15]

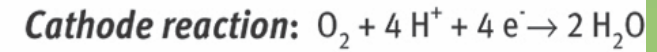
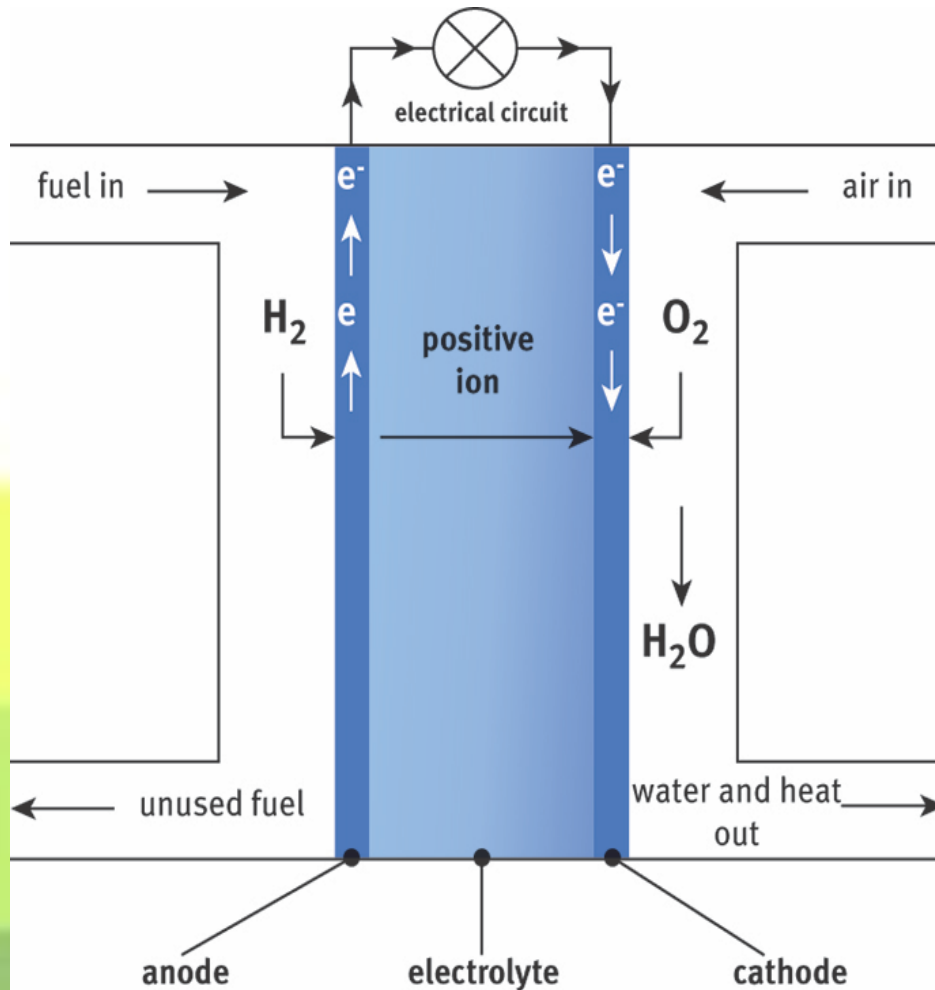


2000s

The fuel cells were employed in vehicles [17]



