CH1002 Energy Management in Chemical Industries

Unit - VI

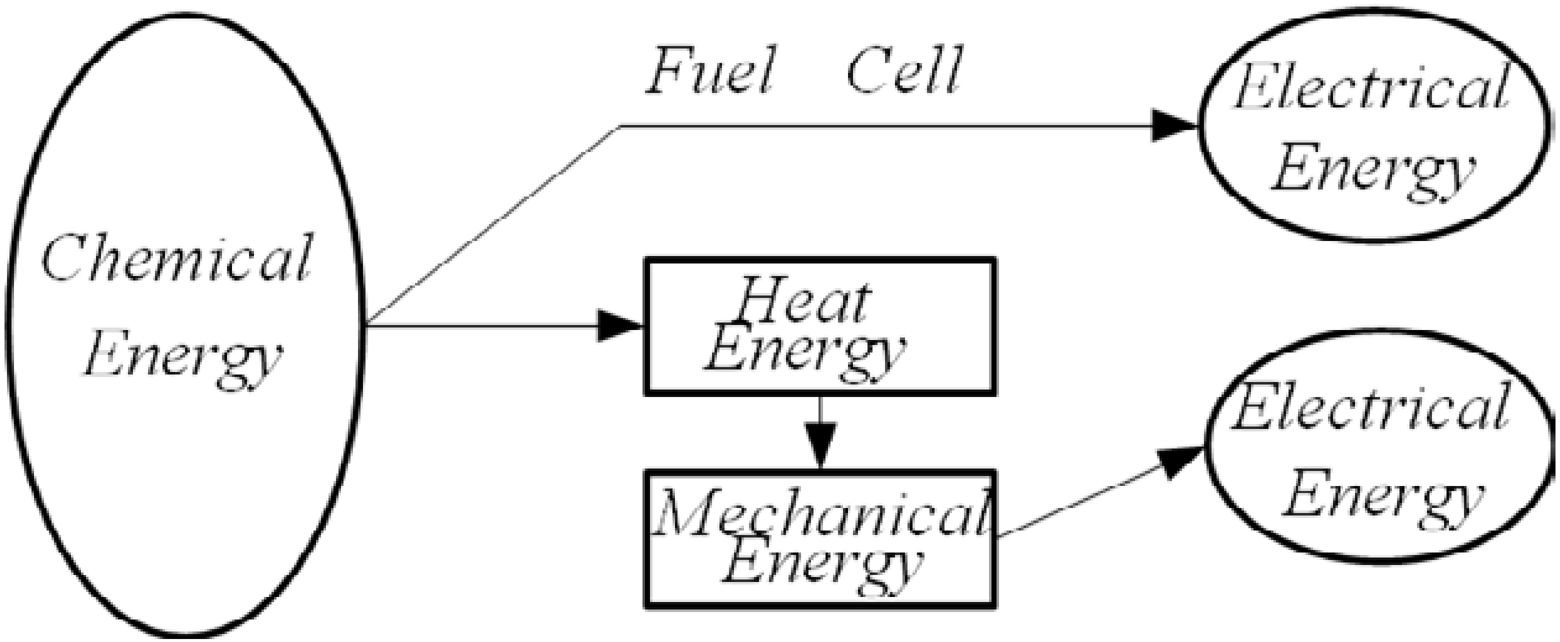
Fuel Cell

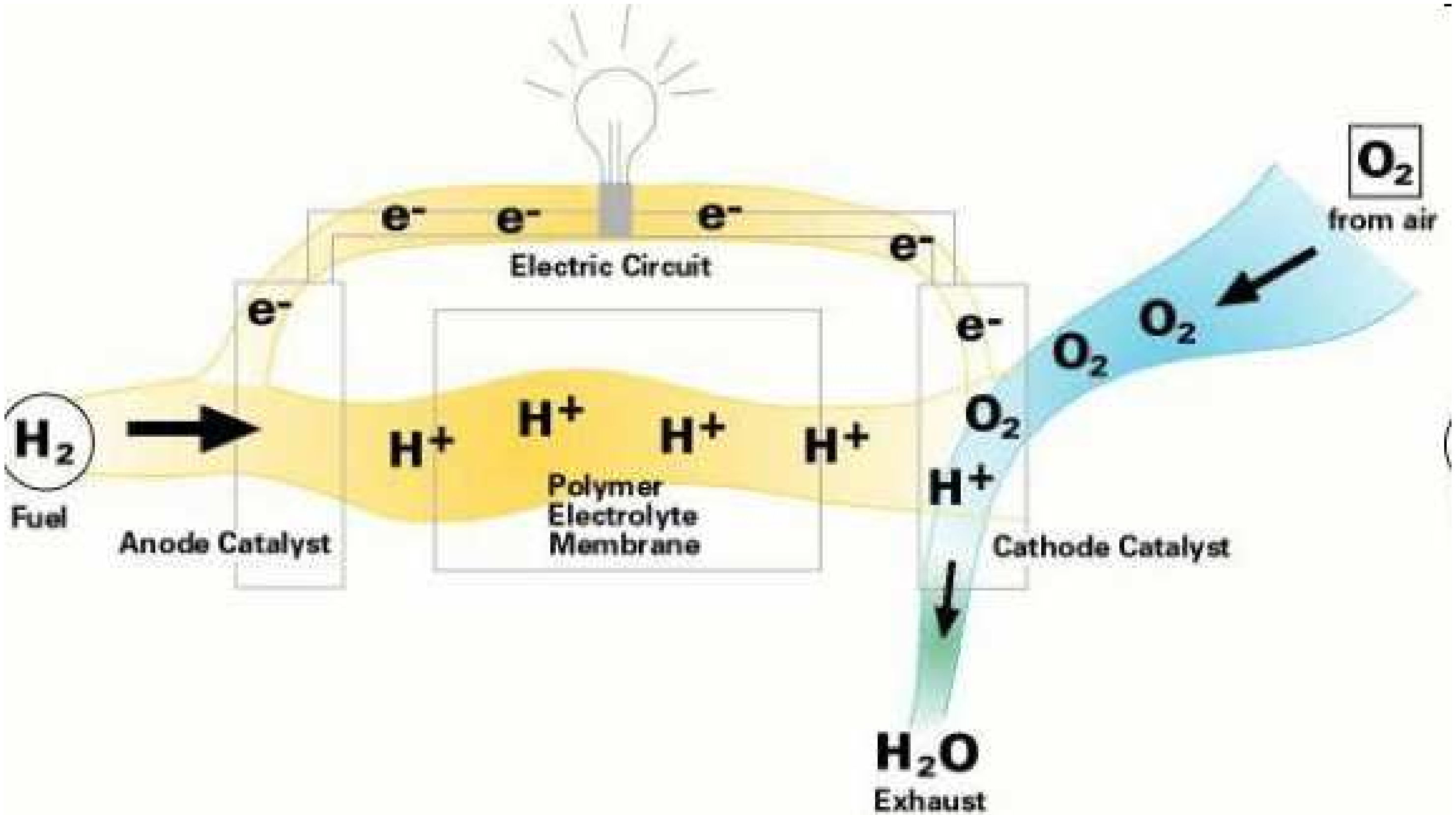
Dr. M. Subramanian

Associate Professor
Department of Chemical Engineering
Sri Sivasubramaniya Nadar College of Engineering
Kalavakkam – 603 110, Kanchipuram (Dist)
Tamil Nadu, India
subramanianm@ssn.edu.in

Introduction

- A fuel cell is an electrochemical device that converts the chemical energy of a fuel and oxidant directly into electric energy.
- Such a direct one-step conversion avoids the inefficient multistep processes involved in heat engines via combustion, thus eliminating the emission of chemical pollutants. Besides being efficient and clean, fuel cells are also compatible with renewable energy sources and carriers for sustainable development and energy security.
- Fuel cells offer additional advantages for both mobile and stationary applications, including quiet operation without vibration and noise; they are therefore candidates for onsite applications. Their inherent modularity allows for simple construction and operation with possible applications for dispersed, distributed, and portable power generation.


Fuel Cell
Electrical Energy
Chemical Energy
Heat Energy
Mechanical Energy
Electrical Energy



e-
e-
e-
e-
Electric Circuit
O2
from air
e-
e-
O2
O2
H2
H+
H+
H+
H+
O2
H+
Fuel
Anode Catalyst
Polymer
Electrolyte
Membrane
Cathode Catalyst
H2O
Exhaust

Fuel Cell Classification

- Fuel cells are often named by the nature of their electrolyte. There are presently six major fuel cell technologies at varying stages of development and commercialization:
  - Alkaline fuel cells (AFC)
  - Polymer-electrolyte-membrane fuel cells (PEMFC)
  - Direct-methanol fuel cells (DMFC)
  - Phosphoric-acid fuel cells (PAFC)
  - Molten-carbonate fuel cells (MCFC)
  - Solid-oxide fuel cells (SOFC)

- Five of these are classified based on their electrolytes used, including the alkaline, phosphoric-acid, polymer-electrolyte-membrane, molten-carbonate, and solid-oxide fuel cell. The direct-methanol fuel cell is classified based on the fuel used for electricity generation.

