Direct Energy Conversion: Fuel Cells

References:

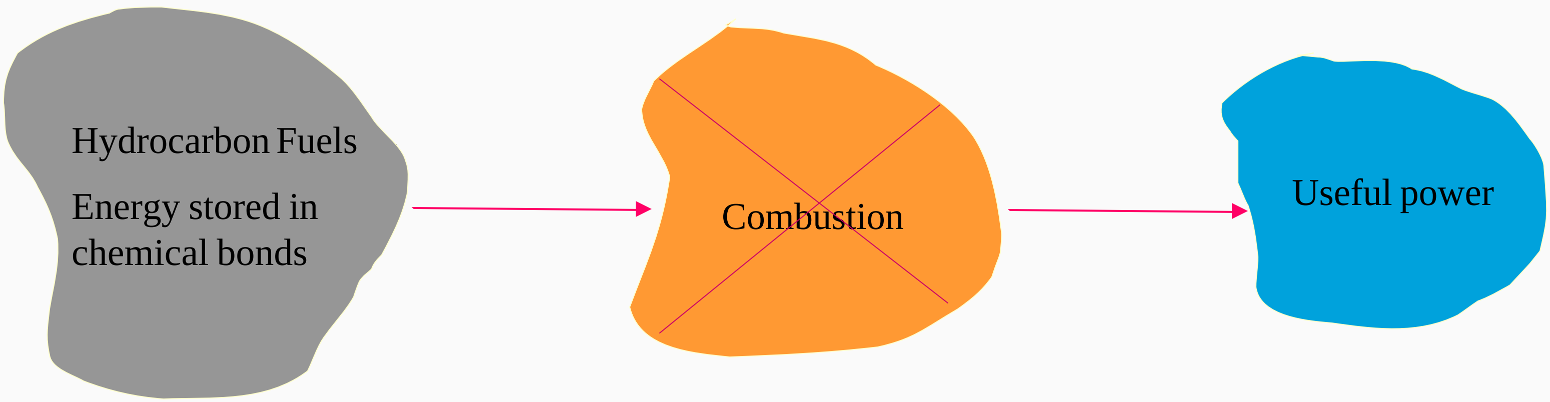
Direct Energy Conversion by Stanley W. Angrist, Allyn and Beacon, 1982.

Fuel Cell Systems, Explained by James Larminie and Andrew Dicks, Wiley, 2003.

Fuel Cell Technology Hand Book, Edited by Gregor Hoogers, CRC Press, 2002

Fuel Cells

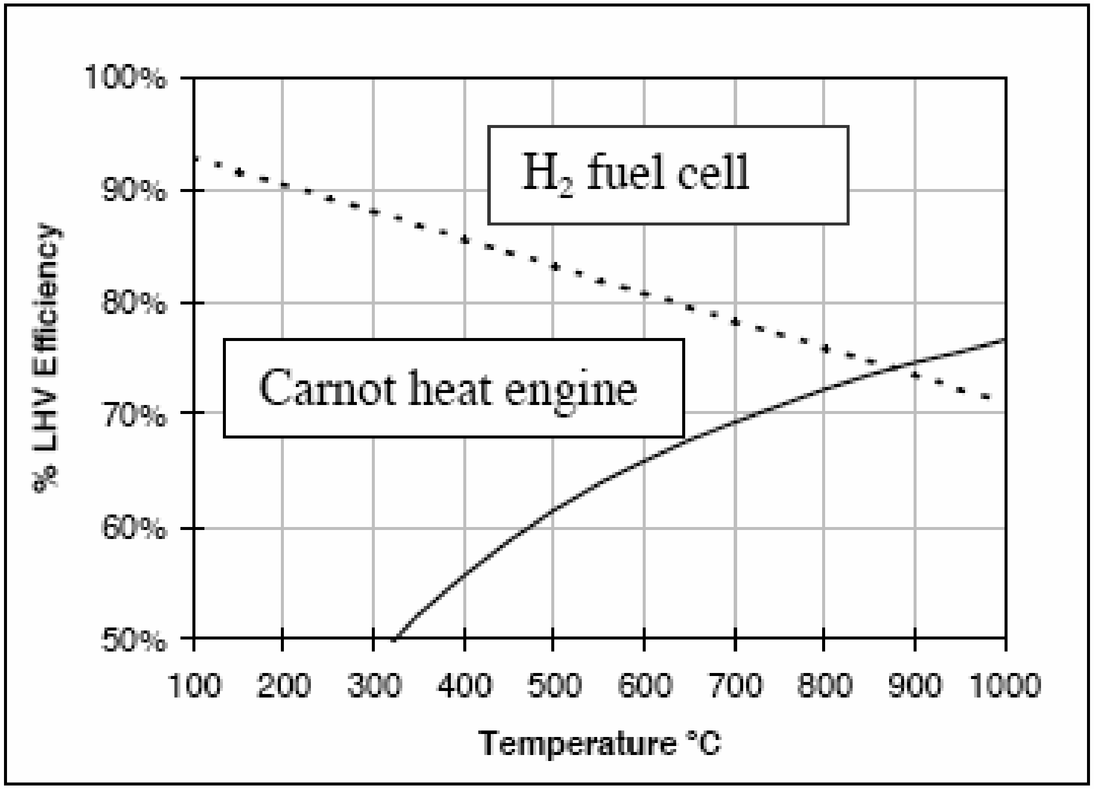
Introduction:



Bypass the conversion-to-heat and mechanical-to-electrical processes

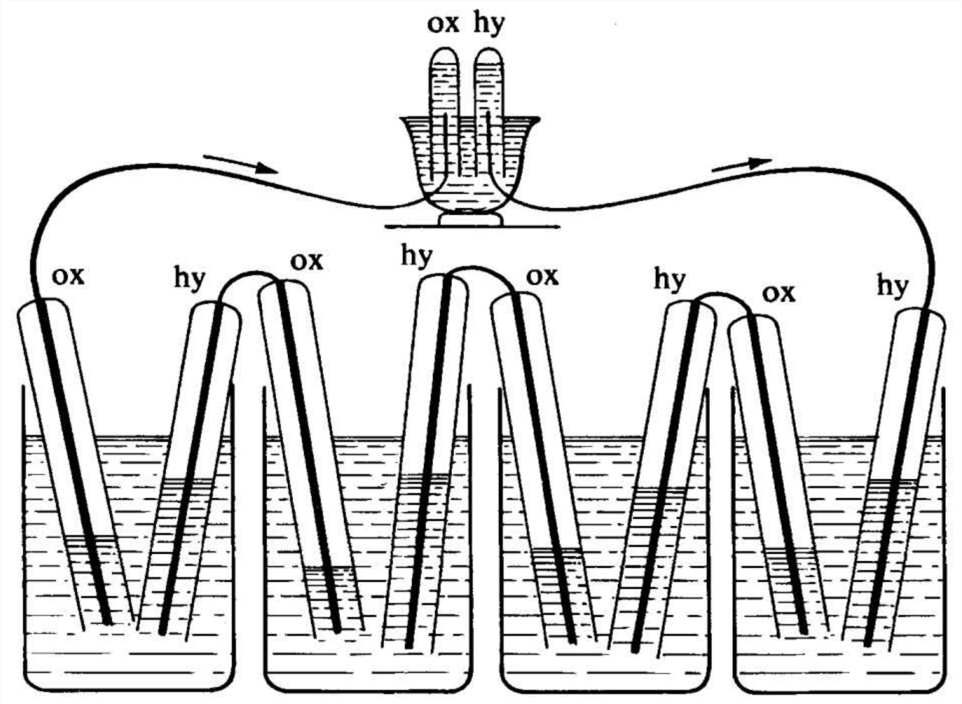
A fuel cell is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low voltage, direct current electrical energy. Since the conversion can be carried out isothermally (at least in theory), the Carnot limitation on efficiency does not apply.

