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## Fuel Cell Performance and Technology Overview

**Course Number:** CH-02-903

**PDH:** 5

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## Module 1: Technology Overview

### Learning Objectives

By the end of this section, you will be able to:

- **Identify** the fundamental electrochemical components and operational mechanisms of a fuel cell.
- **Evaluate** the performance characteristics, temperature ranges, and material requirements of the five primary fuel cell types (PEFC, AFC, PAFC, MCFC, and SOFC).
- **Analyze** the application suitability of various fuel cell technologies for stationary, mobile, and auxiliary power systems.

*Executive Summary:* Fuel cells are electrochemical devices that convert chemical energy directly into electrical energy with high efficiency and low environmental impact. By avoiding combustion and the intermediate steps of heat and mechanical work, they bypass the thermodynamic limitations of the Carnot cycle. While various types exist—classified primarily by their electrolyte—the technology is modular and adaptable for applications ranging from portable power to multi-megawatt stationary plants.

### Introduction

Fuel cells function as electrochemical converters, promising power generation with minimal pollutants. Because they avoid combustion, they produce power with high efficiency. Unlike batteries, which are energy storage devices that eventually discharge, fuel cells act as energy conversion devices that produce power as long as the reductant (fuel) and oxidant are continuously replenished.

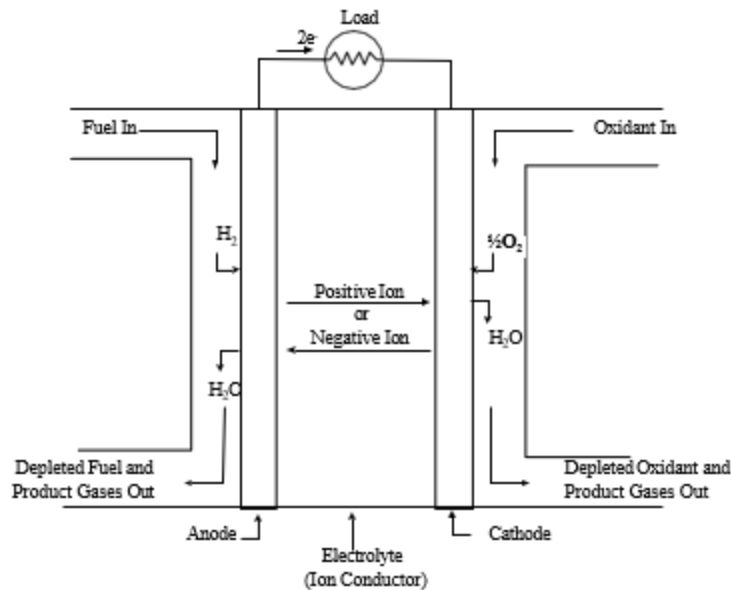
#### Most fuel cell power systems comprise:

- **Unit cells**, where the electrochemical reactions take place.
- **Stacks**, where individual cells are combined in series to form units with desired output.
- **Balance of Plant (BoP)**, which includes fuel processors, thermal management, and power conditioning.

### Unit Cells

#### Basic Structure

The core of a fuel cell is an electrolyte layer in contact with an anode (negative electrode) and a cathode (positive electrode) on either side.



**Figure 1-1:** Schematic of an Individual Fuel Cell

In operation, fuel is fed to the anode and an oxidant (oxygen from air) is fed to the cathode. The electrochemical reactions produce an electric current through the electrolyte while driving a complementary current through the load. Most modern fuel cells use gaseous hydrogen or a hydrogen-rich synthesis gas as fuel.

## Critical Functions of Cell Components

The actual electrochemical reactions occur at the **three-phase interface**, where the electrode meets the electrolyte and the reactant gas.

- **Liquid Electrolyte:** Reactant gases diffuse through a thin film wetting the porous electrode. Excessive electrolyte may "flood" the electrode, restricting gas transport and reducing performance.
- **Solid Electrolyte:** The challenge is to engineer catalyst sites that are electrically and ionically connected. Successful designs often use electrodes with **mixed conductivity** near the catalyst.

## Key Electrode Functions

1. **Conduct electrons** to or from the three-phase interface.
2. **Distribute reactant gases** equally over the cell.
3. **Lead reaction products** away to the bulk gas phase.

## Fuel Cell Stacking

Unit cells are combined in modular stacks to achieve practical voltage and power levels.

### Planar-Bipolar Stacking

The most common design involves connecting multiple unit cells in series via electrically conductive interconnects. The interconnect acts as a **separator plate**, providing an electrical path and a gas barrier.

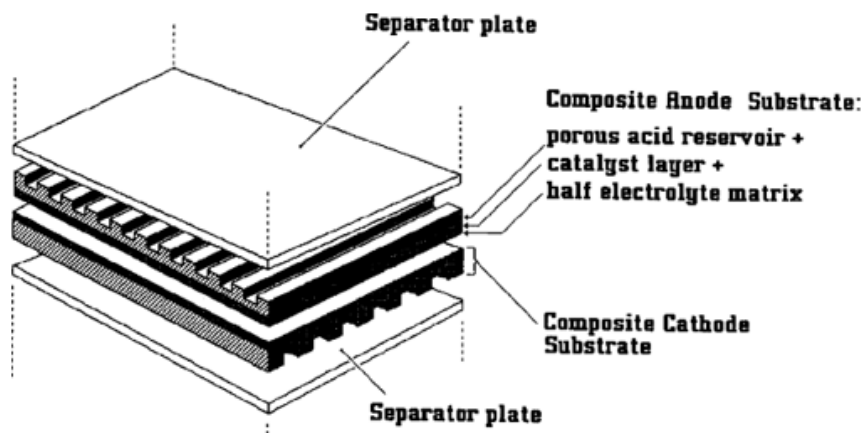


Figure 1-2: Expanded View of a Basic Fuel Cell Unit in a Fuel Cell Stack (1)

### Gas-Flow Arrangements

- **Cross-flow:** Air and fuel flow perpendicular.
- **Co-flow / Counter-flow:** Parallel paths (same or opposite directions).
- **Serpentine / Spiral flow:** Zig-zag or spiral paths for circular cells.