Principle of Operation

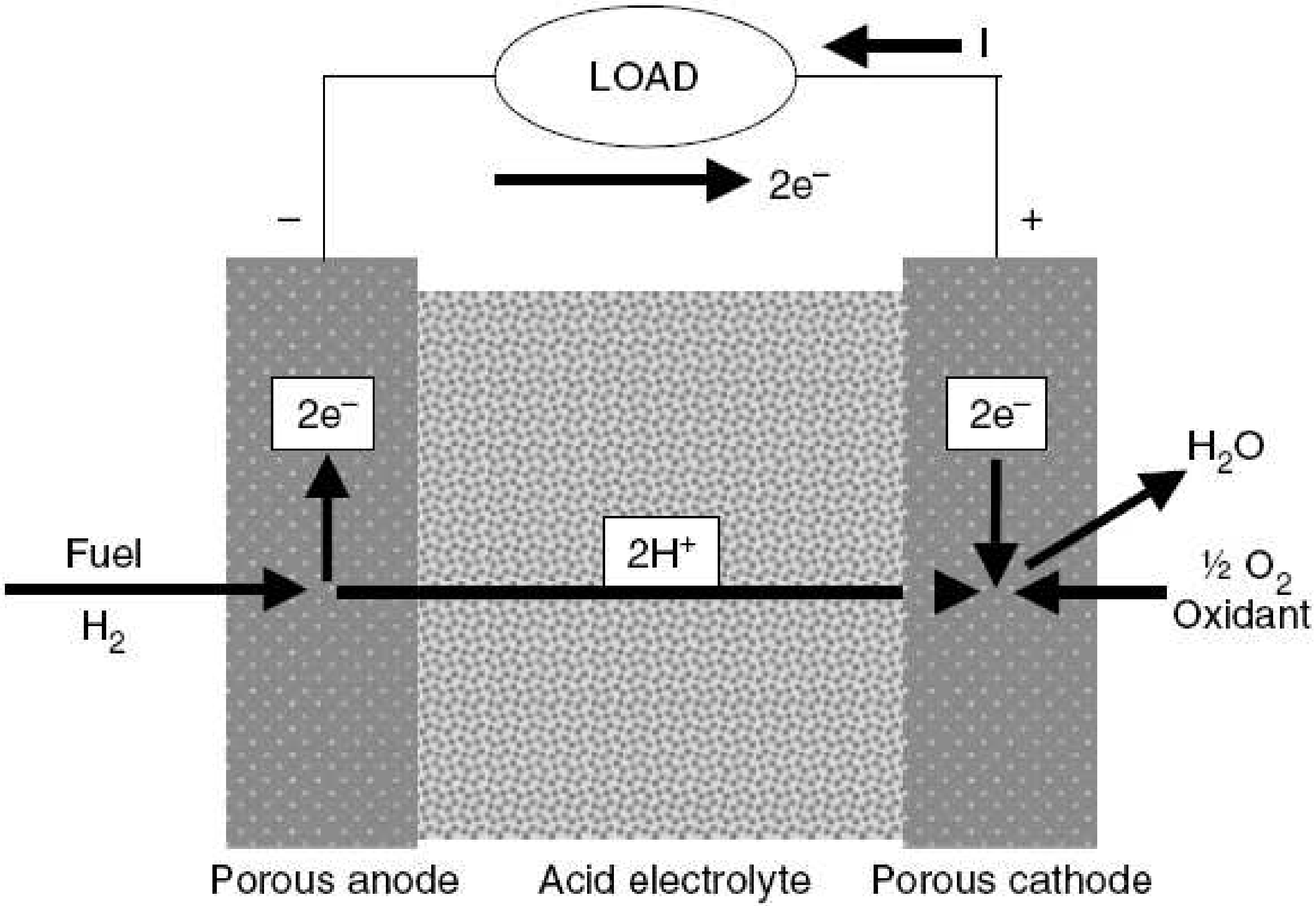
- A fuel cell is composed of three active components: a fuel electrode (anode), an oxidant electrode (cathode), and an electrolyte sandwiched between them.