Fuel Cell Efficiency



Fuel Cells

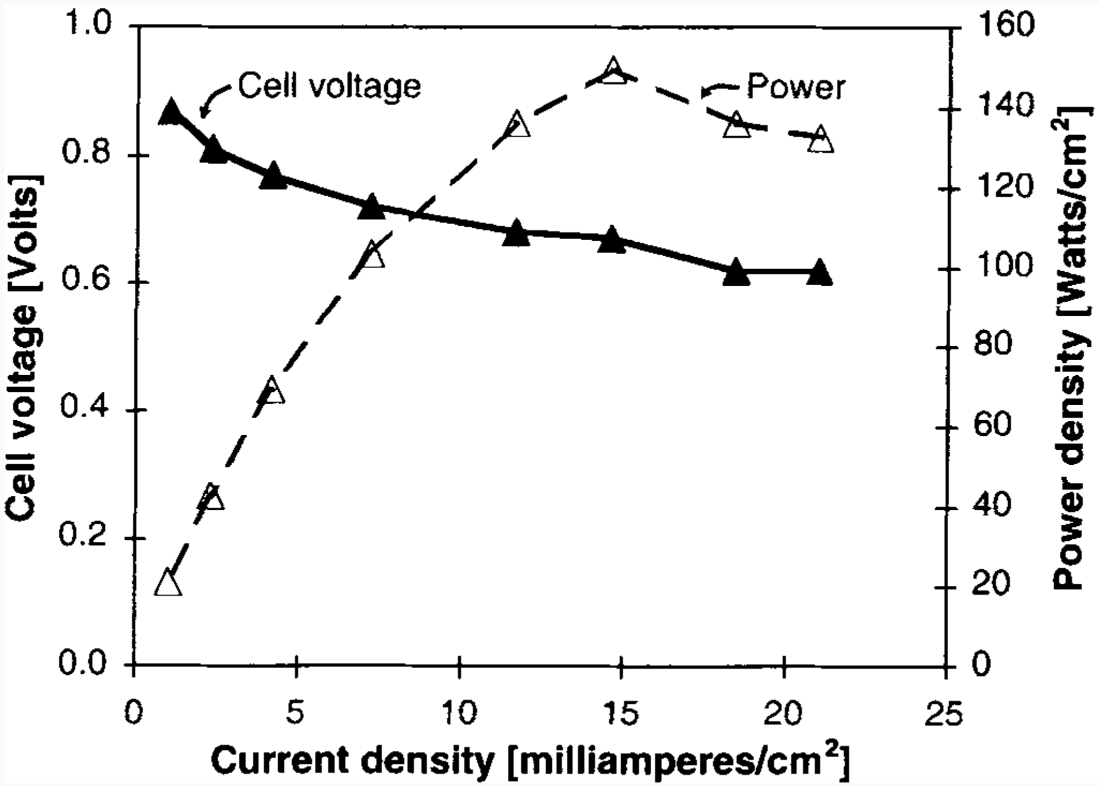
William Grove 1839



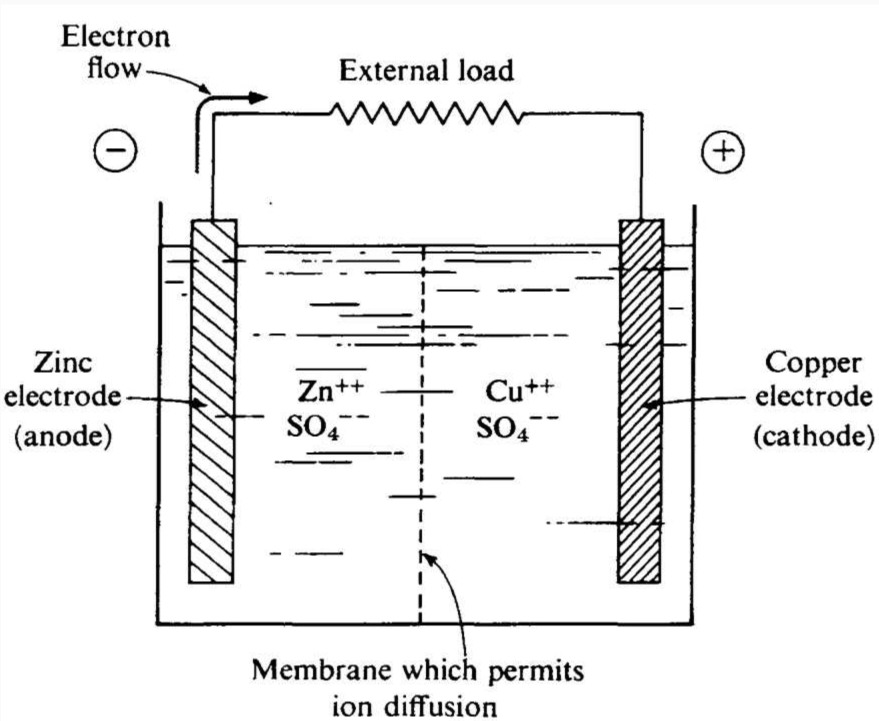
Grove noted with interest that this device, which used platinum electrodes in contact with dilute sulfuric acid would cause permanent deflection of a galvanometer connected to the cell. He also noted the difficulty of producing high current densities in a fuel cell that uses gases.

Fuel Cells

Mond & Langer (1889) - Gas battery



Daniell Cell

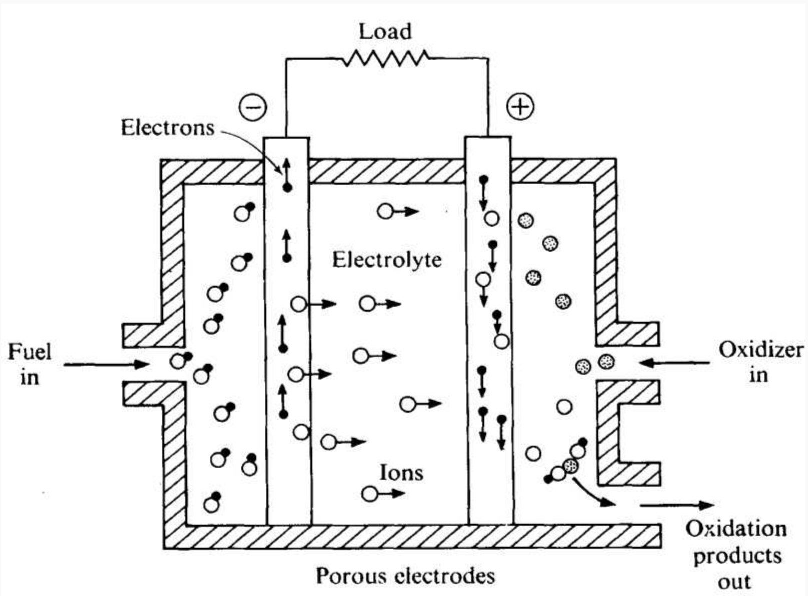


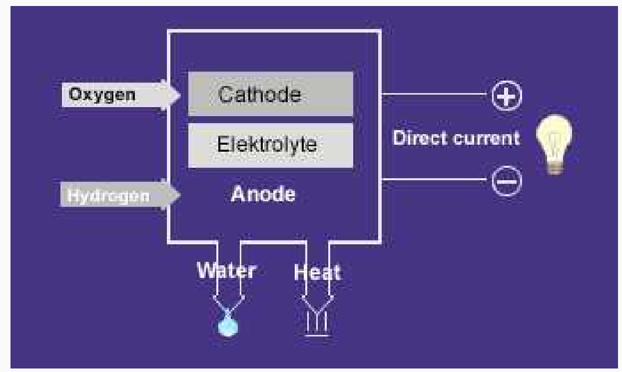
We will use the term anode to mean the electrode at which oxidation takes place - losing of electrons

Cathode is the electrode at which reduction takes place - electrons are gained from the external circuit

Fuel Cell

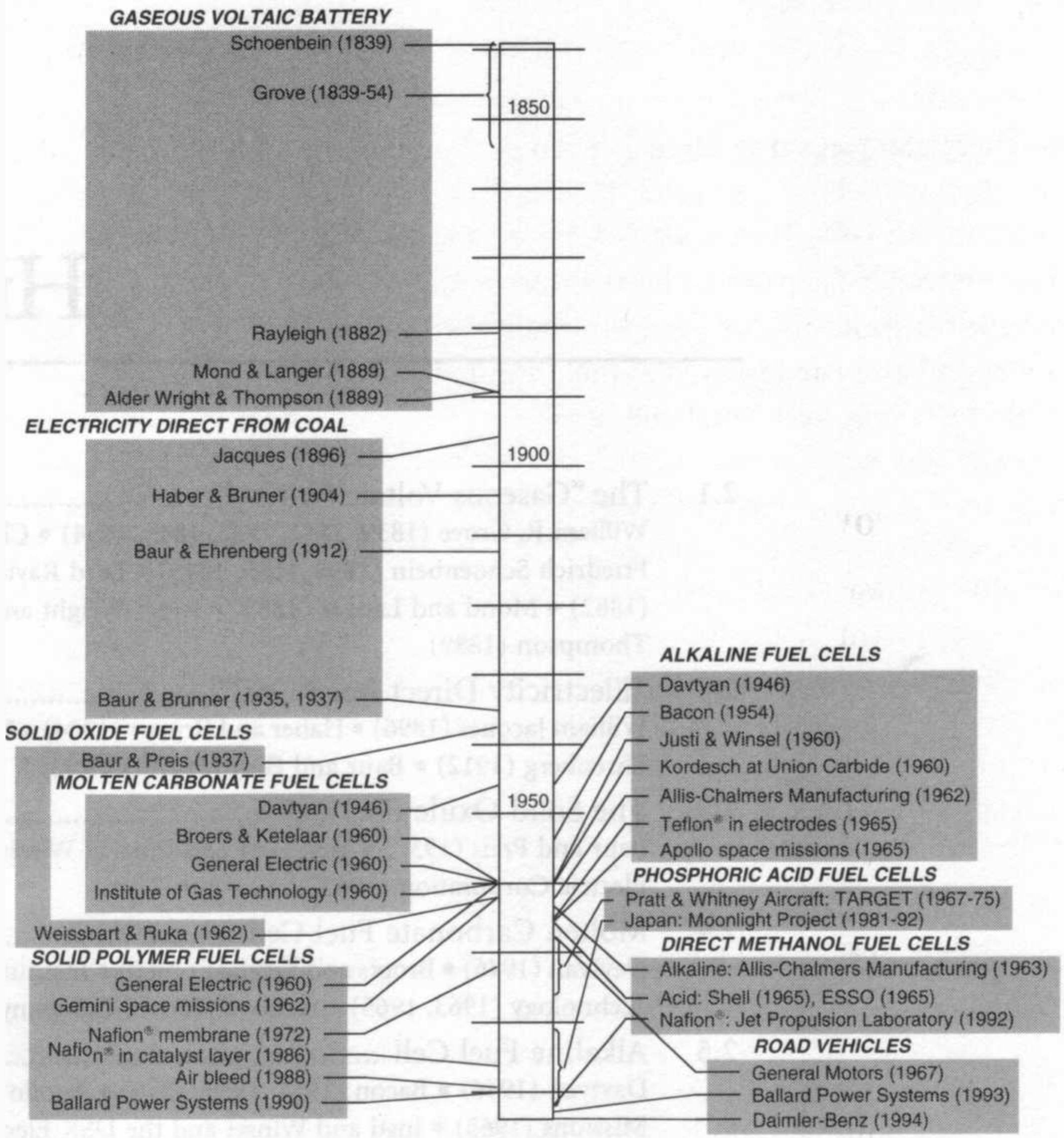
The Fuel Cell is a device which converts hydrogen or other fuel and oxygen into electricity. It achieves this using a process which is the reverse of electrolysis of water first identified by William Grove in 1863.





