

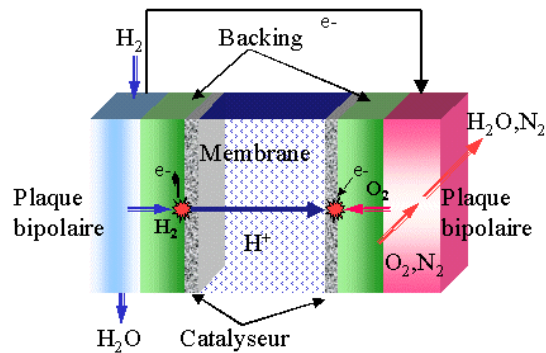
Fuel Cells

Different types

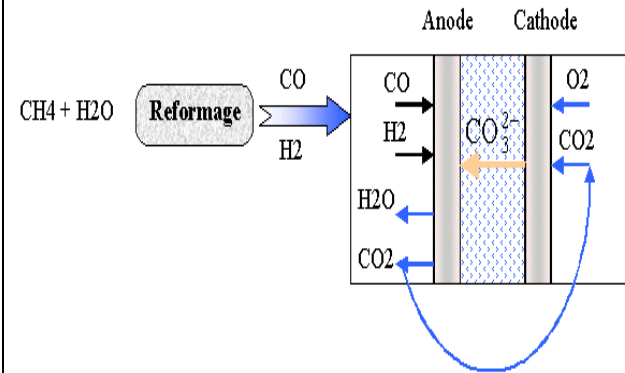
	Fuel Combustive fuel	Electrolyte / Membrane	Electrodes / Catalysts	global reaction
AFC	H ₂ O ₂ , air	liquid : Potassium hydroxide (KOH)	Anode : Al / Ni, Pt-Pd Cathode : Al/ Pt-Au, Ag, NiO _x	Anode : 2H ₂ + 4HO ⁻ ⇒ 4H ₂ O + 4e ⁻ Cathode : O ₂ + 4e ⁻ + 2H ₂ O ⇒ 4HO ⁻
DMFC	CH ₃ OH+ H ₂ O air	Alcaline / Solid, proton exchange polymer membrane	Anode : Pt-Sn, Pt-Re, Pt-Ru	Anode : CH ₃ OH + 4H ₂ O ⇒ 6H ⁺ + 6e ⁻ + CO ₂ Cathode : O ₂ + 4H ⁺ + 4e ⁻ ⇒ 2H ₂ O
PEMFC	H ₂ O ₂ , air	Solid, proton exchange polymer membrane (Nafion®)	Anode : Graphite / Pt Cathode : Graphite / Pt	Anode : 2H ₂ ⇒ 4H ⁺ + 4e ⁻ Cathode : O ₂ + 4H ⁺ + 4e ⁻ ⇒ 2H ₂ O
PAFC	H ₂ , CH ₄ , CH ₃ OH air	liquid : phosphoric acid (H ₃ PO ₄)	Anode : Graphite / Pt Cathode : Graphite / Pt	Anode : 2H ₂ ⇒ 4H ⁺ + 4e ⁻ Cathode : O ₂ + 4H ⁺ + 4e ⁻ ⇒ 2H ₂ O
MCFC	H ₂ , CH ₄ air	liquid : Melted Carbonate / ceramics (LiAlO ₂).	Anode : stainless steel / Ni-Cr, Ni-Al Cathode : stainless steel / NiO _x	Anode : 2H ₂ + 2CO ₃ ²⁻ ⇒ 2H ₂ O + 2CO ₂ + 4e ⁻ Cathode : O ₂ + 2CO ₂ + 4e ⁻ ⇒ 2CO ₃ ²⁻
SOFC	H ₂ , CH ₄ , CH ₃ OH air	solid : ceramics (Zirconia)	Anode : / Zr & Ni cermets Cathode : / ceramics (Mn, La, St)	Anode : 2H ₂ + 2O ²⁻ ⇒ 2H ₂ O + 4e ⁻ 2CO + 2O ²⁻ ⇒ 2CO ₂ + 4e ⁻ Cathode : O ₂ + 4e ⁻ ⇒ 2O ²⁻

Principle of operation

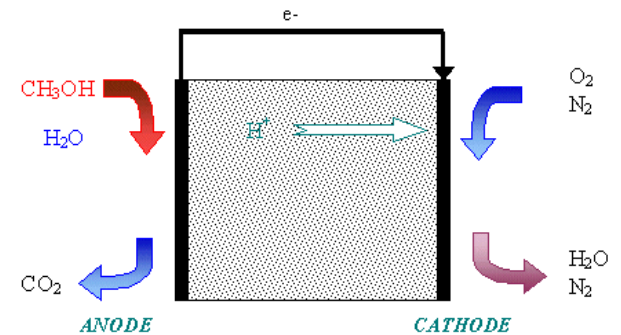
PEMFC :



MCFC :



DMFC :