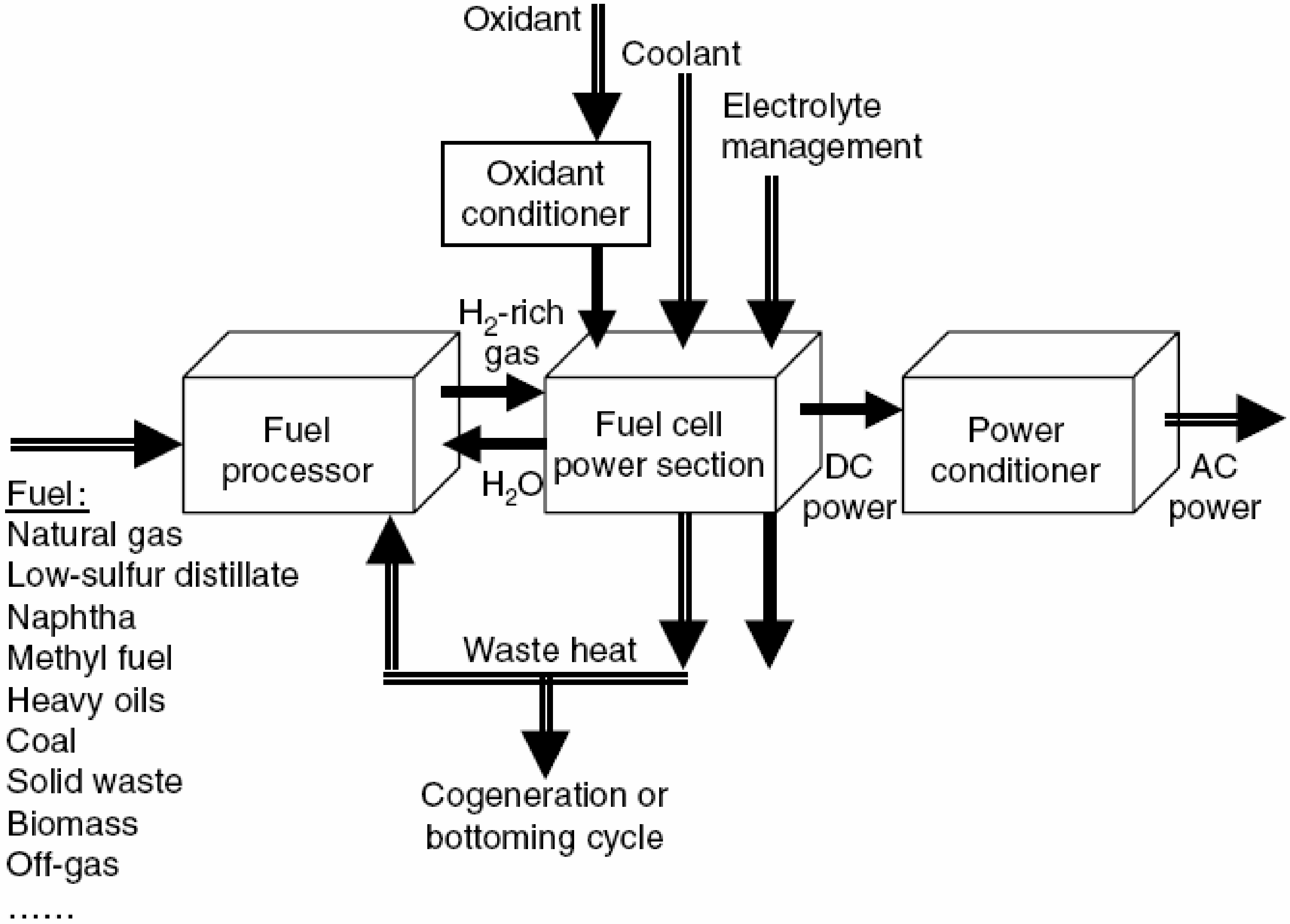
$$\text{Anode reaction}: \; H_2 \Rightarrow 2H^+ + 2e^-$$

$$\text{Cathode reaction}: \; \frac{1}{2}O_2 + 2H^+ + 2e^- \Rightarrow H_2O$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \text{Heat Generated} + \text{Electric Energy}.$$

- Although the half-cell reactions may be quite different in different types of fuel cells (described later), the overall cell reaction remains the same as the equation shown above.