The common types of fuel cells are phosphoric acid (PAFC), molten carbonate (MCFC), proton exchange membrane (PEMFC), and solid oxide (SOFC), all named after their electrolytes. Because of their different materials and operating temperatures, they have varying benefits, applications and challenges, but all share the potential for high electrical efficiency and low emissions. Because they operate at sufficiently low temperatures they produce essentially no NOx, and because they cannot tolerate sulfur and use desulfurized fuel they produce no SOx.

Historical Development



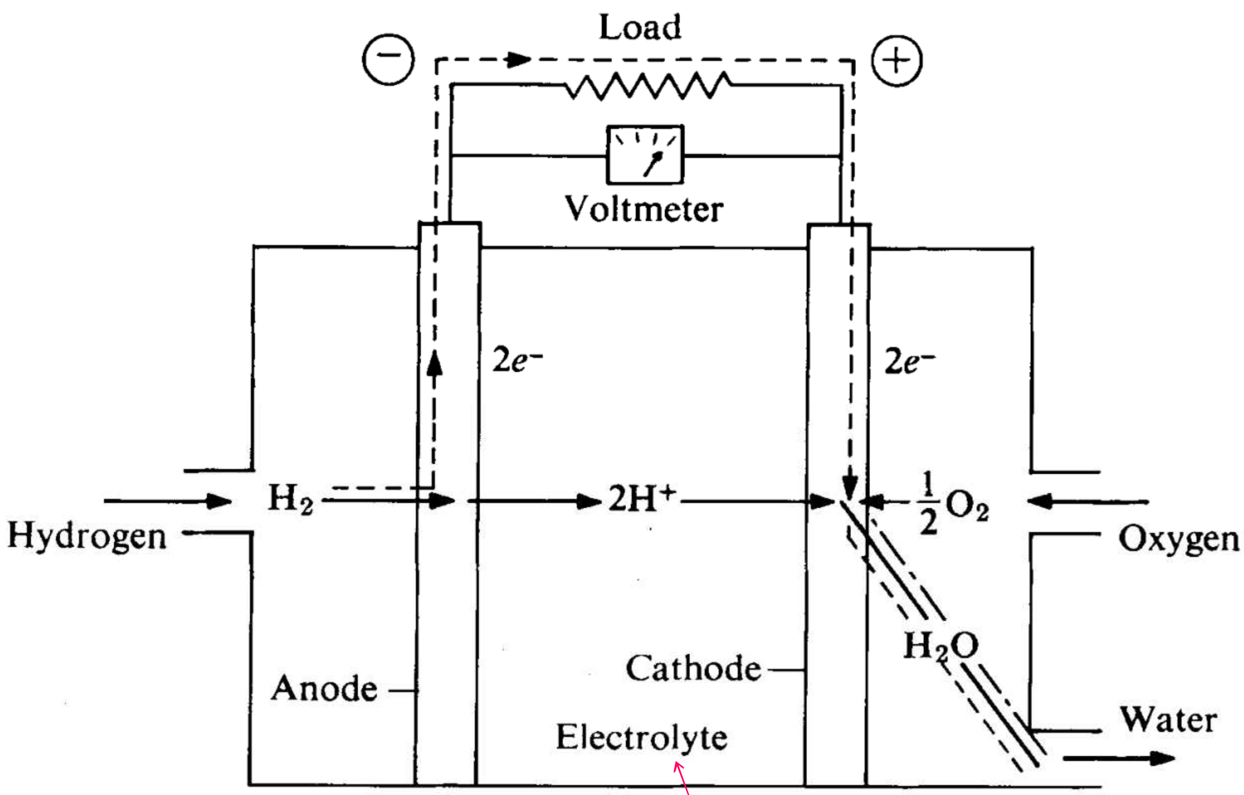
Fuel Cell Types

TABLE 1.1 Currently Developed Types of Fuel Cells and Their Characteristics and Applications

	Fuel Cell Type	Electrolyte	Charge Carrier	Operating Temperature	Fuel	Electric Efficiency (System)	Power Range/ Application
1	Alkaline FC (AFC)	KOH	OH^-	60–120°C	Pure H_2	35–55%	<5 kW, niche markets (military, space)
2	Proton exchange membrane FC (PEMFC)[a]	Solid polymer (such as Nafion)	H^+	50–100°C	Pure H_2 (tolerates CO_2)	35–45%	Automotive, CHP (5–250 kW), portable
	Phosphoric acid FC (PAFC)	Phosphoric acid	H^+	~220°C	Pure H_2 (tolerates CO_2, approx. 1% CO)	40%	CHP (200 kW)
	Molten carbonate FC (MCFC)	Lithium and potassium carbonate	CO_3^{2-}	~650°C	H_2, CO, CH_4, other hydrocarbons (tolerates CO_2)	>50%	200 kW–MW range, CHP and stand-alone
	Solid oxide FC (SOFC)	Solid oxide electrolyte (yttria, zirconia)	O^{2-}	~1000°C	H_2, CO, CH_4, other hydrocarbons (tolerates CO_2)	>50%	2 kW–MW range, CHP and stand-alone

[a] Also known as a solid polymer fuel cell (SPFC).

Hydrogen - Oxygen Fuel Cell



At the anode the hydrogen gas ionizes releasing electrons and creating H^+ ions (or protons). This reaction releases energy.

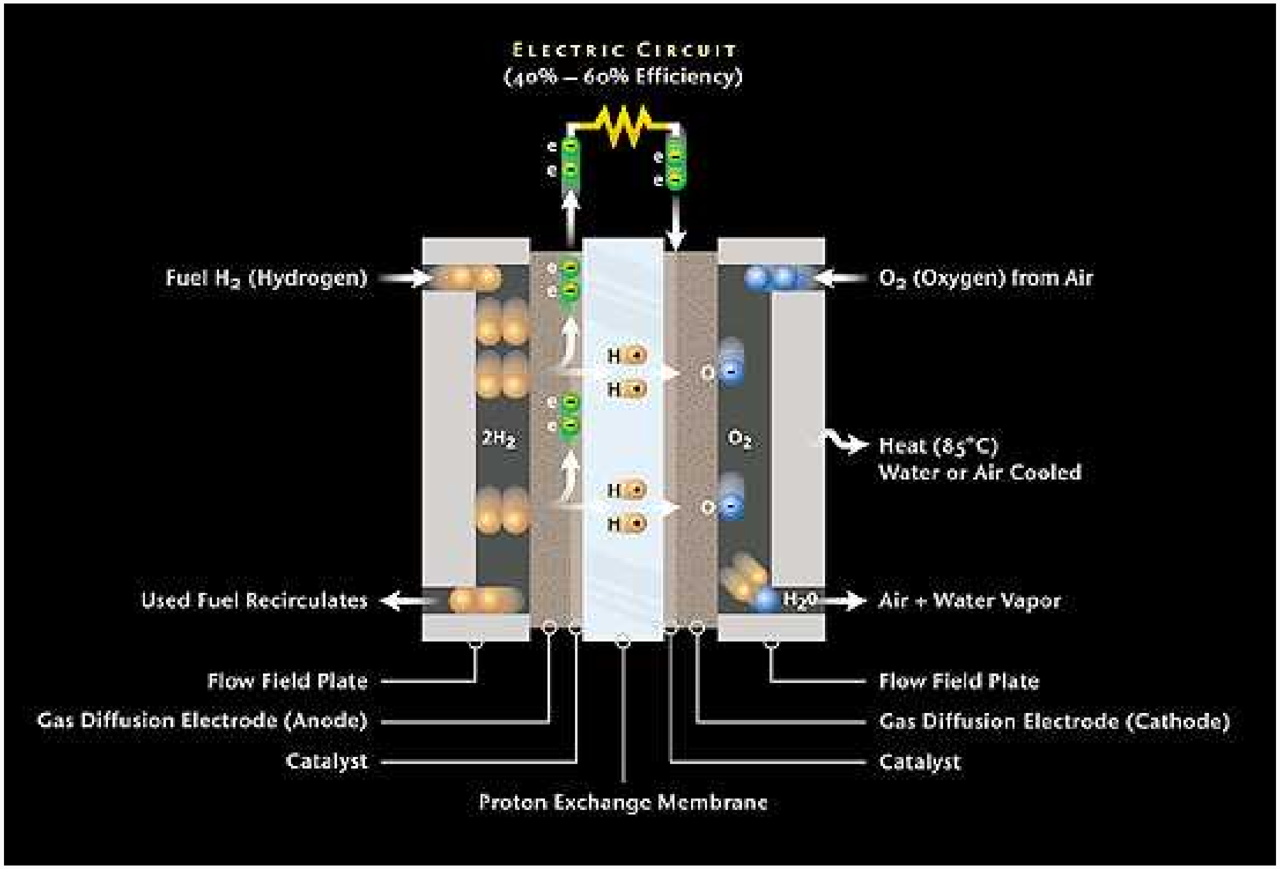
$$2H_2 \rightarrow 4H^+ + 4e^-$$

At the cathode, oxygen reacts with electrons taken from the electrode, and H^+ ions from the electrolyte, to form water

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

An acid with free H^+ ions. Certain polymers can also be made to contain mobile H^+ ions - proton exchange membranes (PEM)

Membrane Electrode Assembly

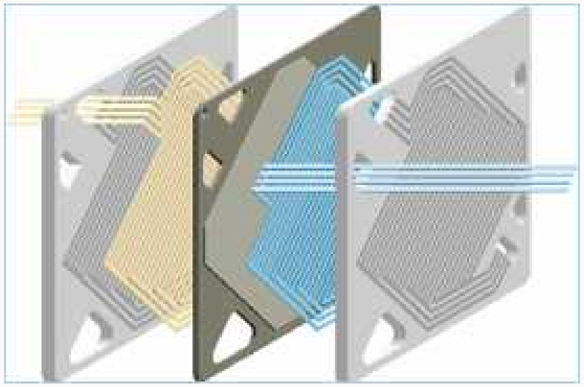


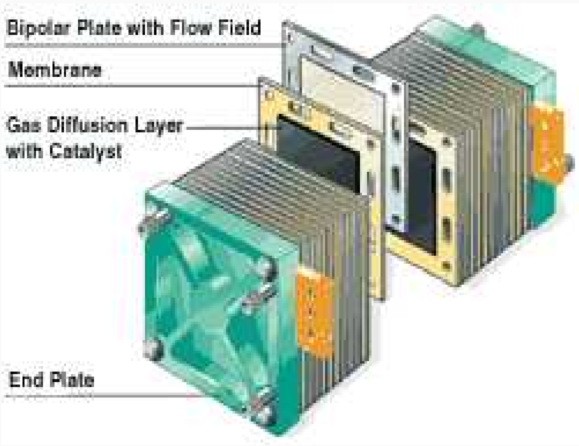
The MEA consists of two electrodes, the anode and the cathode, which are each coated on one side with a thin catalyst layer and separated by a proton exchange membrane (PEM). The flow-field plates direct hydrogen to the anode and oxygen (from air) to the cathode.