Technical data

Type	Temperature of operation	Power per cell surface unit	Power density	Power density	Energy Efficiency	Life duration
AFC	60 to 90 °C	100 mW/cm ²	not available	not available	50 to 60 %	15000 hours
DMFC	60 to 70 °C	200 to 350 mW/cm ²	not available	not available	25 to 40 %	1000 h ??
PEMFC	60 to 90 °C	200 to 350 mW/cm ²	1.4 kW/dm³	1 kW/kg	40 to 60 %	40 000 hours
PAFC	160 to 220 °C	100 to 300 mW/cm ²	not available	not available	55%	40 000 hours
MCFC	620 to 660 °C	100 to 500 mW/cm ²	not available	not available	60 to 65 %	9 000 hours
SOFC	750 to 1000 °C	200 to 500 mW/cm ²	not available	not available	55 % ; 80% (including heat production)	35 000 hours

Fuel Cells

Environmental impact

- fluor present in nafion membranes
- material & electrolyte recycling is required
- Methanol : toxic
- It is necessary Traitement nécessaire des effluents contenant du CO₂

Safety

- Explosion thresold : H₂ in air concentration not to exceed 4% in mass

Applications

Type	Power	Application	Development status
AFC	1-100 kW	transportation, space	marketed
DMFC	1 W-100 kW	portable	development
PEMFC	1 W-1 MW	transportation, stationnary, portable	development marketed in 2002
PAFC	200 kW-10 MW	transportation, stationnary	marketed
MCFC	500 kW-10 MW	stationnary	Research
SOFC	1 kW-10 MW	stationnary, transportation	Research

R&D Perspectives

Cost : to decrease material costs (membranes, electrodes, bipolar plates, catalysts...)

- to develop auxiliaries technology to decrease energy losses occuring in the peripheral system supply.

Life duration : to ease maintenance (out of order cells switch ...)

To increase material robustness (membranes, catalysts...)

Temperature :

PEMFC : ↗ operating temperature

SOFC : ↘ operating temperature

MCFC : to develop corrosion resistant materials in melted carbonates and high temperature media

Economical data

Current costs:

AFC : no data

DMFC : no data

PEMFC : 6 000 - 20 000 €/kW

PAFC : 2400 - 5000 €/kW

MCFC : ≅ 10 000 €/kW

SOFC : 30 000 €/kW ??

Targeted costs:

stationnary applications: 1000 €/kW (40 000 h)

automotive applications: 100 €/kW (4 000 h)

Manufacturers active on the market:

AFC : Zevco, IFC, Siemens, Astris, Fuji Electric...

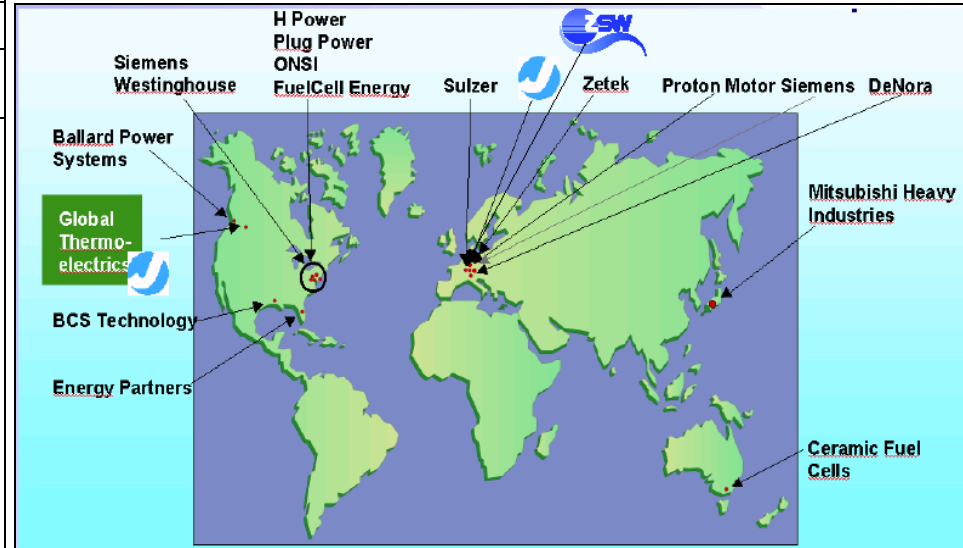
DMFC : Hitachi, Sanyo, Alsthom, Siemens, ...

PEMFC : Ballard, De Nora, ERL, ...

PAFC : IFC, Fuji Electric, Westinghouse, Toshiba, Sanyo, Engelhard ...

MCFC : Toshiba, General electric, Matsushita, Mitsubishi, Ensaldo, ...

SOFC : Siemens, Fuji, Sulzer, Westinghouse, TNO, KepCo, ...



Worldwide fuel cells manufacturers

R&D Institutes involved in the field:

CNRS, CEA, CENERG, ZSW, Los Alamos National Lab., ...