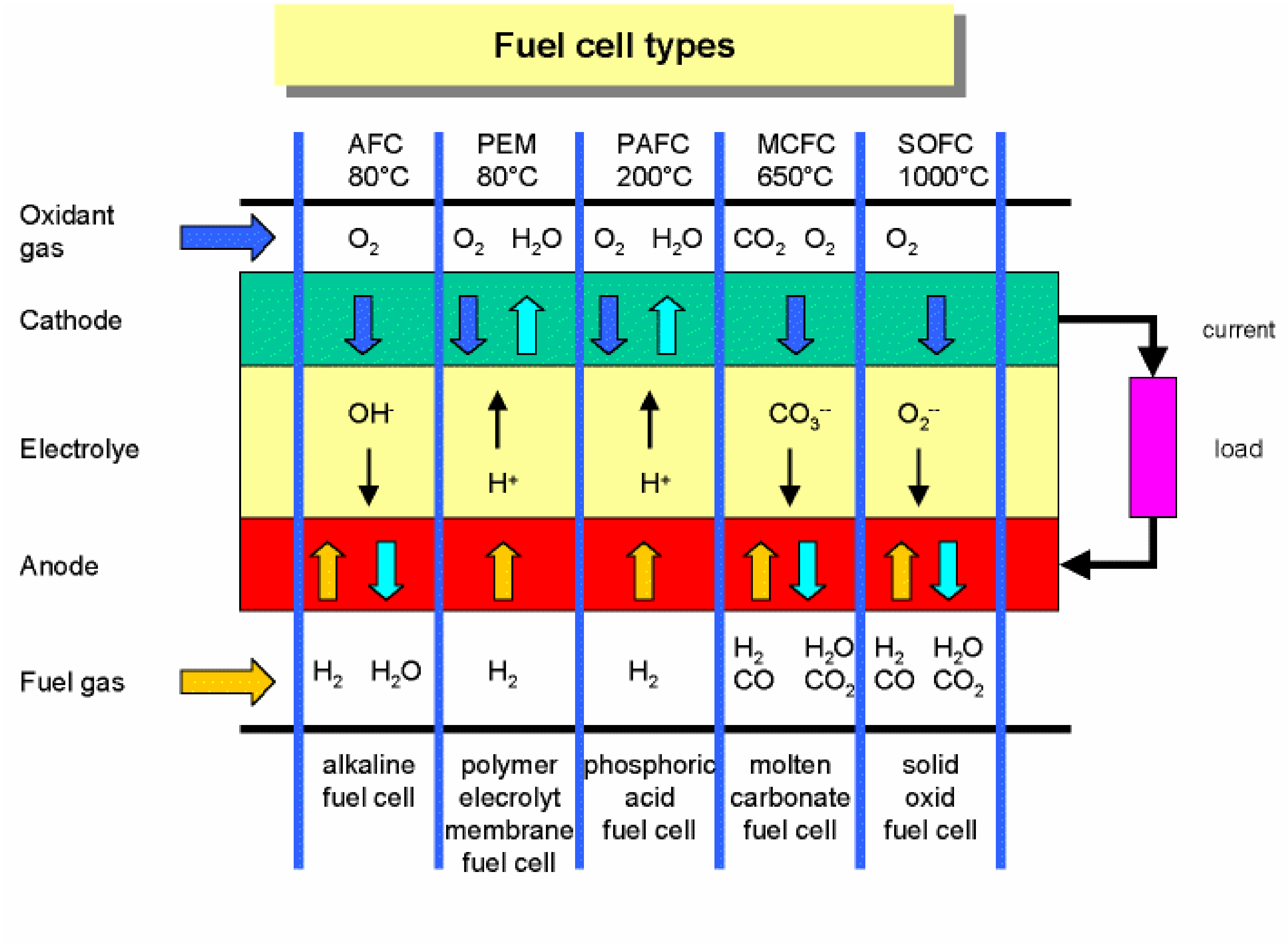

LOAD
I
2e⁻
–
+
2e⁻
2e⁻
H2O
Fuel
2H+
½ O2
Oxidant
H2
Porous anode
Acid electrolyte
Porous cathode


Oxidant
Coolant
Electrolyte management
Oxidant conditioner
H2-rich gas
Fuel processor
Fuel cell power section
H2O
DC power
Power conditioner
AC power
Fuel :
Natural gas
Low-sulfur distillate
Naphtha
Methyl fuel
Heavy oils
Coal
Solid waste
Biomass
Off-gas
……
Waste heat
Cogeneration or bottoming cycle

Cell Potential

- If pure hydrogen and oxygen are used as reactants to form water as product, then the standard potential of cell is 1.229 V for the product water in liquid form, 1.185 V if the product water is in vapor form.

