Fuel Cells

Fuel cells: Introduction

Fuel cell characteristics

Thermodynamics of fuel cells

Fuel cell types

emphasis on PEM fuel cell

What Is a Fuel Cell?

Early 1839 William Grove discovered the basic operating principle of fuel cells, by reversing water electrolysis to generate electricity from Hydrogen and Oxygen.

The principle that he discovered remains unchanged today.

A fuel cell is an electrochemical “device” that continuously converts chemical energy into electric energy (and some heat) for as long as fuel and oxidant are supplied.

Unlike engines or batteries, a fuel cell does not need recharging, it operates quietly and efficiently.

When hydrogen is used as fuel it generates only power & drinking water, so emissions are zero.

The primary components of a FCs are:

1. an ion conducting electrolyte,
2. a cathode, and
3. an anode,
4. as shown schematically in Figures

1. Together, these three are often referred to as the simply a single-cell fuel cell.

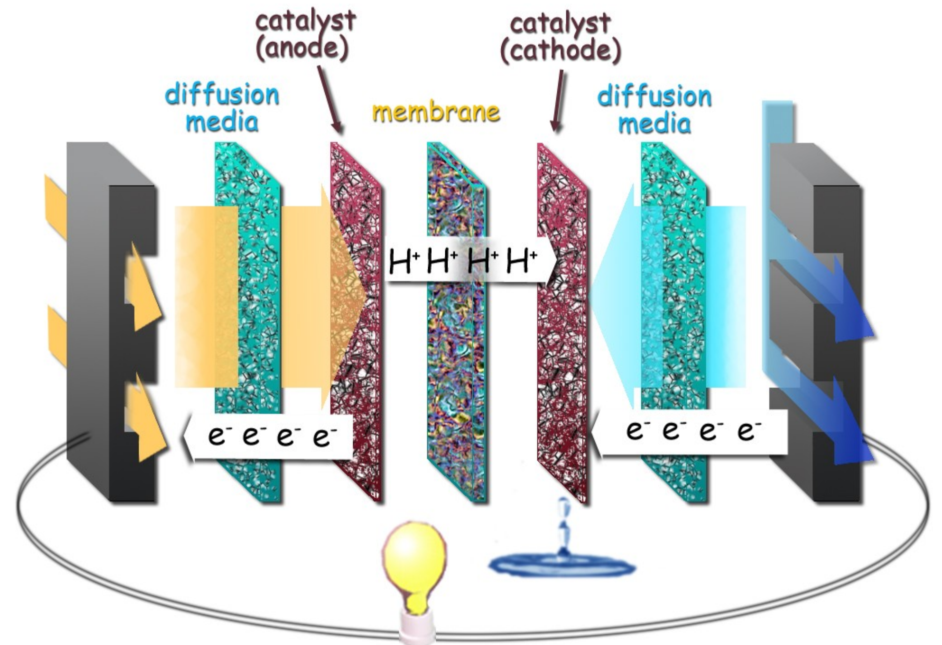
Electrode: a thin catalyst layer pressed between the ionomer membrane and porous, electrically conductive substrate.

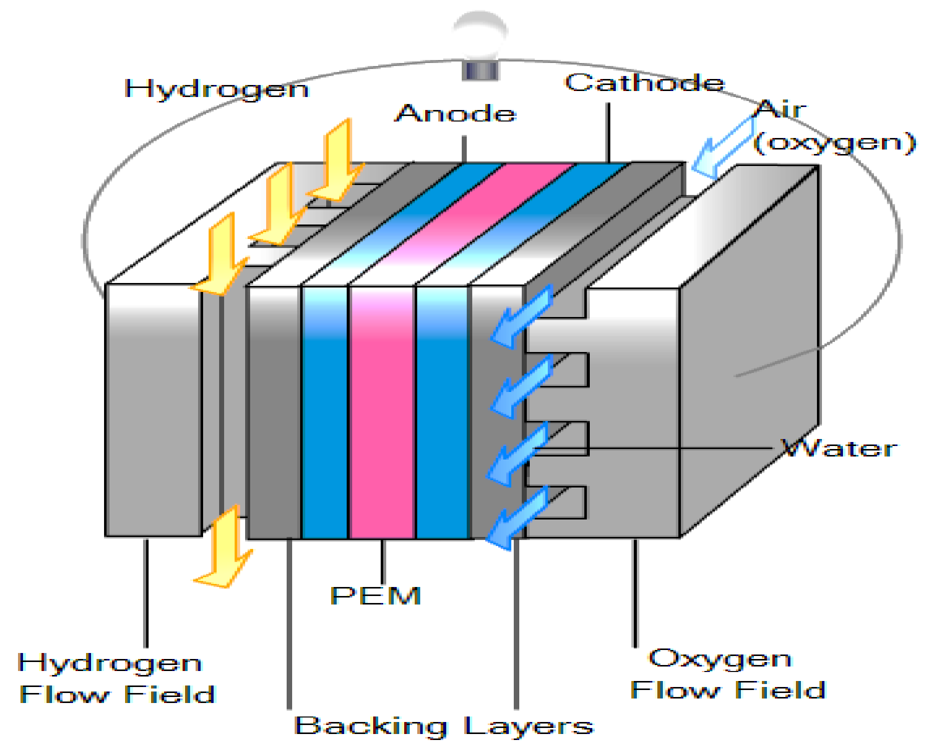
Electrolyte: A chemical compound that conducts ions from one electrode to the other inside a fuel cell.