2.0 Basic Principle



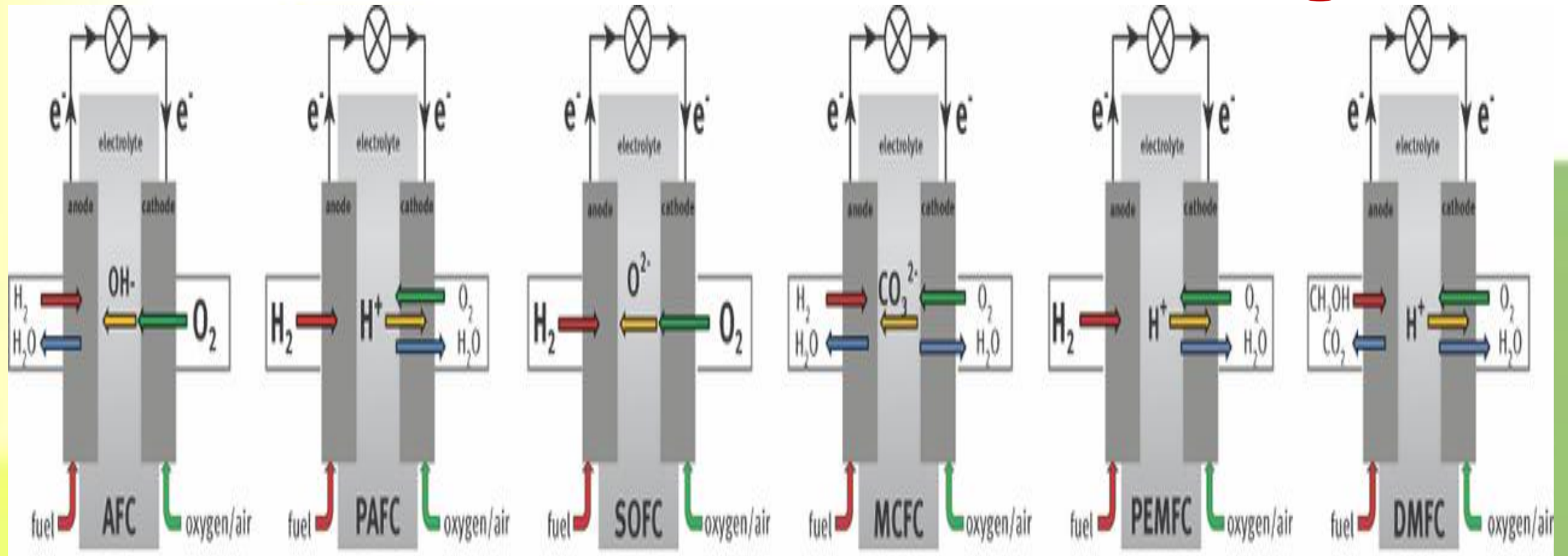
3.0 Fuel Cell

- Device to convert chemical energy directly into electrical energy;
- It comprises of two electrodes, Anode and Cathode separated by electrolyte;
- All fuel cells technologies require hydrogen and oxygen. Hydrogen gas and oxygen gas from the air are continually supplied to anode and cathode, respectively;
- At anode, hydrogen reacts with catalyst, producing positively charged protons (H^+) and negatively charged electrons (e^-);
- Electrolyte membrane allows only positive ions to pass through from anode to the cathode side and serve as insulator for electrons.

4.0 Types of Fuel Cells

Fuel Cell Type	AFC	PAFC	SOFC	MCFC	PEMFC	DMFC
Common electrolyte	Solution of potassium hydro	Phosphoric acid	Solid ceramic inorganico	Molten potassium or lithium carbonate	Solid polymeric protonex	Solid polymer membrane
Anode reaction	$2\text{H}_2 + 4\text{OH}^- \rightarrow 4\text{H}_2\text{O} + 4\text{e}^-$	$2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$	$2\text{O}_2 + 2\text{H}_2 \rightarrow 2\text{H}_2\text{O} + 4\text{e}^-$	$2\text{H}_2 + 2\text{CO}_3^{2-} \rightarrow 2\text{H}_2\text{O} + 2\text{CO}_2 + 4\text{e}^-$	$2\text{H}_2 \rightarrow 4\text{H}^+ + 2\text{e}^-$	$\text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + 6\text{H}^+ + 6\text{e}^-$
Cathode reaction	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$	$\text{O}_2 + 4\text{e}^- \rightarrow 2\text{O}_2^-$	$\text{O}_2 + 2\text{CO}_2 + 4\text{e}^- \rightarrow 2\text{CO}_3^{2-}$	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$	$3\text{O}_2 + 12\text{H}^+ + 12\text{e}^- \rightarrow 6\text{H}_2\text{O}$
Fuel	Pure H_2	Pure H_2	$\text{H}_2, \text{CO}, \text{CH}_4$, other hydro	$\text{H}_2, \text{CO}, \text{CH}_4$, other hydro carbons	Pure H_2	CH_3OH
Oxidant	O_2 in air	O_2 in air	O_2 in air	O_2 in air	O_2 in air	O_2 in air
Charge carrier	OH^-	H^+	O_2^-	CO_3^{2-}	H^+	H^+
Operating temperature (°C)	60–200	150–250	600–1000	600–700	50–200	60–200
Capacity (kW)	10–100	50–1000	<1–3000	<1–1000	<1–250	0.001–100
Electrical Efficiency (%)	60	>40	50–60	>50–60	35–45	30–40
Power density (Wm^{-2})	~1.0	0.8–1.9	0–1.5	1.5–2.6	3.8–6.5	1.0–2.0
Installation cost (US \$kW ⁻¹)	1800–1900	2100	3000	2000–3000	<1500	1500–1800

5.0 Chemical Reaction and Electron Migration



6.0 Fuel Cell for Mobility

6.1 Mobility

- By utilizing fuel cell technology with pure hydrogen as input, can benefit both, increased mileage and zero emissions;
- Fuel cell technology has the potential to revolutionize the mobility sector;
- Hydrogen based transportation will become reality in India soon;
- With large population of three-wheeler and two-wheeler, significant opportunity to transform, the transportation for people and goods, on a large scale;
- By utilizing a Proton Exchange Membrane, Fuel Cell (PEMFC) with hydrogen, a three-wheeler can achieve a range upto **200 km**, a bus can travel to **600 km**, and a heavy-duty truck can reach nearly, **1,000 km**.

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6.2 Technologies

- Combination of hydrogen fuel cells, advanced batteries and supercapacitors will be key technologies in the upcoming years.

6.3 Present Constraints

- Fuel cell technology has safety risk, especially associated with hydrogen storage;
- Fuel cell technology is expensive.

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6.4 Research and Development

- Low temperature PEMFC stacks;
- PEMFC using metal bipolar plates, fuel cell architecture, power train integration, control strategies and testing processes;
- Initial capital investment and total cost of ownership (TCO) for PEMFC systems are still very high;
- Indigenous technology development is the need of the hour;
- Development of stacks with increased power density and increased durability, which enable number of components and simplify system-level operations;
- Integration of stacks with suitable hydrogen generation system;
- Several companies are working on LTPEM and HTPEM fuel cells.



Thank You