When hydrogen reaches the catalyst layer, it separates into protons (hydrogen ions) and electrons.

The free electrons, produced at the anode, are conducted in the form of a usable electric current through the external circuit. At the cathode, oxygen from the air, electrons from the external circuit and protons combine to form water and heat.

Fuel Cell Stack





Hydrogen

Hydrogen flows through channels in flow field plates to the anode where the platinum catalyst promotes its separation into protons and electrons. Hydrogen can be supplied to a fuel cell directly or may be obtained from natural gas, methanol or petroleum using a fuel processor, which converts the hydrocarbons into hydrogen and carbon dioxide through a catalytic chemical reaction.

Membrane Electrode Assembly

Each membrane electrode assembly consists of two electrodes (the anode and the cathode) with a very thin layer of catalyst, bonded to either side of a proton exchange membrane.

Air

Air flows through the channels in flow field plates to the cathode. The hydrogen protons that migrate through the proton exchange membrane combine with oxygen in air and electrons returning from the external circuit to form pure water and heat. The air stream also removes the water created as a by-product of the electrochemical process.

Flow Field Plates

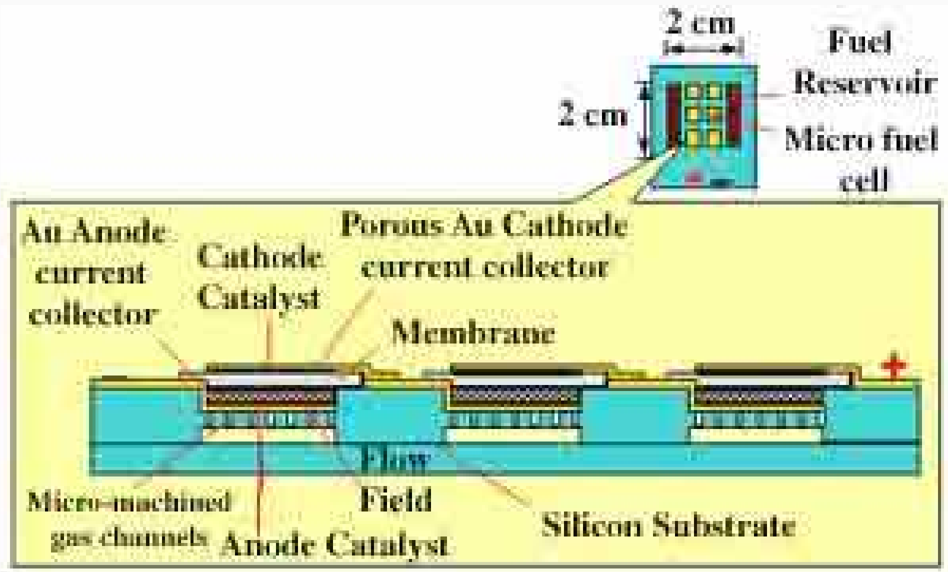
Gases (hydrogen and air) are supplied to the electrodes of the membrane electrode assembly through channels formed in flow field plates.

Fuel Cell Stack

To obtain the desired amount of electrical power, individual fuel cells are combined to form a fuel cell stack. Increasing the number of cells in a stack increases the voltage, while increasing the surface area of the cells increases the current.

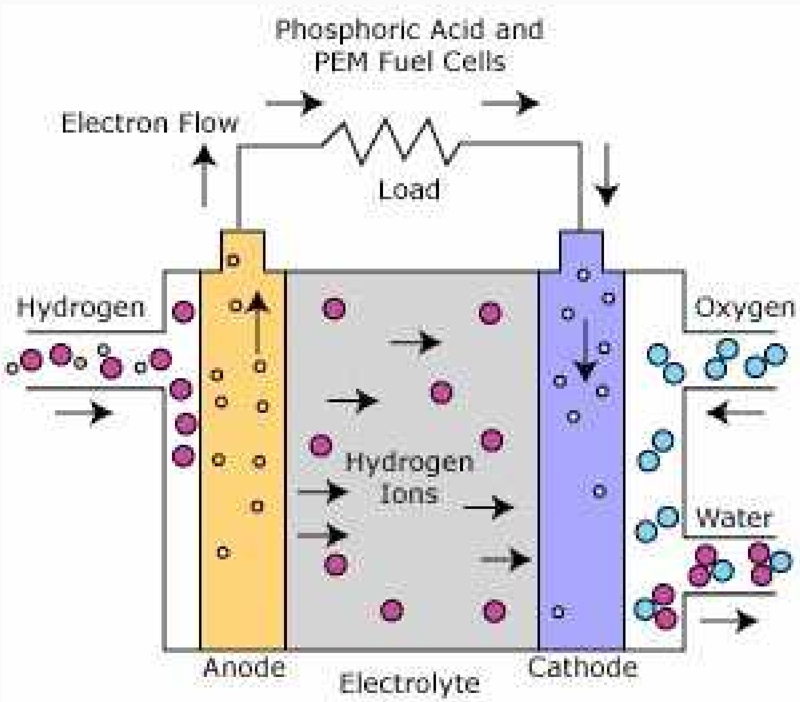
Micro Fuel Cell

The fuel cells are 5 mm^3 and generate up to 100 mWatts.



CWRU (Case Western Reserve University) researchers have miniaturized this process through the use of micro fabrication technology, which is used to print multiple layers of fuel cell components onto a substrate. Inks were created to replicate the components of the fuel cell, which means that the anode, cathode, catalyst and electrolyte are all made of ink, rather than traditional fuel cell materials. Researchers screen printed those inks onto a ceramic or silicon structure to form a functioning fuel cell.

Proton Exchange Membrane Fuel Cells (PEMFC)



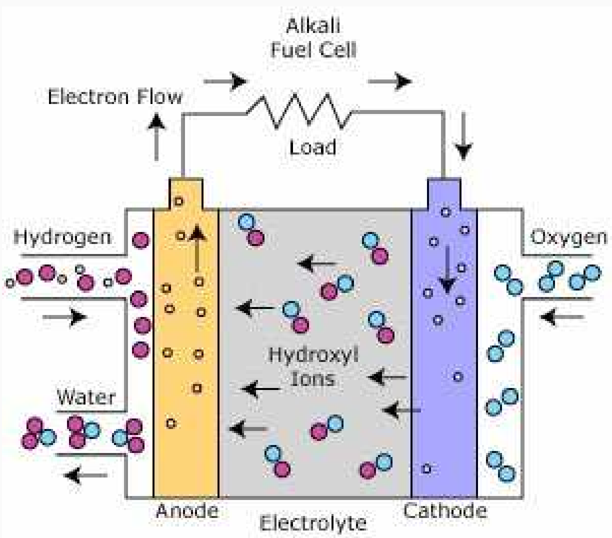
PEM fuel cells use a solid polymer membrane (a thin plastic film) as the electrolyte. This polymer is permeable to protons when it is saturated with water, but it does not conduct electrons.

The reactions at the electrodes are as follows:

Anode Reactions: $2H_2 => 4H+ + 4e-$
Cathode Reactions: $O_2 + 4H+ + 4e- => 2 H_2O$
Overall Cell Reactions: $2H_2 + O_2 => 2 H_2O$

Compared to other types of fuel cells, PEMFCs generate more power for a given volume or weight of fuel cell. This high-power density characteristic makes them compact and lightweight. In addition, the operating temperature is less than 100ºC, which allows rapid start-up. These traits and the ability to rapidly change power output are some of the characteristics that make the PEMFC the top candidate for automotive power applications.