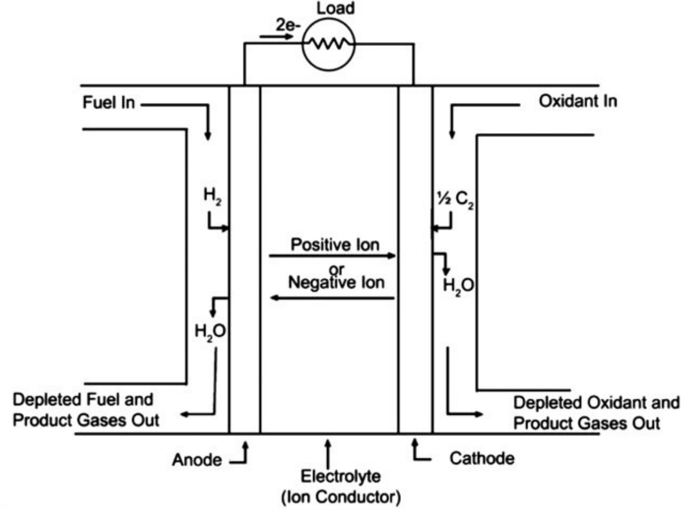
Catalyst: A substance that causes or speeds a chemical reaction without itself being affected.

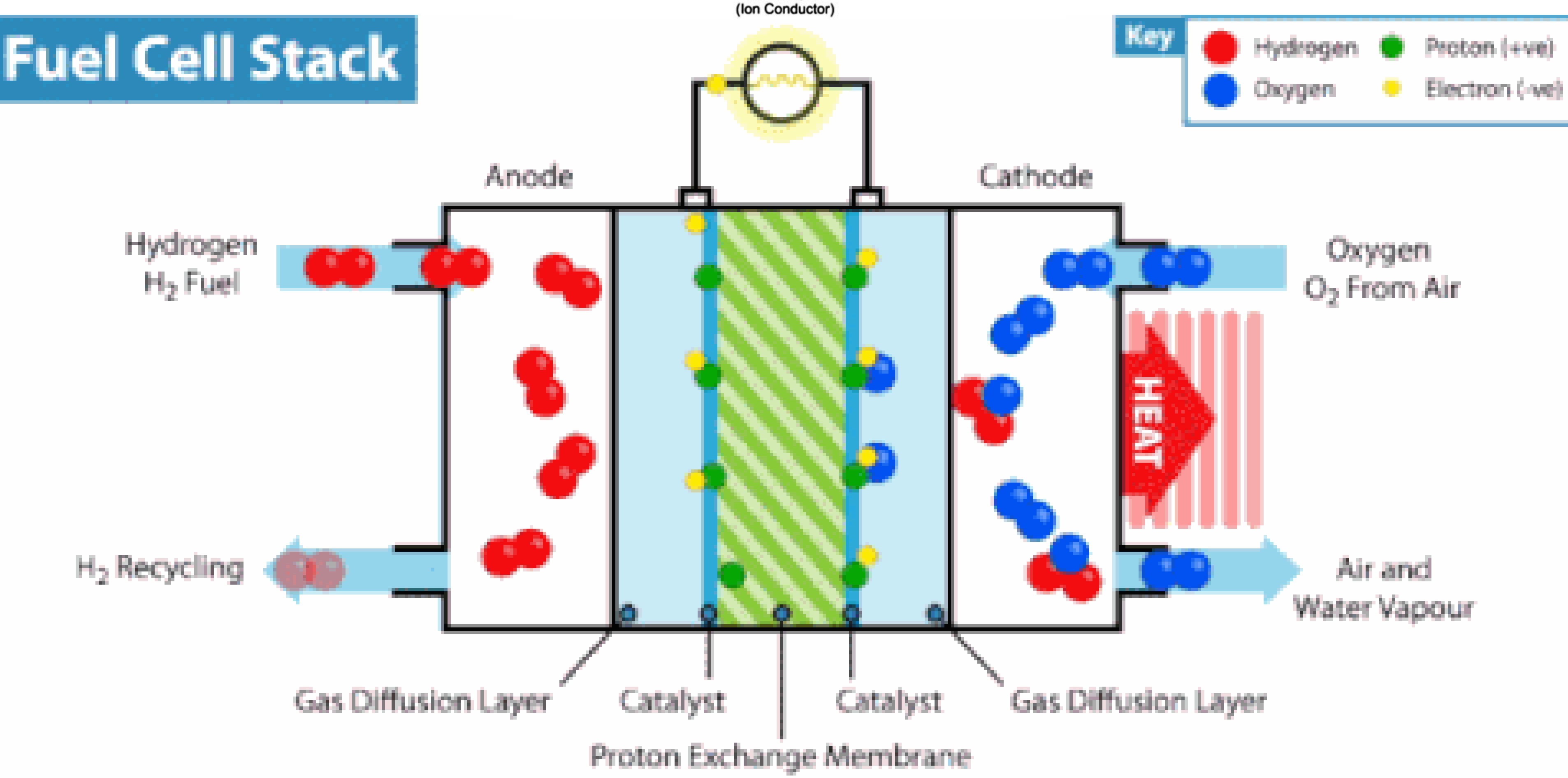
Bipolar plates: connecting the anode of one cell to the cathode of the adjacent cell.

