PEM Fuel Cells – Structure, Operation, Materials, Applications, Challenges

1. **PEMFCs** Proton Exchange Membrane Fuel Cells (PEMFCs) are the most commercially developed type of hydrogen fuel cell, operating at low temperatures and widely used in transport and portable power applications. This lecture explores their structure, working principle, low-temperature operation, key materials, applications, and challenges related to cost and durability.

PEMFCs have emerged as the leading hydrogen fuel cell technology due to their low operating temperatures, fast start-up capability, and suitability for automotive and portable applications. This report analyzes the structure, principle of operation, key materials, applications, and challenges of PEMFCs.

1. Structure and Working Principle

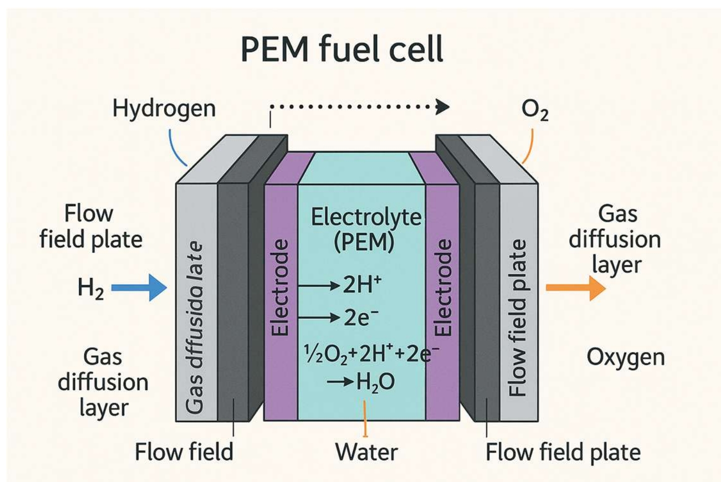
PEMFCs consist of an anode, cathode, polymer electrolyte membrane, and catalysts. At the anode, hydrogen is oxidized into protons and electrons. Protons migrate through the membrane, while electrons travel through the external circuit to the cathode, where oxygen reduction occurs, forming water.

Reactions:

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

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

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



3. Low-Temperature Operation

PEMFCs operate between 60–80 °C. This enables rapid start-up, compact design, and suitability for vehicles. However, impurities such as CO can poison the catalyst, requiring pure hydrogen.

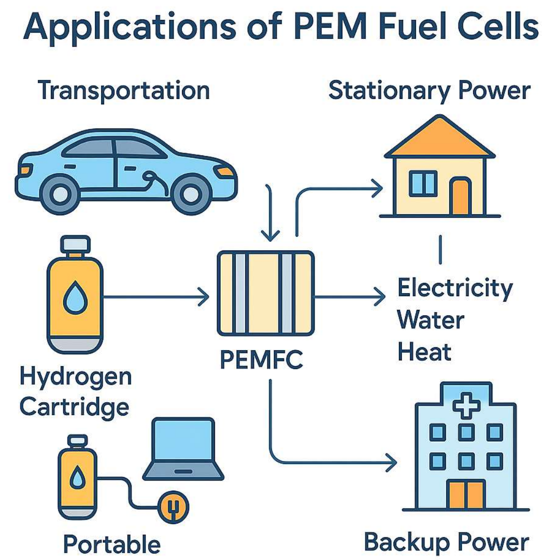
4. Key Materials

• Polymer Membrane (Nafion): high proton conductivity, requires hydration.
• Platinum Catalyst: high activity but expensive and prone to poisoning.
• Gas Diffusion Layers: ensure reactant distribution.
• Bipolar Plates: provide structural integrity and current collection.

5. Applications

PEMFCs are applied in:
• Cars – Toyota Mirai, Hyundai Nexo.

• Buses – London and Tokyo fleets.
• Portable devices – backup power, military electronics.



Application of PEM Fuel

Their scalability from small portable systems to large vehicles demonstrates versatility.

6. Challenges: Cost and Durability

• Cost: platinum loading and Nafion membranes are expensive.
• Durability: catalyst degradation, membrane thinning, and water management issues.
Addressing these challenges is critical for large-scale commercialization.

PEMFCs are the most commercially advanced fuel cell type but face significant cost reduction and durability challenges. Research focuses on reducing platinum use, developing new membranes, and improving water/thermal management.

8. Conclusion & Outlook

PEMFCs will continue to dominate hydrogen mobility and portable power applications. Future advancements in materials science and cost reduction strategies will be key to widespread adoption.