- The potential of a working cell is typically around 0.7 - 0.8 V, and it is normally too small for practical applications because of the limited power available from a single cell. Therefore, many individual cells are connected (or stacked) together to form a fuel cell stack.



Fuel cell types
AFC 80°C
PEM 80°C
PAFC 200°C
MCFC 650°C
SOFC 1000°C
Oxidant gas
O2
O2 H2O
O2 H2O
CO2 O2
O2
Cathode
current
OH-
H+
H+
CO3--
O2--
Electrolye
load
Anode
Fuel gas
H2 H2O
H2
H2
H2 H2O CO CO2
H2 H2O CO CO2
alkaline fuel cell
polymer elecrolyt membrane fuel cell
phosphoric acid fuel cell
molten carbonate fuel cell
solid oxid fuel cell

Type	Technology Characteristics			
	Electrolyte	Operating Temperature	Efficiency (HHV)	Power Density
AFC	Potassium Hydroxide	50-200C	45-60% up to 70 with CHP	0.7-8.1kW/m2
PEM	Polymer	50-100C	35-55%	3.8-13.5.1kW/m2
DMFC	Polymer Membrane	50-200C	40-50% up to 80% with CHP	1-6kW/m2
PAFC	Phosphoric Acid	160-210C	40-50%	0.8-1.9 kW/m2
MCFC	Lithium or potassium carb0nate	800-800C	50-60% up to 80% with CHP	0.1-1.5 kW/m2
SOFC	Ceramic composed of calcium or zirconium oxides	500-1000C	50-65% up to 75% with CHP	1.5-5.0 kW/m2

Type	Fuel Source		Technology Development			
	Fuels	Reforming	Stage of Development	Materials	Issues	Uses
AFC	H2	External	Mature technology	Platinum catalyst	Requires very little H2	Space vehicles
PEM	H2, reformate	External	Prototype	Platinum catalyst	Small amounts of CO will poison catalyst	Automobiles, busses
DMFC	Methanol, ethanol, gasoline	Not required	Prototype	Platinum catalyst		Small CHP, transportation, portable
PAFC	H2, reformate	External	Commercially available	Platinum catalyst	Sulfur must be removed if fuel is gasoline	Medium CHP, buses
MCFC	H2, CO, reformate	External or internal	Full-scale demonstration	Nickel catalyst	High temperature means more resistance to CO poisoning	Large CHP
SOFC	H2, CO2, CH4,	External or internal	Protoype	Ceramic		All sizes of CHP

Technological Status

- **AFC**s have the best performance when operating on pure hydrogen and oxygen, its intolerance of carbon dioxide hinders its role for terrestrial applications.

- **PEMFCs -** Significant progress is being made for PEMFC, although it is still too expensive to be competitive in the marketplace. However, the PEMFC is believed to be the most promising candidate for transportation applications because of its high power density, fast startup, high efficiency, and easy and safe handling. But until its cost is lowered by at least orders of magnitude, it will not be economically acceptable.

- **DMFCs** - due to the difficulty of on-board fuel (hydrogen) storage and the lack of infrastructure for fuel (hydrogen) distribution, DMFCs are believed by some to be the most appropriate technology for vehicular application.

Technological Status (contd.)

- **PAFC**s - this is the most commercially developed fuel cell, operating at intermediate temperatures. PAFCs are being used for combined heat and power applications with high energy efficiency.

- **MCFC**s and **SOFC**s - The high-temperature fuel cells like MCFCs and SOFCs may be most appropriate for cogeneration and combined cycle systems (with gas or steam turbine as the bottoming cycle).
  - The MCFCs have the highest energy efficiency attainable from methane to electricity conversion in the size range of 250 kW to 20 MW; whereas the SOFCs are best suited for baseload utility applications operating on coal-derived gases.
  - It is estimated that the MCFC technology is about five to ten years away from commercialization, and the SOFCs are probably years afterwards.

References

- Goswami, and Kreith, Energy Conversion, CRC Press, 2008.