Gas diffusion layer: a layer between the catalyst layer and bipolar plates, also called electrode substrate or diffusor/current collector.

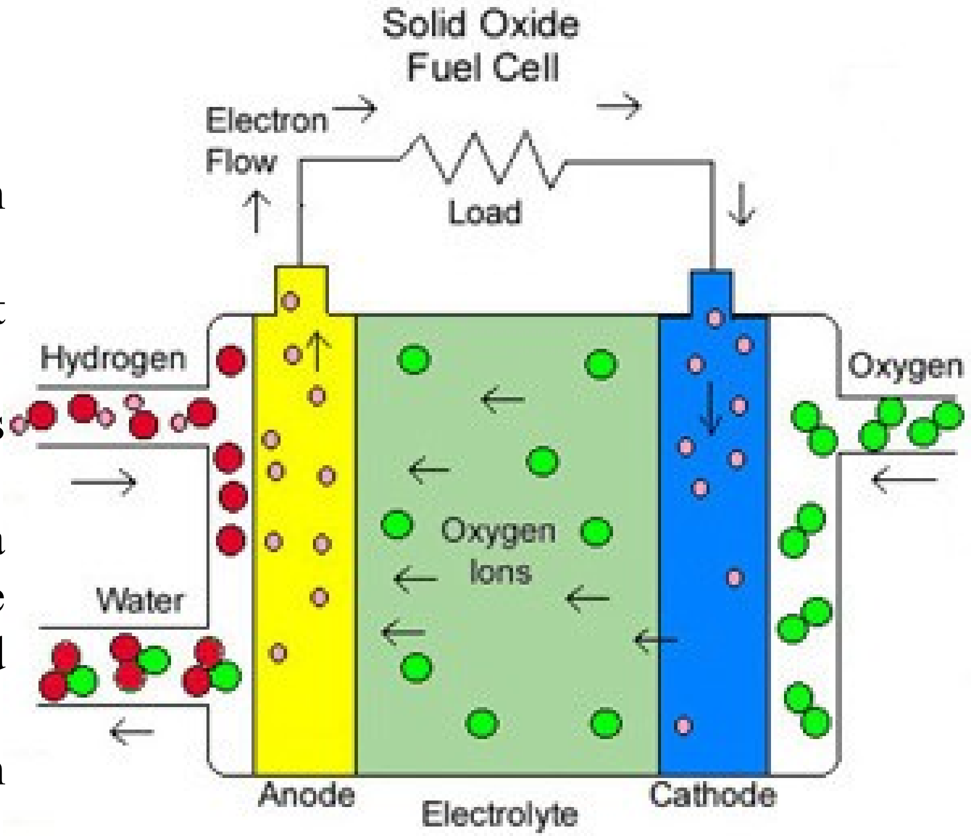





Load
2e-
Fuel In
Oxidant In
H_2
½ C_2
Positive Ion
or
Negative Ion
H_2O
H_2O
Depleted Fuel and
Product Gases Out
Depleted Oxidant and
Product Gases Out
Anode
Electrolyte
(Ion Conductor)
Cathode


Fuel Cell Stack
Key
Hydrogen
Proton (+ve)
Oxygen
Electron (-ve)
Anode
Cathode
Hydrogen
H_2 Fuel
Oxygen
O_2 From Air
HEAT
H_2 Recycling
Air and
Water Vapour
Gas Diffusion Layer
Catalyst
Catalyst
Gas Diffusion Layer
Proton Exchange Membrane

How does Fuel cell work:



1. It is an electrochemical energy conversion device.
2. This works like batteries, but they do not run down or need recharging.
3. They produce electricity and heat if fuel is supplied.
4. A fuel cell consists of two electrodes - a negative electrode (or anode) and a positive electrode (or cathode) - sandwiched around an electrolyte.
5. The atoms are stripped of their electrons in the anode.
6. The positively charged protons pass through the membrane to the cathode and the negatively charged electrons are forced through a circuit, generating electricity.
7. After passing through the circuit, the electrons combine with the protons and Oxygen from the air to generate the fuel cells by products water and heat.

The fuel cell can be represented as:

1. At anode $H_2 \rightarrow 2H^+ + 2e^-$
2. At Cathode $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
3. Overall reaction $H_2 + \frac{1}{2} O_2 = H_2O$

1. The **anode**, the **negative** post of the fuel cell, has several jobs.
2. It conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.
3. The cathode, the positive post of the fuel cell, has channels etched into it that distribute the oxygen to the surface of the catalyst.
4. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.
5. The electrolyte is the proton exchange membrane.
6. This specially treated material, which looks something like ordinary kitchen plastic wrap, only conducts positively charged ions.
7. The membrane blocks electrons. For a PEMFC, the membrane must be hydrated in order to function and remain stable.
8. The catalyst is a special material that facilitates the reaction of oxygen and hydrogen.
9. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth.
10. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen.
11. The platinum-coated side of the catalyst faces the PEM.

Fuel cell Basic Chemistry & Thermodynamics

- Fuel + oxidant → H_2O + other products + electricity
- $H_2 + ½ O_2 \rightarrow H_2O$, $\Delta H = 286$ kJ/mol
- Enthalpy that can be converted to electricity in a fuel cell corresponds to Gibbs free energy.
- $\Delta G = \Delta H - T\Delta S$
- $W_{el} = qE = nFE$
- $W_{el} = -\Delta G$
- $E_{theo} = \frac{-\Delta G}{nF} = \frac{237{,}340\ J/mol}{2 \times 96{,}485\ As/mol} = \mathbf{1.23\ V}$

Classification of Fuel cells:

1. **Primary fuel cell:** The reactants are passed through the cell only once and the products of the reaction being discarded. (H_2 - O_2 fuel cell)
2. **Secondary fuel cell:** The reactant are passed through the fuel cell many times because they are generated by different methods. (Nitric oxide – Chlorine fuel cell)

According to the Application:

3. **Stationary,**
4. **Portable**
5. **Mobile**

According to the Operating temperature:

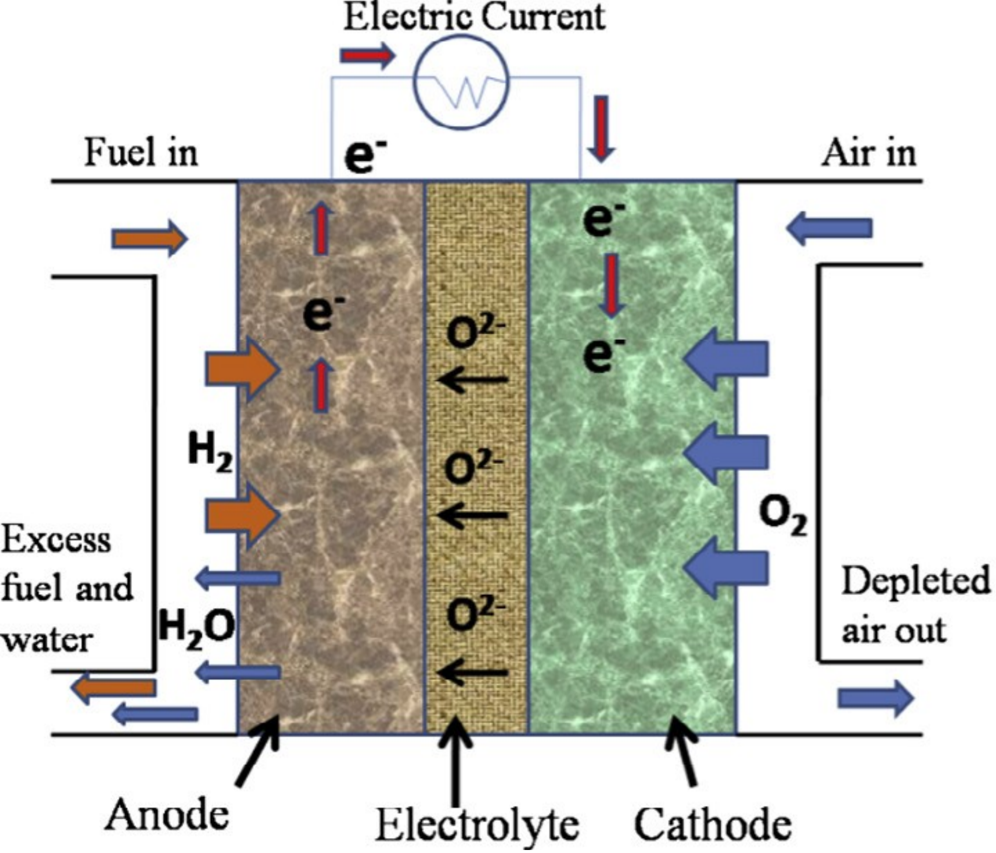
6. **Low temperature (25 to 100°C)**
   Proton exchange membrane fuel cell (PEMFC), Direct methanol fuel cell (DMFC)
7. **Medium temperature (100 to 500°C)**
   Alkaline Electrolyte fuel cell, Phosphoric acid Fuel cell (PAFC)
8. **High temperature (500 to 1000°C)**