Alkaline Fuel Cell



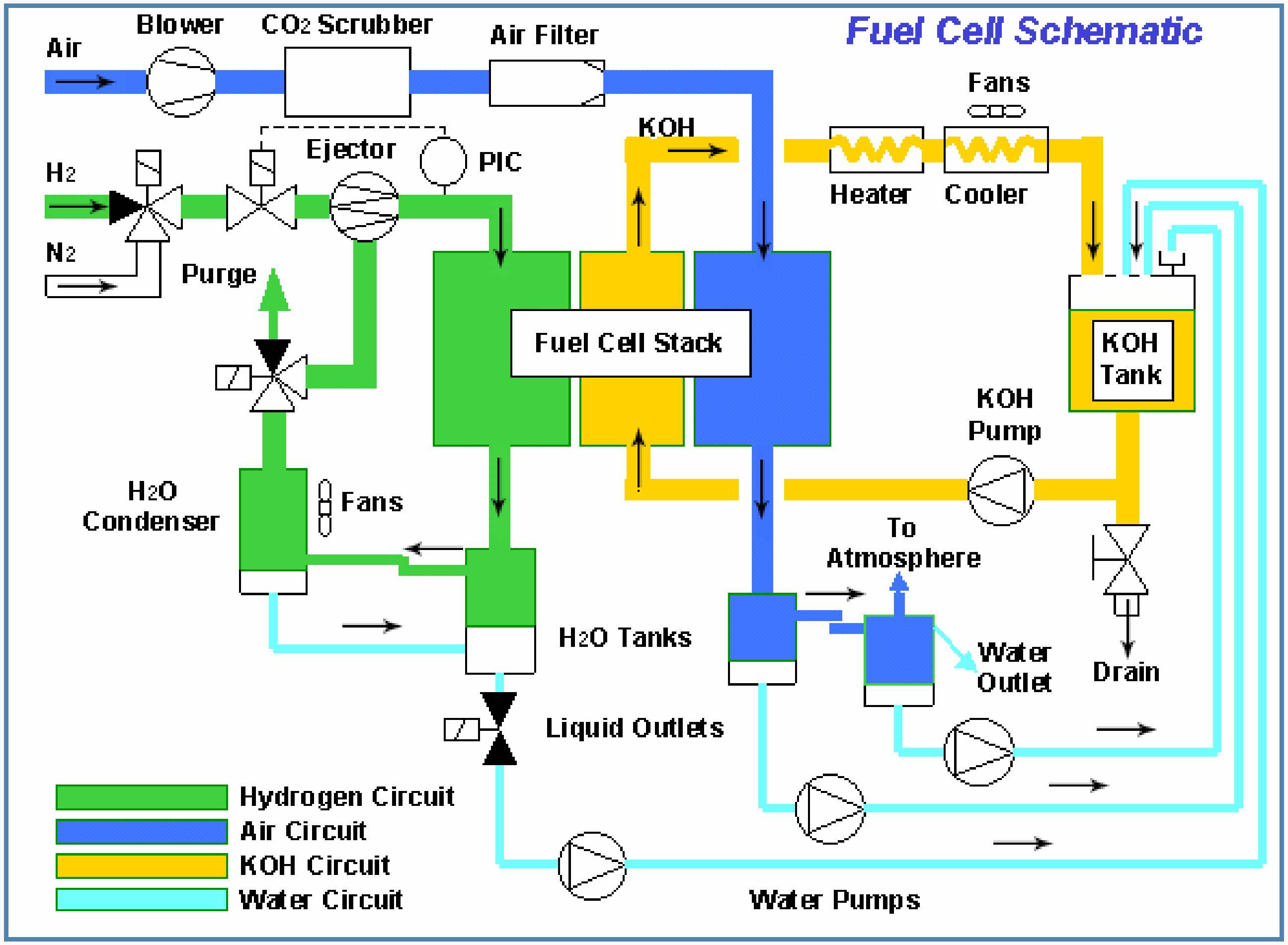
Alkaline fuel cells (AFC) are one of the most developed technologies and have been used since the mid-1960s by NASA in the Apollo and Space Shuttle programs. The fuel cells on board these spacecraft provide electrical power for on-board systems, as well as drinking water. AFCs are among the most efficient in generating electricity at nearly 70%.

Alkaline fuel cells use an electrolyte that is an aqueous (water-based) solution of potassium hydroxide (KOH) retained in a porous stabilized matrix. The concentration of KOH can be varied with the fuel cell operating temperature, which ranges from 65°C to 220°C. The charge carrier for an AFC is the hydroxyl ion (OH-) that migrates from the cathode to the anode where they react with hydrogen to produce water and electrons. Water formed at the anode migrates back to the cathode to regenerate hydroxyl ions. Therefore, the chemical reactions at the anode and cathode in an AFC are shown below. This set of reactions in the fuel cell produces electricity and by-product heat.

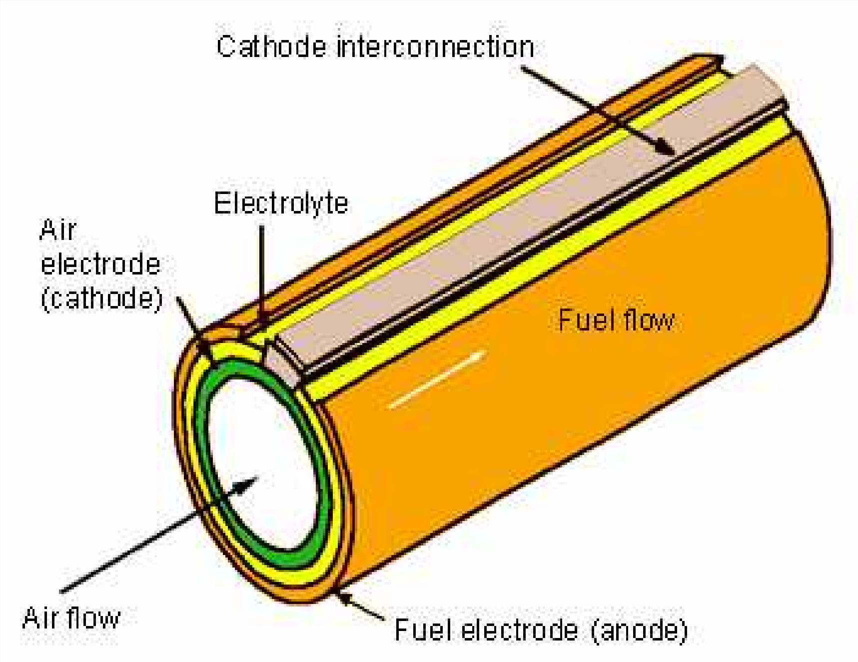
Anode Reaction:	$2 H_2 + 4 OH^- \Rightarrow 4 H_2O + 4 e^-$
Cathode Reaction:	$O_2 + 2 H_2O + 4 e^- \Rightarrow 4 OH^-$
Overall Net Reaction:	$2 H_2 + O_2 \Rightarrow 2 H_2O$

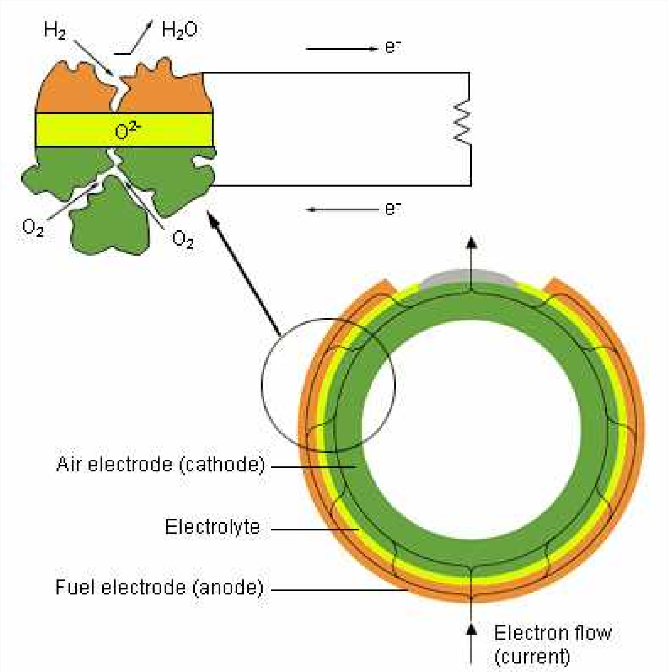
One characteristic of AFCs is that they are very sensitive to CO_2 that may be present in the fuel or air. The CO_2 reacts with the electrolyte, poisoning it rapidly, and severely degrading the fuel cell performance. Therefore, AFCs are limited to closed environments, such as space and undersea vehicles, and must be run on pure hydrogen and oxygen. Furthermore, molecules such as CO, H_2O and CH_4, which are harmless or even work as fuels to other fuel cells, are poisons to an AFC.

