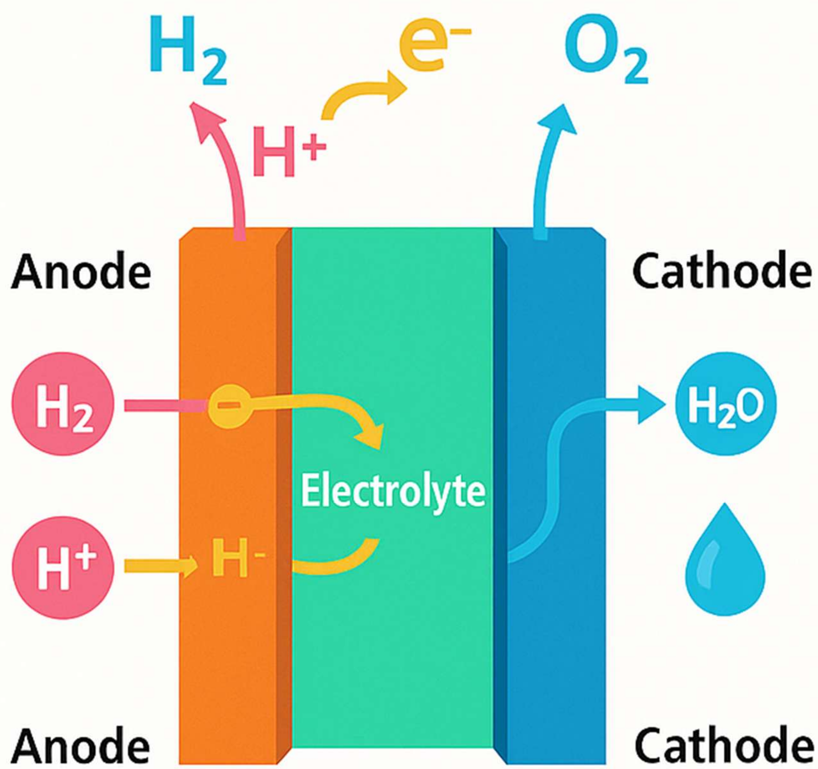
Hydrogen Fuel Cell

Department of New and Renewable Energies

2025–2026



Asst. Prof.

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Electrochemical Principles and Fuel Cell Basics

1. Introduction to Electrochemical Reactions

Electrochemical reactions form the foundation of fuel cell operation. Oxidation refers to the loss of electrons, while reduction refers to the gain of electrons. In a fuel cell, hydrogen oxidation at the anode and oxygen reduction at the cathode are coupled to generate electricity.

Example reaction in PEMFC:

Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

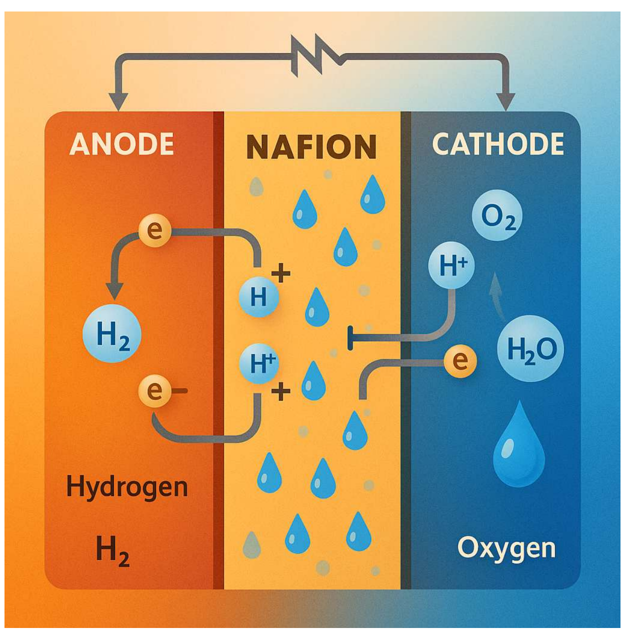
Overall: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

2. Role of Electrodes and Electrolytes

Electrodes serve as reaction sites for fuel and oxidant. The anode enables hydrogen oxidation, while the cathode supports oxygen reduction. Electrolytes conduct ions, ensuring charge balance. PEMFCs use proton-conducting membranes, while SOFCs use ceramic electrolytes for oxygen ion conduction.

3. Proton Exchange vs Ion Conduction

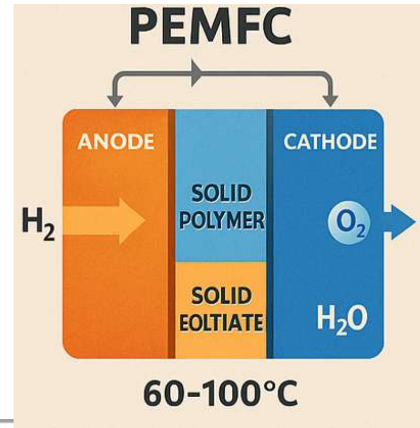
In PEMFCs, protons migrate through the polymer electrolyte membrane (e.g., Nafion). In SOFCs, O^{2-} ions travel through a ceramic material (yttria-stabilized zirconia). These mechanisms define operating temperatures and material choices.