   Molten Carbonate fuel cell (MCFC), Solid Oxide Fuel Cell (SOFC)
4. **Very high temperature (>1000 °C)**

According to the type of electrolyte:

5. **Aqueous**
6. **Non-aqueous**
7. **Molten or solid**

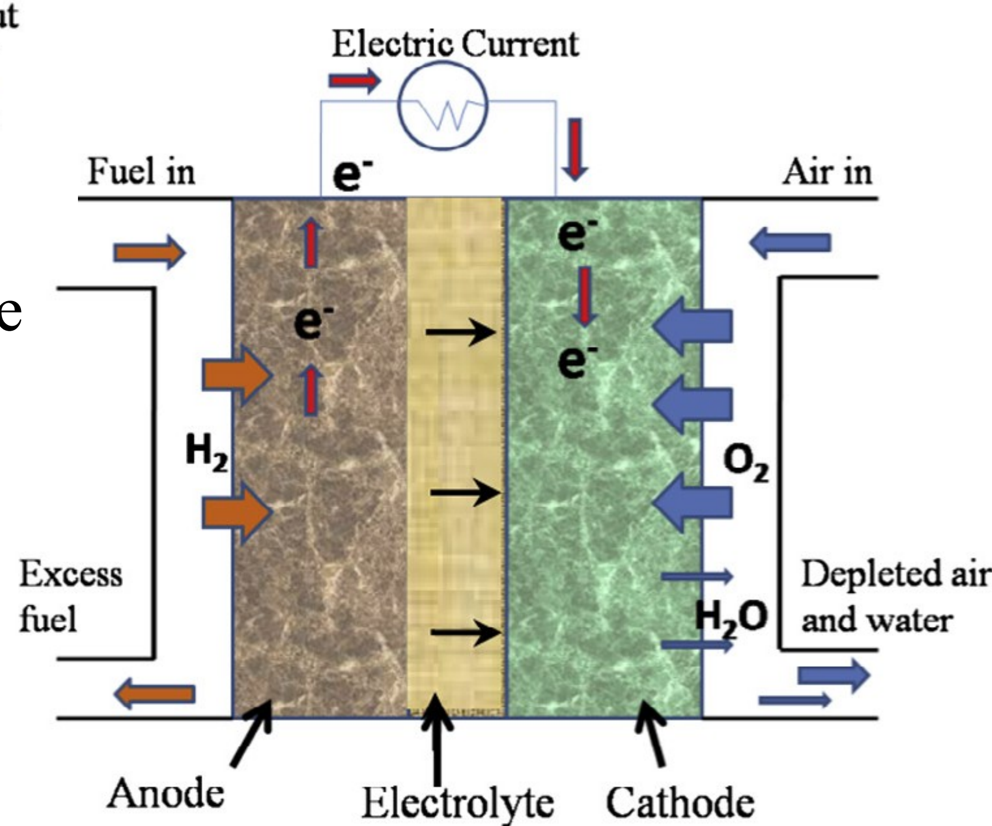
According to the physical state of fuel:

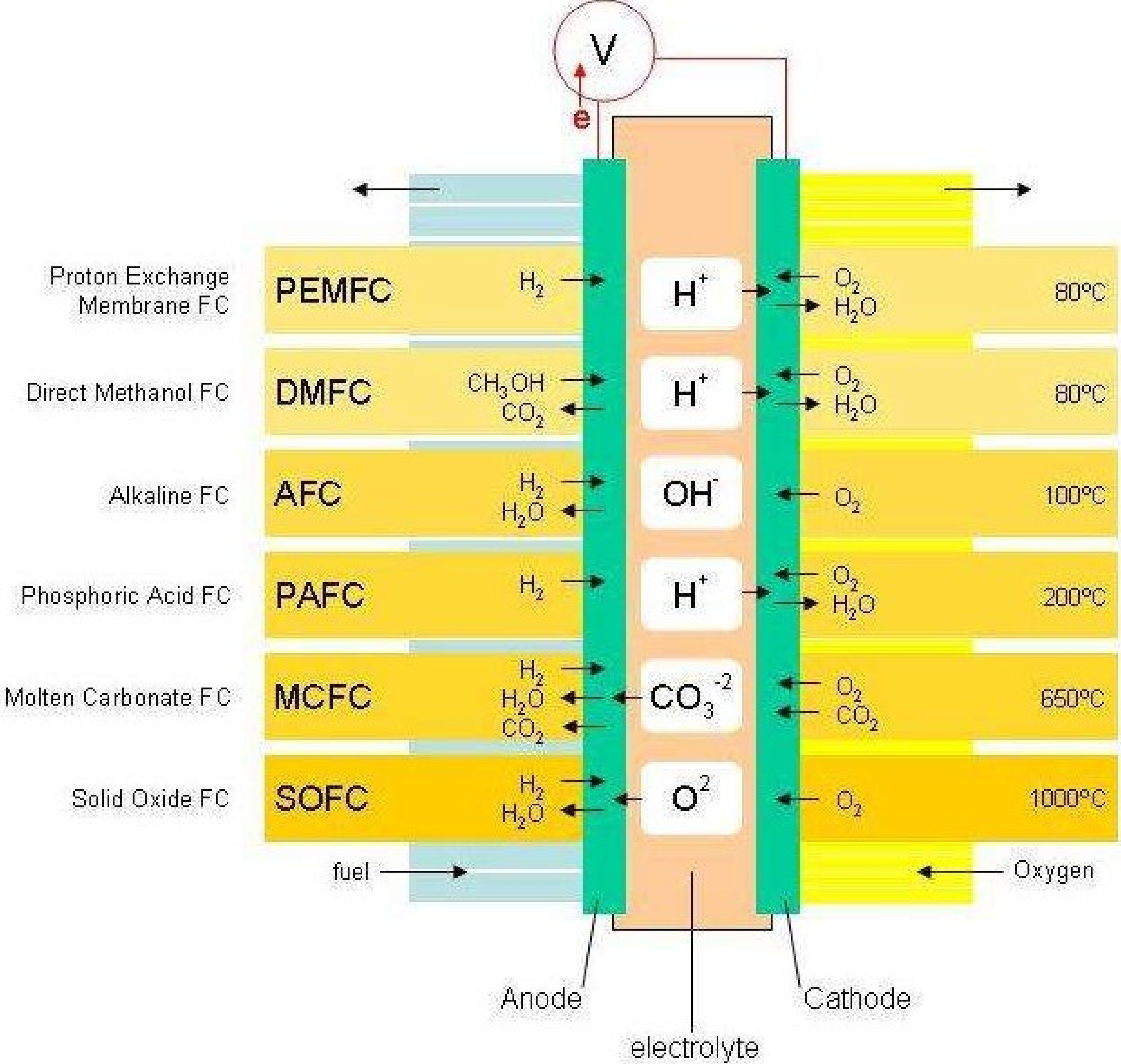
8. **Gas (Hydrogen, Lower hydrocarbons)**
9. **Liquid (Alcohols, Hydrazine, higher hydrocarbons)**
10. **Solid (metals)**