### Stacks with Tubular Cells

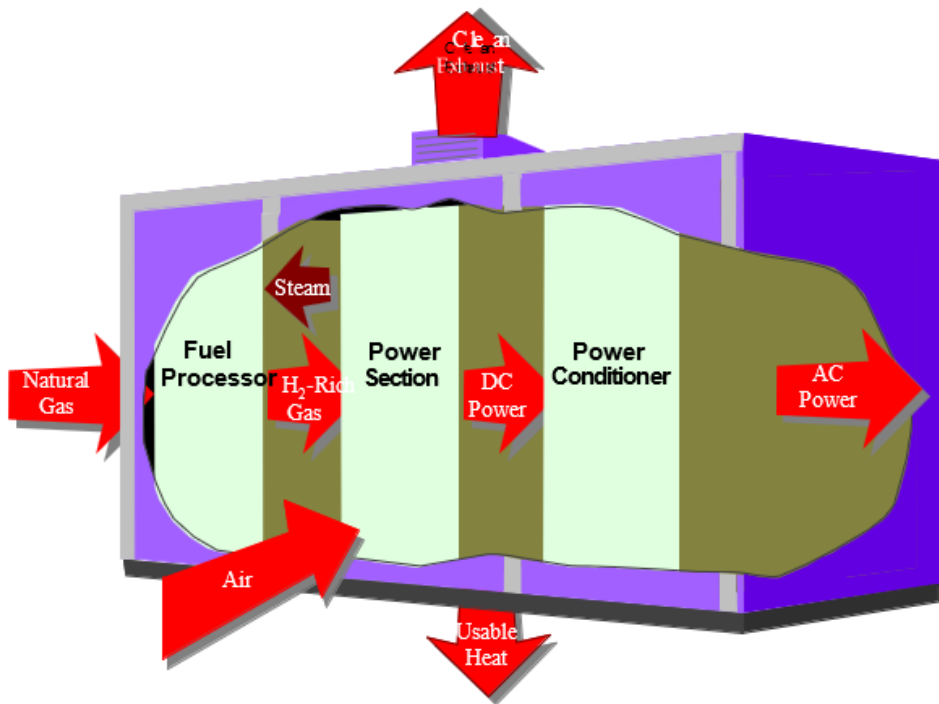
Tubular cells offer advantages in sealing and structural integrity, specifically for high-temperature technologies. However, they present a geometric challenge in achieving high power density.

### Fuel Cell Systems

The **Balance of Plant (BoP)** represents a significant fraction of system weight, volume, and cost.

## Key Components

- **Fuel Preparation:** Impurity removal and reforming (converting hydrocarbons to hydrogen).
- **Air Supply:** Compressors, blowers, and filters.
- **Thermal Management:** Maintaining stack temperature.
- **Water Management:** Ensuring hydration and managing reaction products.
- **Electric Power Conditioning:** Converting variable DC to regulated AC or DC.



**Figure 1-3:** Fuel Cell Power Plant Major Processes

## Fuel Cell Types

Fuel cells are primarily classified by the electrolyte used, which dictates the operating temperature and the degree of fuel processing required.

Table 1-1: Summary of Major Differences of the Fuel Cell Types

	PEFC	AFC	PAFC	MCFC	SOFC
Electrolyte	Hydrated Polymeric Ion Exchange Membranes	Mobilized or Immobilized Potassium Hydroxide in asbestos matrix	Immobilized Liquid Phosphoric Acid in SiC	Immobilized Liquid Molten Carbonate in LiAlO <sub>2</sub>	Perovskites (Ceramics)
Electrodes	Carbon	Transition metals	Carbon	Nickel and Nickel Oxide	Perovskite and perovskite / metal cermet
Catalyst	Platinum	Platinum	Platinum	Electrode material	Electrode material
Interconnect	Carbon or metal	Metal	Graphite	Stainless steel or Nickel	Nickel, ceramic, or steel
Operating Temperature	40 – 80 °C	65°C – 220 °C	205 °C	650 °C	600-1000 °C
Charge Carrier	H <sup>+</sup>	OH <sup>-</sup>	H <sup>+</sup>	CO <sub>3</sub> <sup>=</sup>	O <sup>=</sup>
External Reformer for hydrocarbon fuels	Yes	Yes	Yes	No, for some fuels	No, for some fuels and cell designs
External shift conversion of CO to hydrogen	Yes, plus purification to remove trace CO	Yes, plus purification to remove CO and CO <sub>2</sub>	Yes	No	No
Prime Cell Components	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic
Product Water Management	Evaporative	Evaporative	Evaporative	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Liquid Cooling Medium	Process Gas + Electrolyte Circulation	Process Gas + Liquid cooling medium or steam generation	Internal Reforming + Process Gas	Internal Reforming + Process Gas

## Polymer Electrolyte Fuel Cell (PEFC)

**⚠ Safety Constraint:** PEFCs are easily poisoned by trace levels of **CO and sulfur species**. Extensive fuel processing and purification are mandatory if using hydrocarbon fuels.

## Alkaline Fuel Cell (AFC)

**Disadvantage:** Extreme sensitivity to **CO<sub>2</sub>** requires highly pure H<sub>2</sub> and the removal of CO<sub>2</sub> from ambient air, impacting system cost and size.



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