# AFCs, PAFCs, and MCFCs – Comparative Analysis

This section examines three important types of fuel cells: Alkaline Fuel Cells (AFCs), Phosphoric Acid Fuel Cells (PAFCs), and Molten Carbonate Fuel Cells (MCFCs). Their structure, operating principles, efficiency, applications, and challenges are reviewed, followed by a comparative analysis of their performance and cost.

Alkaline Alkaline Fuel Cells (AFCs), Phosphoric Acid Fuel Cells (PAFCs), and Molten Carbonate Fuel Cells (MCFCs) stand out as mature systems that highlight both the strengths and challenges of electrochemical energy conversion. AFCs are one of the earliest developed fuel cells, using an aqueous solution of potassium hydroxide as the electrolyte. They are known for high electrical efficiency and low operating temperatures (60–90 °C), making them suitable for space applications and specialized power systems. However, their extreme sensitivity to carbon dioxide limits commercial viability, as even small $CO_2$ concentrations reduce performance.

PAFCs, by contrast, employ concentrated phosphoric acid as the electrolyte and operate at intermediate temperatures around 150–200 °C. Their higher tolerance to fuel impurities compared to AFCs allows them to utilize reformed hydrogen from fossil fuels. They have been commercially deployed for stationary power generation, especially in hospitals and office complexes, where both electricity and useful heat can be harnessed through combined heat and power (CHP). Yet, their relatively modest efficiency and sluggish electrode kinetics remain technical constraints.

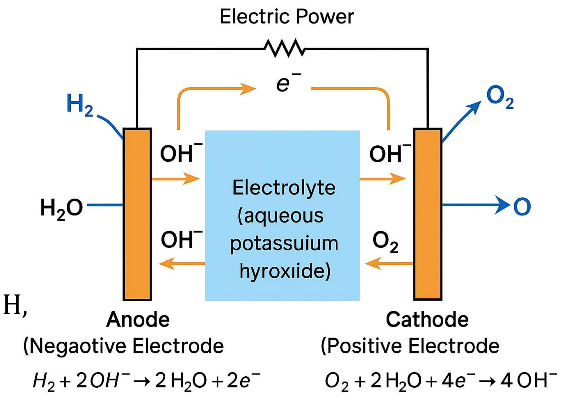
MCFCs, operating at much higher temperatures (600–700 °C) with molten carbonate salts as the electrolyte, offer distinct advantages such as internal fuel reforming and the ability to use natural gas or biogas directly. They are particularly suited for large-scale power plants, achieving high efficiencies and effective $CO_2$ capture. Nevertheless, material degradation and complex thermal management continue to hinder long-term durability.

Comparative Table of AFCs, PAFCs, and MCFCs

| Feature / Type | AFC (Alkaline Fuel Cell) | PAFC (Phosphoric Acid Fuel Cell) | MCFC (Molten Carbonate Fuel Cell) |
|---|---|---|---|
| **Electrolyte** | Aqueous potassium hydroxide (KOH) | Concentrated phosphoric acid ($H_3PO_4$) | Molten carbonate salts ($Li_2CO_3$, $K_2CO_3$) |
| **Operating Temp.** | 60–90 °C (low temperature) | 150–200 °C (intermediate) | 600–700 °C (high temperature) |
| **Fuel Type** | Pure hydrogen (sensitive to $CO_2$) | Hydrogen, reformate fuels | Hydrogen, natural gas, biogas, CO |
| **Efficiency** | 50–60% (high in controlled settings) | ~40% electrical, up to 80% with CHP | 50–60% electrical, >80% with CHP |
| **Applications** | Space missions (NASA), submarines, niche portable systems | Stationary power (hospitals, offices, distributed generation) | Large-scale power plants, industrial CHP, $CO_2$ capture systems |
| **Advantages** | High efficiency; fast start-up; lightweight | Tolerates some fuel impurities; CHP capable; proven commercialization | Fuel flexibility; internal reforming; high efficiency; suitable for $CO_2$ capture |
| **Limitations** | Extreme $CO_2$ sensitivity; expensive catalysts; limited lifetime | Sluggish kinetics; lower efficiency than newer designs; costly | High operating temp → corrosion, materials degradation; complex thermal management |

## 1. Fuel Cells (AFCs) features

- Electrolyte: aqueous KOH solution.
- Operating temperature: 60–90 °C.
- Efficiency: ~60%.
- Applications: space (Apollo missions), submarines, and military units.
- Challenges: $CO_2$ sensitivity – atmospheric $CO_2$ reacts with KOH, forming carbonates that reduce conductivity.




**Fuel Cells (AFCs)**

## 2.1 Chemical reactions Fuel Cells (AFCs)

1. **Anode (Negative Electrode):**
   - Hydrogen gas ($H_2$) is supplied.
   - Reaction:

     $$\mathbf{H_2 + 2OH^- \rightarrow 2H_2O + 2e^-}$$

     Hydrogen molecules are oxidized, releasing electrons.