a. oxide-ion conducting electrolyte

b. proton conducting electrolyte



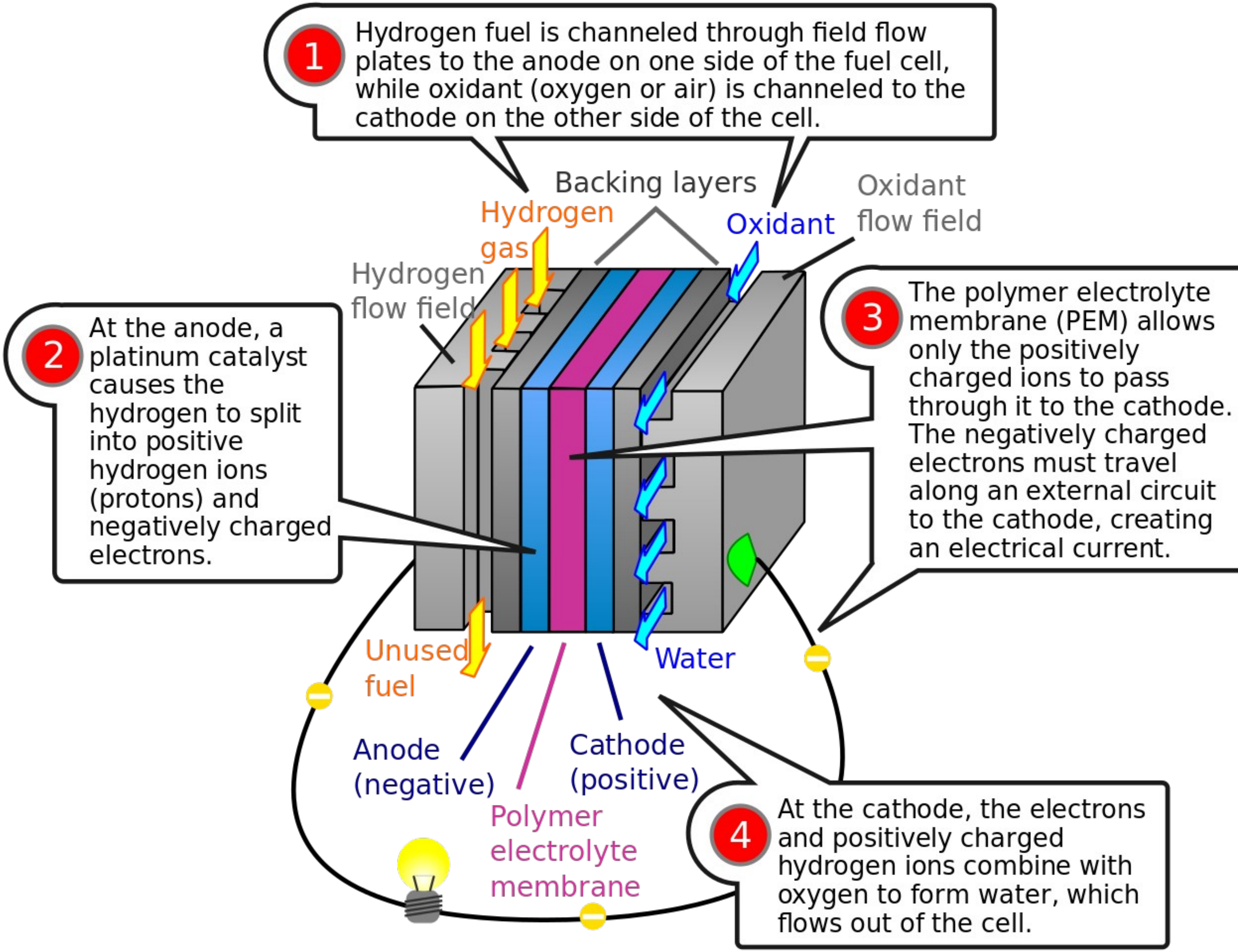

V
e
Proton Exchange Membrane FC
PEMFC
H_2
H^+
O_2
H_2O
80°C
Direct Methanol FC
DMFC
CH_3OH
CO_2
H^+
O_2
H_2O
80°C
Alkaline FC
AFC
H_2
H_2O
OH^-
O_2
100°C
Phosphoric Acid FC
PAFC
H_2
H^+
O_2
H_2O
200°C
Molten Carbonate FC
MCFC
H_2
H_2O
CO_2
CO_3^{-2}
O_2
CO_2
650°C
Solid Oxide FC
SOFC
H_2
H_2O
O^2
O_2
1000°C
fuel
Oxygen
Anode
electrolyte
Cathode

Fuel Cell	Electrolyte	Qualified Power (W)	Working Temperature (°C)	Electrical Efficiency	Status
Alkaline fuel cell	Aqueous alkaline solution (e.g., potassium hydroxide)	10 kW to 100 kW	60-120	35-55	Commercial/Research
Direct methanol fuel cell	Polymer membrane (ionomer)	100 kW to 1 mW	60-200	20-30	Commercial/Research
Phosphoric acid fuel cell	Molten phosphoric acid (H_3PO_4)	up to 10 MW	150-220	40	Commercial/Research
Molten carbonate fuel cell	Molten alkaline carbonate (e.g., sodium bicarbonate $NaHCO_3$)	100 MW	600-650	>50	Commercial/Research
Solid oxide fuel cell	O^{2-}-conducting ceramic oxide (e.g., zirconium dioxide, ZrO_2)	up to 100 MW	700–1000	>50	Commercial/Research
Proton exchange membrane fuel cell	Polymer membrane (ionomer) (e.g., Nafion® or Polybenzimidazole fiber)	100 W to 500 kW	50-100	35-45	Commercial/Research

Characteristics of Fuel Cells

Fuel Cells	Attractive Attributes	Undesirable Attributes
Phosphoric Acid Fuel Cell (PAFC).	-Low temperatures suitable for portable device applications -Ability for variable power output -Broad fuel choice	-Uses expensive platinum as a catalyst. -Electrolyte is poor conductor at low temperatures
Proton Exchange Membrane Fuel Cell (PEM).	-Low operating temperature suitable for transportation and portable devices -High power density	-Uses expensive platinum as a catalyst -Sensitivity to fuel impurities