Alkaline Fuel Cell System



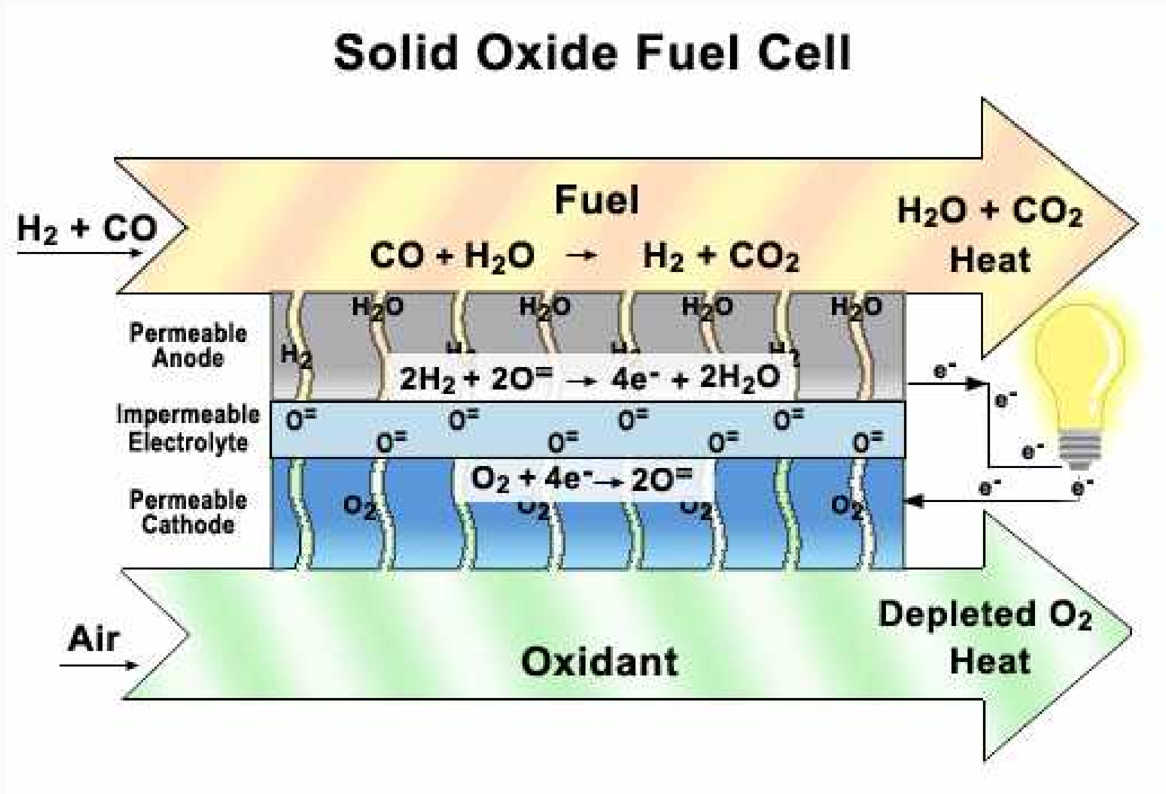
Solid Oxide Fuel Cell



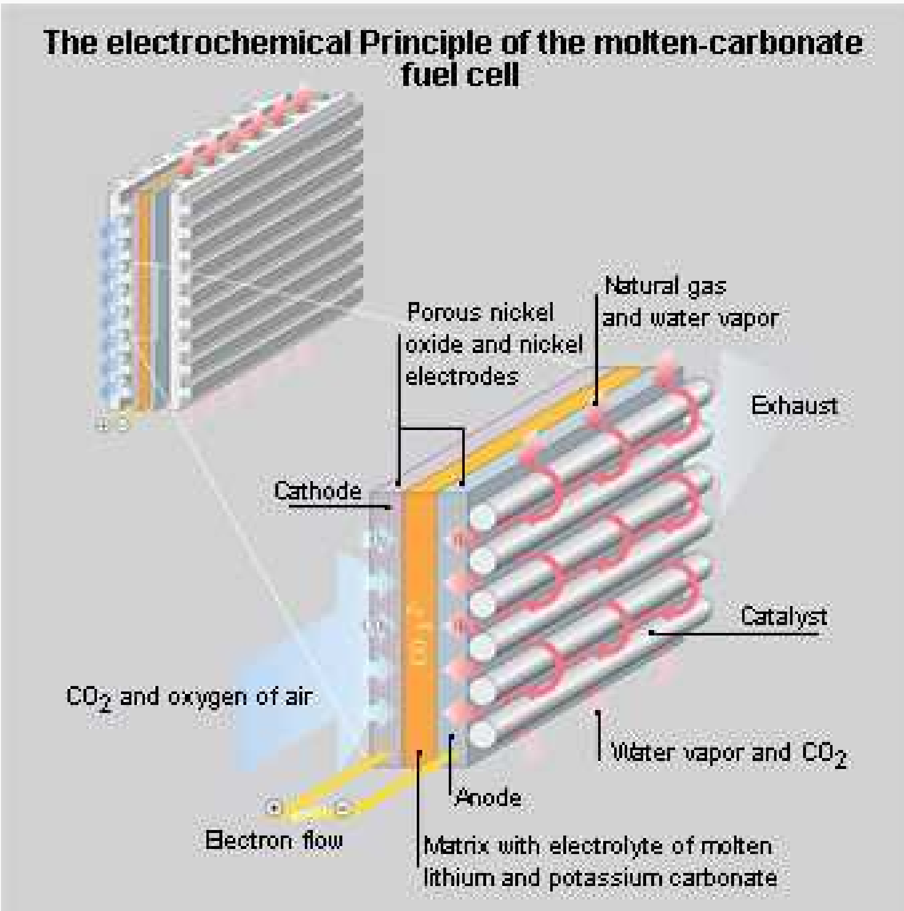


Solid oxide fuel cells (SOFC) can also utilize carbon monoxide (CO). This makes them more fuel flexible and also generally more efficient with available fuels, such as natural gas or propane. Hydrogen and CO can be produced from natural gas and other fuels by steam reforming, for example. Fuel cells like SOFCs that can reform natural gas *internally* have significant advantages in efficiency and simplicity when using natural gas because they do not need an external reformer. When the ions reach the fuel at the anode they oxidize the hydrogen to H_2O and the CO to CO_2. In doing so they release electrons, and if the anode and cathode are connected to an external circuit this flow of electrons is seen as a dc current. This process continues as long as fuel and air are supplied to the cell.

Solid Oxide Fuel Cell

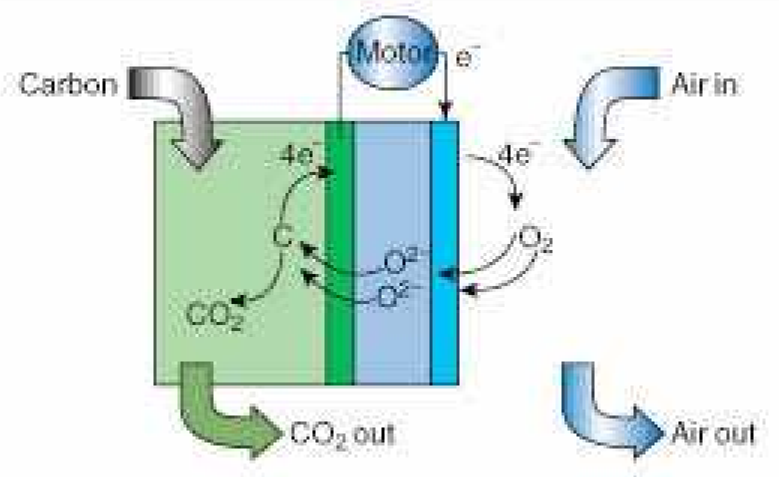


Molten-carbonate Fuel Cell



The diaphragm between the anode and the cathode consists of a matrix filled with a carbonate electrolyte. Carbonate ions (CO_3^{2-}) pass through the diaphragm and reach the anode. Here they discharge an oxygen atom, which combines with the hydrogen flowing past to form water (H_2O). This sets carbon dioxide (CO_2) and two electrons free. The electrons flow over an electronic conductor to the cathode: current flows. Similarly, the remaining carbon dioxide (CO_2) is fed to the cathode side, where it absorbs the electrons and an oxygen atom from the air that is flowing past. It then re-enters the process as a carbonate ion.

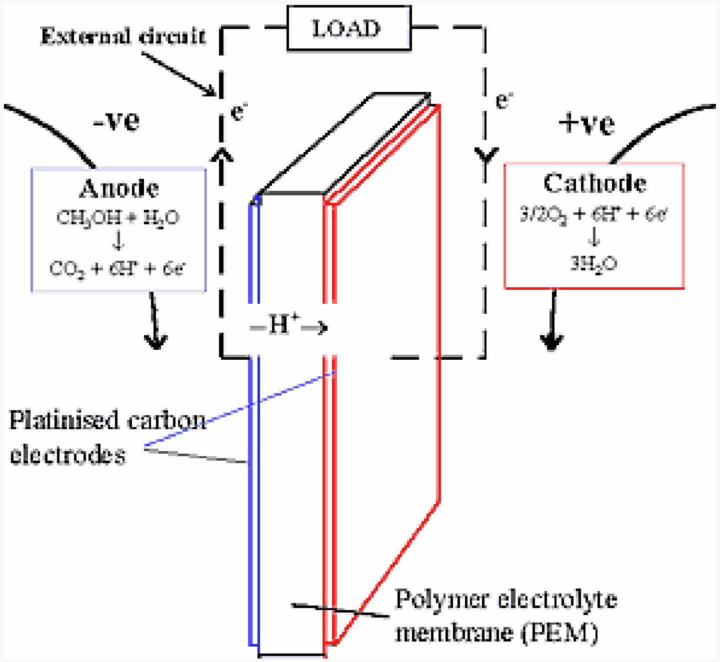
Carbon Conversion Fuel Cell



Carbon (C) and oxygen (O_2) can react in a high-temperature fuel cell with the carbon, delivering electrons (e) to an external circuit that can power a motor. The net electrochemical reaction— carbon and oxygen forming carbon dioxide—is the same as the chemical reaction for carbon combustion, but it allows greater efficiency for electricity production. The pure carbon dioxide (CO_2) product can be sequestered in an underground reservoir or used to displace underground deposits of oil and gas.

Instead of using gaseous fuels, as is typically done, the new technology uses aggregates of extremely fine (10- to 1,000-nanometer-diameter) carbon particles distributed in a mixture of molten lithium, sodium, or potassium carbonate at a temperature of 750 to 850°C. The overall cell reaction is carbon and oxygen (from ambient air) forming carbon dioxide and electricity. The reaction yields 80 percent of the carbon–oxygen combustion energy as electricity. It provides up to 1 kilowatt of power per square meter of cell surface area—a rate sufficiently high for practical applications. Yet no burning of the carbon takes place.