2. **Electrolyte:**
   - Aqueous solution of **potassium hydroxide (KOH)**.
   - Provides **$OH^-$ ions** that move between anode and cathode.
   - The electrolyte is not consumed, but it facilitates ion transfer.
3. **Cathode (Positive Electrode):**
   - Oxygen gas ($O_2$) is supplied.
   - Reaction:

     $$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

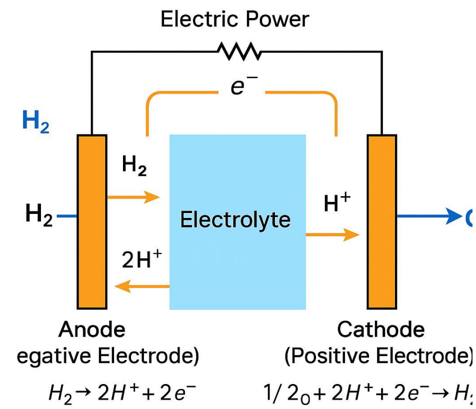
     Oxygen is reduced, forming hydroxyl ions that migrate back to the anode.

4. **External Circuit:**
   - Electrons produced at the anode travel through an **external circuit** to the cathode.
   - This flow of electrons provides **usable electric power**.
5. **Overall Reaction**

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electricity} + \text{Heat}$$

## 3. Phosphoric Acid Fuel Cells (PAFCs) features

• Electrolyte: phosphoric acid ($H_3PO_4$).
• Operating temperature: 150–220 °C.
• Efficiency: 40–50% (up to 85% in CHP).
• Applications: stationary power (200 kW to 10 MW).
• Challenges: lower power density, acid corrosion, high cost




## 2. 1 Chemical reaction of Phosphoric Acid Fuel Cells (PAFCs)

**At the Anode (negative electrode):**

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

- Hydrogen gas is oxidized, releasing protons and electrons.

**At the Cathode (positive electrode):**

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

Oxygen reacts with protons (coming through the electrolyte) and electrons (from the external circuit) to form water.

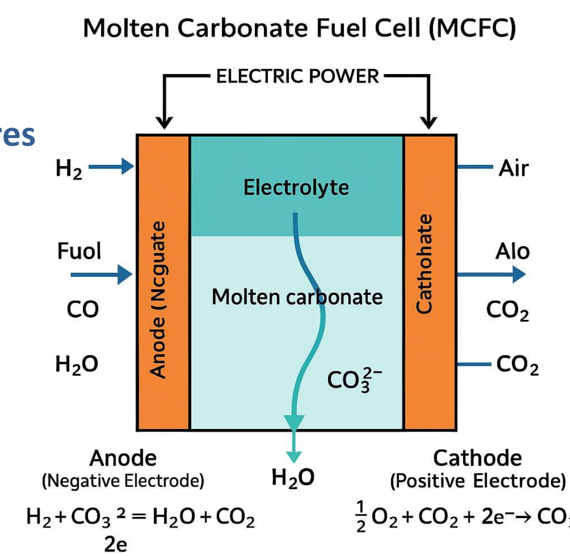
**Overall Cell Reaction:**

$H_2 + 1/2\ O_2 \rightarrow H_2O$+Electricity + Heat

## 4. Molten Carbonate Fuel Cells (MCFCs) features

• Electrolyte: molten carbonate salts ($Li_2CO_3/K_2CO_3$).
• Operating temperature: 600–700 °C.

• Efficiency: 50–60%.
• Applications: large stationary power plants, industrial CHP.
• Challenges: electrode corrosion, slow start-up, material degradation.



## 4.1 Chemical reaction of Fuel cell MCFCs

**Electrochemical Reactions:**

- **Anode (negative electrode):**

  $H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$

  or with CO:

  $CO + CO_3^{2-} \rightarrow 2CO_2 + 2e^-$

  **Cathode (positive electrode):**

  $\frac{1}{2} O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$

- **Overall Reaction:**

  $H_2 + 1/2\ O_2 + CO_2 \rightarrow H_2O + CO_2$

## 5. Comparative Analysis

A comparative study shows that:
• AFCs: high efficiency, low cost, but $CO_2$ sensitive.
• PAFCs: mature for stationary use, tolerant to $CO_2$, but costly and lower power density.
• MCFCs: high efficiency and fuel flexibility, but expensive and suffer from durability issues.

Each type of fuel cell fills a niche in the energy landscape. AFCs are suited for closed environments, PAFCs for stationary distributed generation, and MCFCs for large-scale power. Cost and durability remain the biggest barriers to commercialization.

## 6. Conclusion & Outlook

AFCs, PAFCs, and MCFCs illustrate the diversity of fuel cell technologies. Future developments aim to improve electrolytes, reduce costs, and enhance durability. Hybrid systems combining fuel cells with renewables and storage may offer practical solutions.

## References

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[3] Barbir, F. PEM Fuel Cells: Theory and Practice. Elsevier, 2013.
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