Molten Carbonate Fuel Cell (MCFC)	-High operating temperature improves efficiency for base load power plants.	-Not suitable for small-sized applications
Solid Oxide Fuel Cell (SOFC)	-High operating temperature improves efficiency for base load power plants. -Solid electrolyte improves conductivity	- Electrolyte is made from ceramics and solid zirconium oxide that is a rare mineral
Alkaline Fuel Cells (AFC)	-Low temperature and high fuel-to-electricity efficiency	-Requirement of pure hydrogen and allergic to carbon dioxide
Direct Methanol Fuel Cells (DMFC).	-Eliminates need for fuel reformer drawing hydrogen directly from the anode -Low temperatures suitable for portable devices	-Fuel crossing from anode to cathode without producing electricity

Proton exchange membrane fuel cell



Hydrogen Fuel cell vs Battery

S No	Hydrogen Fuel Cell	Galvanic Cell (Battery)
01	Open system	Closed system
02	Anode and cathode are gases make contact with a platinum catalyst.	Anode and cathode are metals.
03	Reactants are externally supplied, no recharging required.	Reactants are internally conducted, require periodic recharging.

Advantages of Fuel cells:

1. These are eco-friendly
2. High conversion efficiency
3. Extremely low emissions
4. Noise less operations so readily accepted in residential areas
5. Availability to use at any location. So less transmission and distribution losses.
6. No requirements of cooling tower as conventional plants
7. Less space is require as compared to conventional plants

Disadvantages of Fuel cells:

1. Higher initial cost
2. Lower service life
3. Fuelling fuel cells is still a major problem since the production, transportation, distribution and storage of hydrogen is difficult.
4. The technology is not yet fully developed, and few products are available.
5. Fuel cells are currently very expensive to produce, since most units are hand made.