Hydrogen fuel cell illustrates Nafion as . Proton Exchange membrane

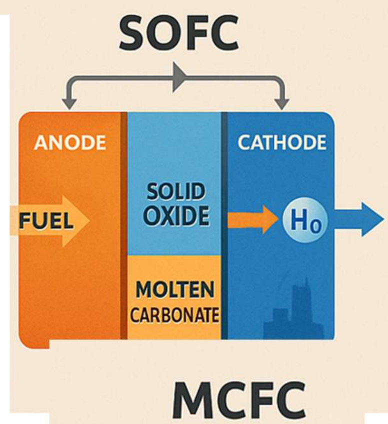
4. Types of Fuel Cells – Overview

4.1 PEMFC (Proton Exchange Membrane Fuel Cell)



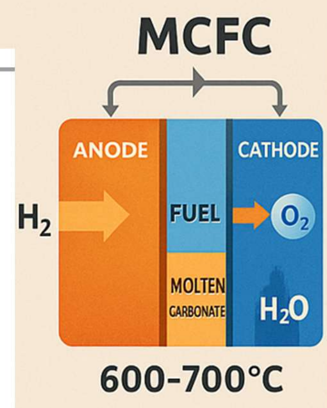
- Electrolyte: Solid polymer (e.g., Nafion).
- Operating Temp: Low (60–90 °C).
- Efficiency: 40–50%.
- Applications: Cars, buses, portable power.
- Pros: Quick start-up, compact, clean.
- Cons: Needs pure hydrogen, costly catalysts (Pt).

4.2 . SOFC (Solid Oxide Fuel Cell)



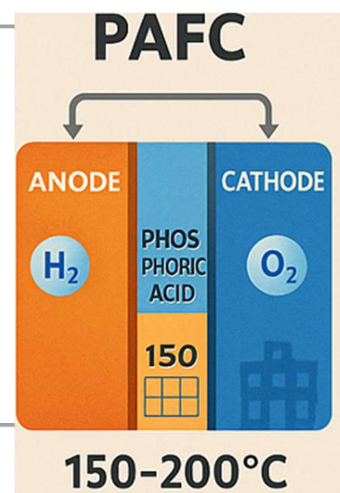
- Electrolyte: Solid ceramic (e.g., Yttria-stabilized zirconia).
- Operating Temp: Very high (600–1,000 °C).
- Efficiency: 45–65% (up to 85% with CHP).
- Applications: Stationary power, large-scale electricity,
- combined heat & power (CHP).
- Pros: Can use different fuels (H_2, CO, hydrocarbons).
- Cons: Slow start-up, high temp materials challenges.

4.3 . MCFC (Molten Carbonate Fuel Cell)



- Electrolyte: Molten carbonate salts.
- Operating Temp: High (600–700 °C).
- Efficiency: 45–55% (up to 85% CHP).
- Applications: Utility power plants, industrial uses.
- Pros: Can use CO, natural gas; high efficiency.
- Cons: Corrosive electrolytes, material durability issues.

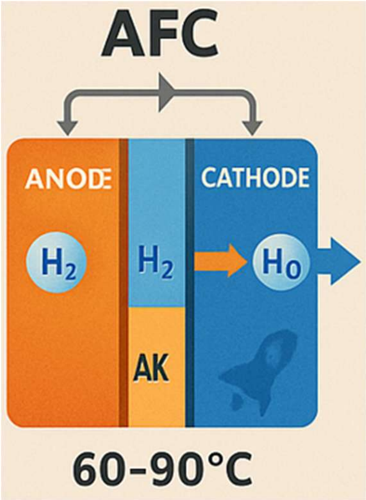
4.4 PAFC (Phosphoric Acid Fuel Cell)



- Electrolyte: Liquid phosphoric acid.
- Operating Temp: Medium (150–220 °C).
- Efficiency: ~40% (up to 80% with CHP).
- Applications: Hospitals, hotels, small stationary power.
- Pros: More tolerant to fuel impurities.
- Cons: Large, heavy, less efficient for vehicles.

4.5. AFC (Alkaline Fuel Cell)

- Electrolyte: Aqueous potassium hydroxide (KOH).
- Operating Temp: 60–90 °C (some >200 °C).
- Efficiency: 50–60%.
- Applications: Spacecraft (NASA Apollo, Shuttle), submarines.
- Pros: High efficiency, quick start-up.
- Cons: Sensitive to CO_2 contamination, fuel purity needed.



5. Comparison with Conventional Batteries

Fuel cells differ from batteries:
• Continuous fuel supply (no recharge needed).
• Higher energy density potential.
• Batteries are closed systems with limited energy content.
Thus, fuel cells complement rather than replace batteries.

6. Efficiency and Sustainability

Fuel cells reach 40–65% efficiency compared to 30% for engines. making them environmentally sustainable. Integration with renewable hydrogen enhances sustainability.

7. Case Study & Conclusion

Case: PEMFCs in buses reduce emissions by 50% compared to diesel. Conclusion: Electrochemical fundamentals enable fuel cells to offer high-efficiency, sustainable energy conversion.

Figures

: Oxidation and reduction in PEMFC.