References

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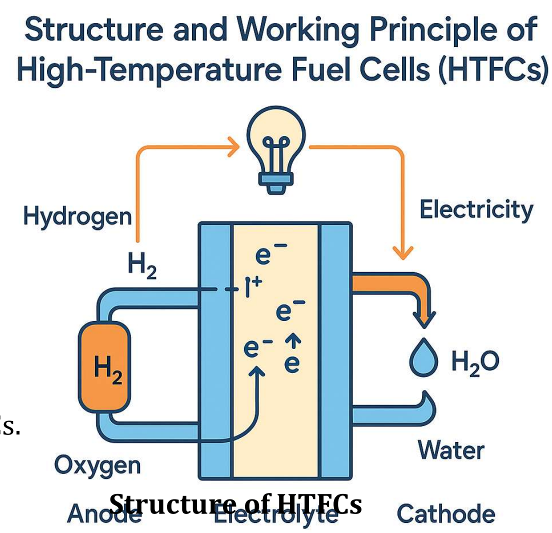
High-Temperature Fuel Cells (HTFCs)

1. **High-temperature fuel cells (HTFCs),** such as solid oxide fuel cells (SOFCs) and molten carbonate fuel cells (MCFCs), operate between 600 and 1000 °C and are designed primarily for stationary power generation. This lecture examines their structure, ceramic electrolyte materials, advantages, applications, and challenges including thermal management and degradation.

Fuel cells can be classified by their operating temperature. HTFCs, operating at 600–1000 °C, are suited for stationary power applications due to their high efficiency and fuel flexibility. This report focuses on SOFCs and MCFCs.

2. Structure and Working Principle

SOFCs employ a solid ceramic electrolyte such as yttria-stabilized zirconia (YSZ) that conducts oxygen ions. MCFCs use molten carbonate salts as electrolytes. High operating temperatures enable internal reforming of hydrocarbons, improving efficiency but posing thermal challenges.



Structure of HTFCs

3. Ceramic Electrolyte Materials

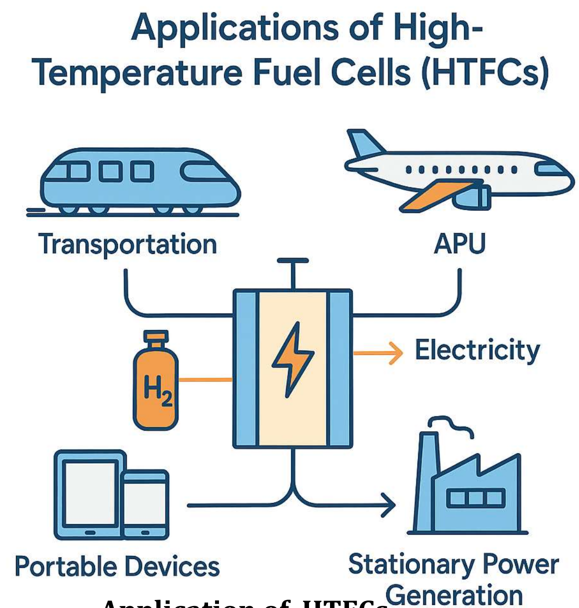
- Yttria-Stabilized Zirconia (YSZ): stable oxygen ion conductor at ~1000 °C.
- Doped ceria: higher conductivity but prone to reduction.
- Molten carbonate salts (Li_2CO_3/K_2CO_3): electrolyte for MCFCs.

4. Advantages

- High efficiency: 50–65% (up to 85% with CHP).
- Fuel flexibility: H_2, CO, CH_4, syngas.
- Cogeneration potential: electricity and heat.

5. Applications

HTFCs are primarily used in stationary applications:
• Distributed generation
• Industrial combined heat and power (CHP)
• Large-scale demonstration projects in Japan, Germany, and the USA.



Application of HTFCs

6. Challenges

• Thermal management: long start-up times, thermal cycling stresses.
• Material degradation: electrolyte cracking, electrode poisoning.
• High cost of ceramic materials and complex manufacturing.

HTFCs offer superior efficiency and fuel flexibility compared to low-temperature fuel cells. However, their slow start-up and high-temperature requirements restrict them to stationary applications. Research focuses on developing intermediate-temperature SOFCs to balance efficiency and durability.

7. Conclusion & Outlook

HTFCs are expected to play a crucial role in stationary power systems, particularly when integrated with renewables. Advances in ceramic materials, degradation resistance, and cost reduction will determine their future viability.

References

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