Direct Methanol Fuel Cell



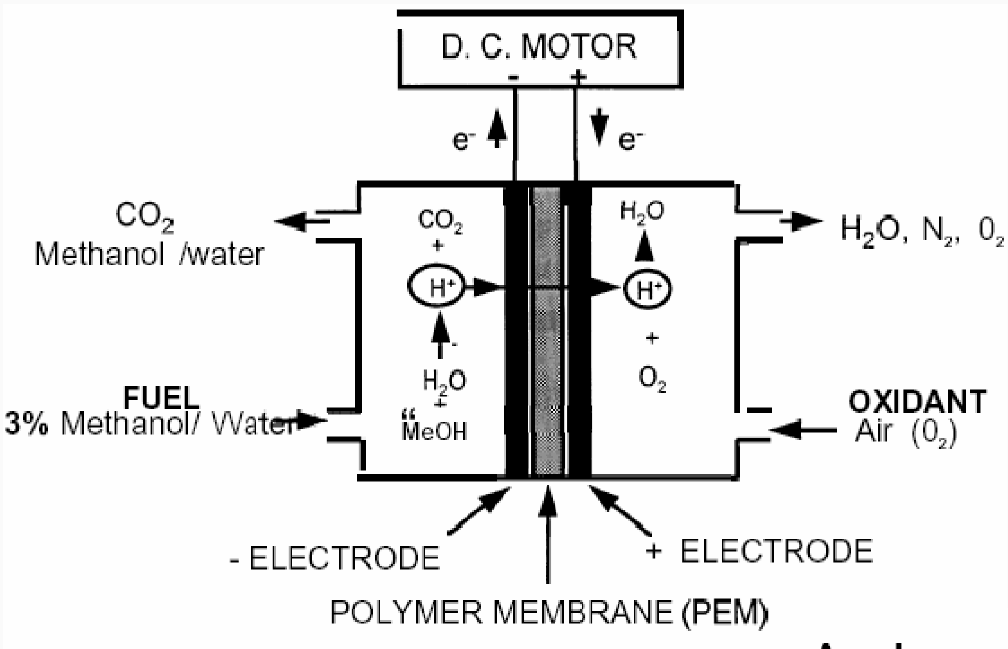
Fuel cell that utilizes methanol as fuel. When providing current, methanol is electrochemically oxidized at the anode electrocatalyst to produce electrons which travel through the external circuit to the cathode electrocatalyst where they are consumed together with oxygen in a reduction reaction. The circuit is maintained within the cell by the conduction of protons in the **electrolyte**.

In modern cells, electrolytes based on proton conducting polymer electrolyte membranes (e.g., Nafion™) are often used, since these allow for convenient cell design and for high temperature and pressure operation. The overall reaction occurring in the DMFC is the same as that for the direct combustion of methanol,

$$CH_3OH + 3/2O_2 \longrightarrow CO_2 + 2H_2O$$

Since the fuel cell operates isothermally, all the free energy associated with this reaction should in principle be converted to electrical energy. However, kinetic constraints within both electrode reactions together with the net resistive components of the cell means that this is never achieved. As a result, the working voltage of the cell falls with increasing current drain. These losses are known as polarization and minimizing the factors that give rise to them is a major aim in fuel cell research.

Direct Methanol Fuel Cell

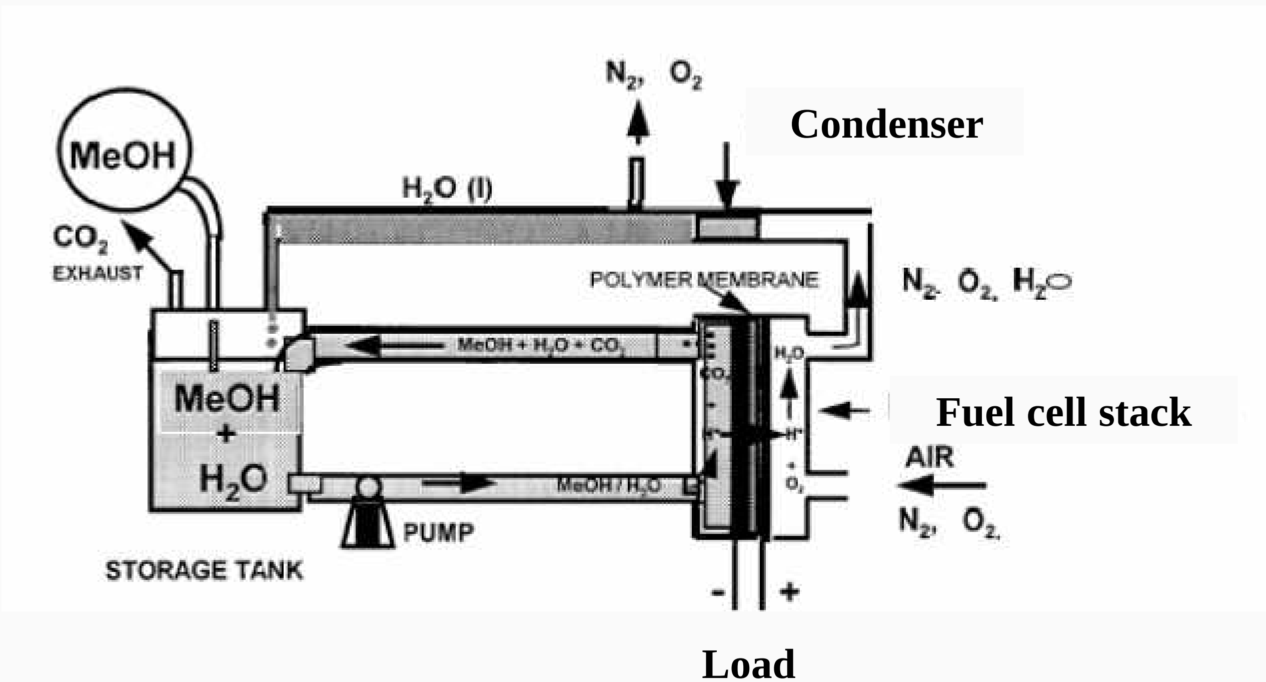


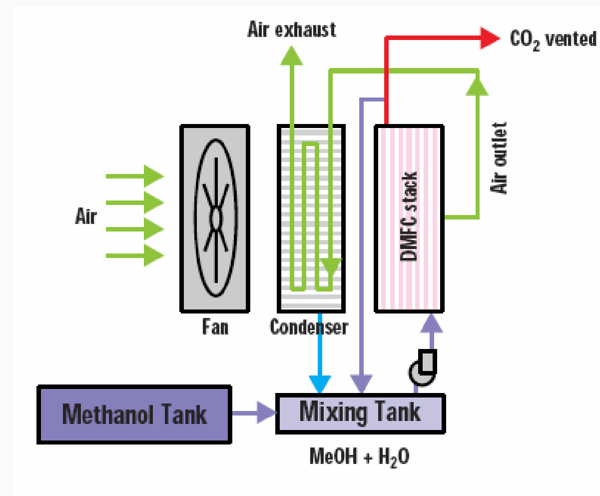
Anode	$CH_3OH + H_2O = CO_2 + 6H^+ + 6e^-$
Cathode	$6H^+ + 3/2O_2 + 6e^- = 3H_2O$
Net Reax	$CH_3OH + 3/2O_2 = CO_2 + 2H_2O$

1 LITER OF CH_3OH CAN PRODUCE ~ 5000 Wh

34% (1700 Wh/l) ACHIEVED THUS FAR

Direct Methanol Fuel Cell





Schematic of direct methanol fuel cell system.
(Courtesy: Los Alamos National Laboratory)

Fuel Cell Applications

Stationary power generation ~ 5 - 250 kW

Portable applications ~ 1 kW or lower

Automotive applications ~ 5 - 100 kW

Airplane Applications ~ 10 - 250 kW

1kW = 1.3404826 horsepower

Stationary Power Generation

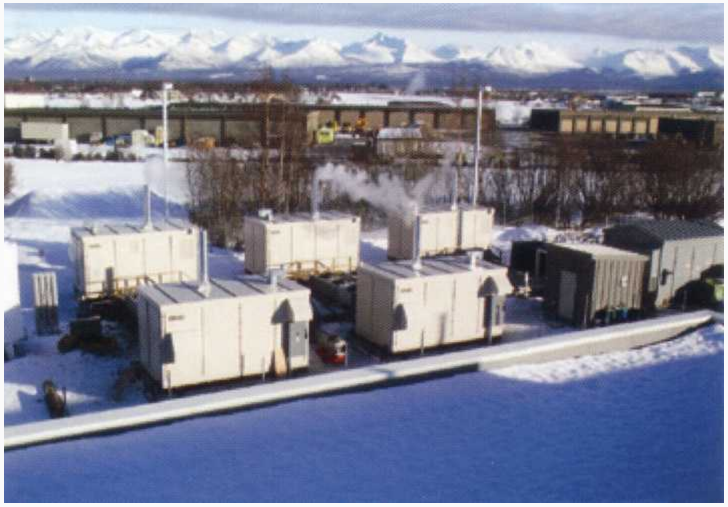
Important factors:

The hours of operation per year

The electric efficiency of the electricity generation process

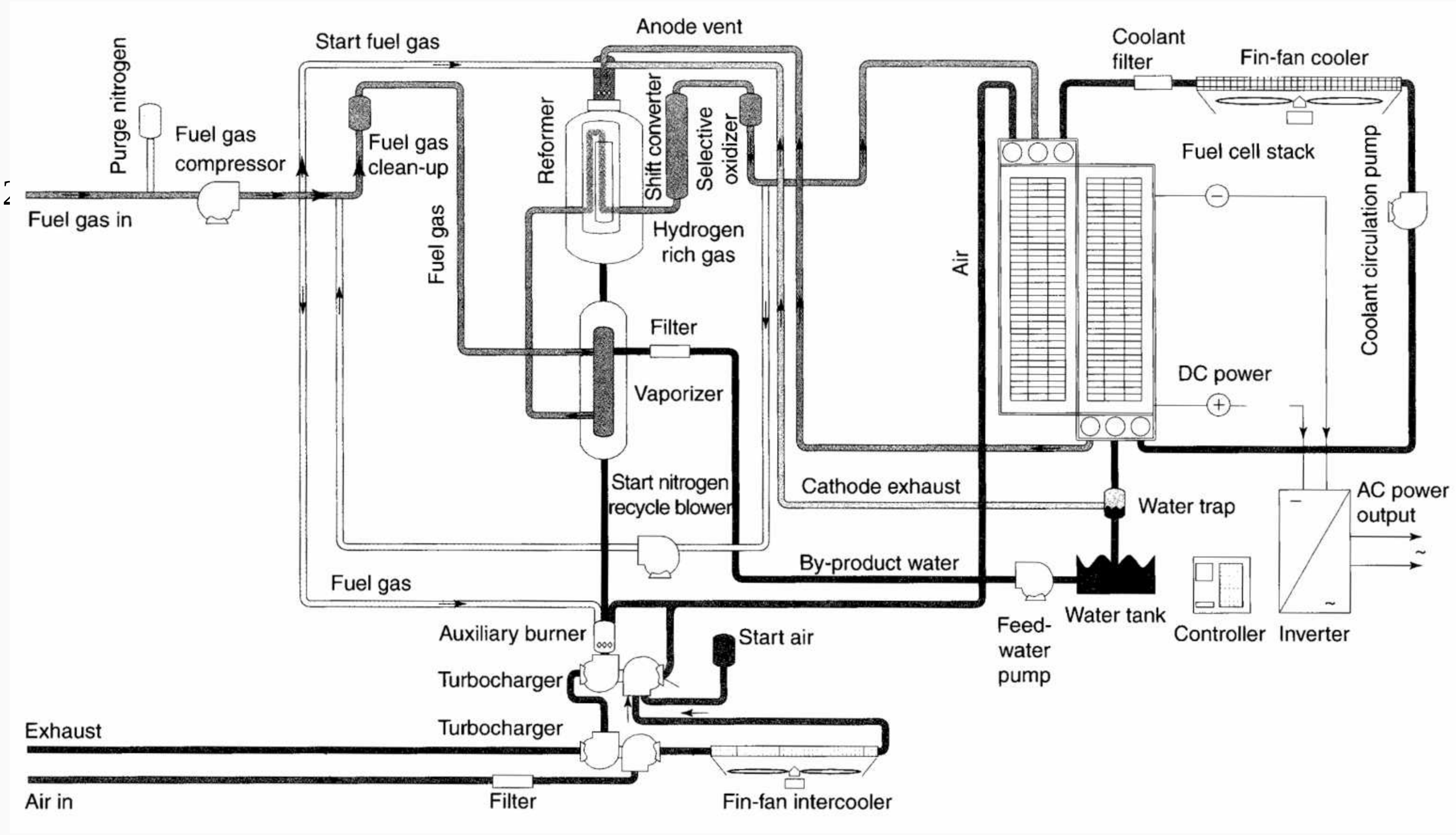
The capital investment

Fuel cells are particularly suitable for on-site power generation. Utilizing the heat generated by the fuel cell improves the overall efficiency - Combined Heat and Power generation (CHP).



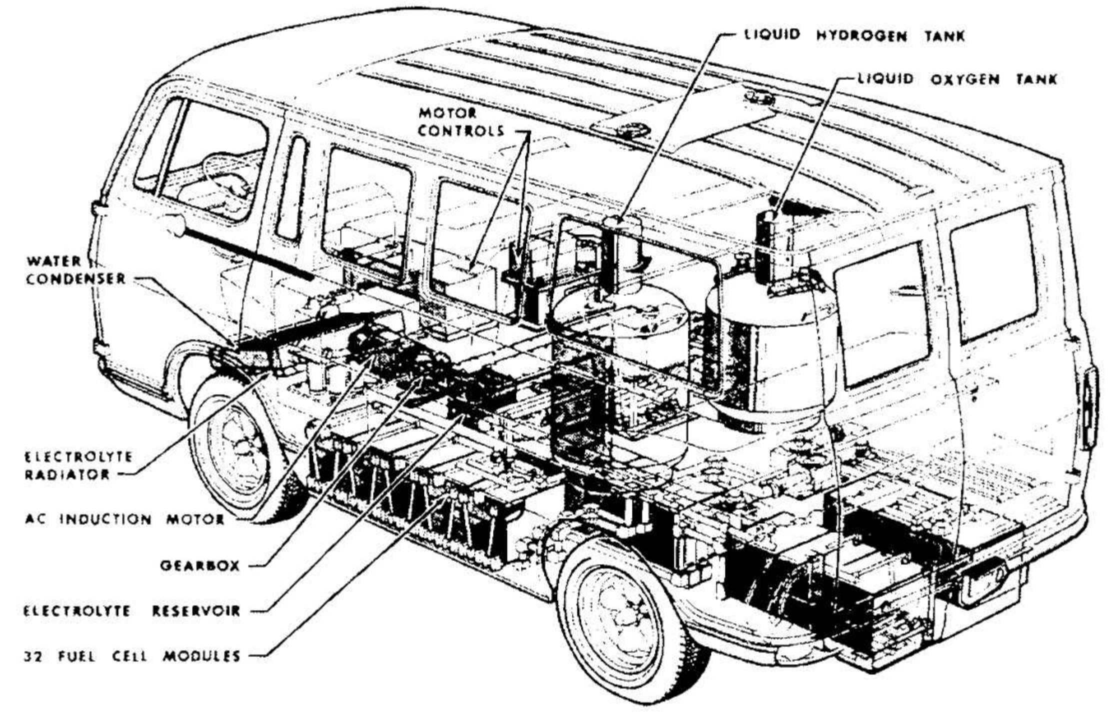
PEMPC Power Plant

Process Flow Diagram for a Ballard 250 kW PEMFC Plant



GM Fuel Cell Powered Automobile

Electrovan -1967

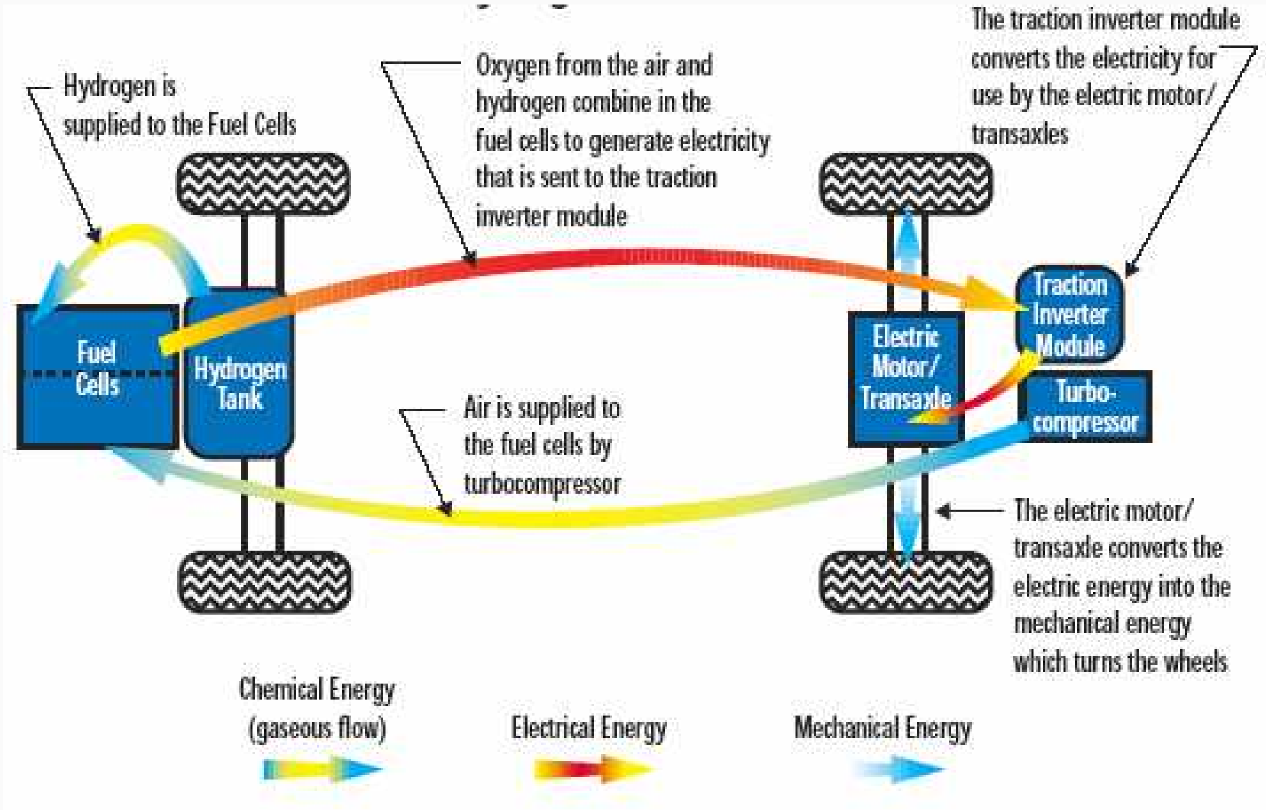


Alkaline fuel cell modules supplying 32 kW

Zero Emission Vehicle - 2006

PEM FC modules

Hydrogen Fuel Cell Car



The P2000, from Ford Motor Company, is a zero-emission vehicle that utilizes a direct hydrogen polymer electrolyte fuel cell. (Courtesy of Ford Motor Co.)

Automotive Applications

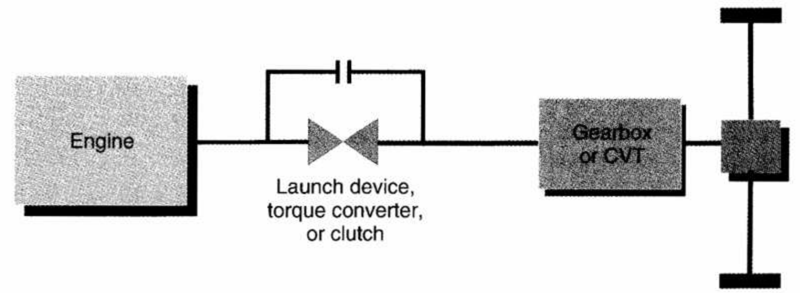


Figure 11.5 Conventional ICE vehicle power train.

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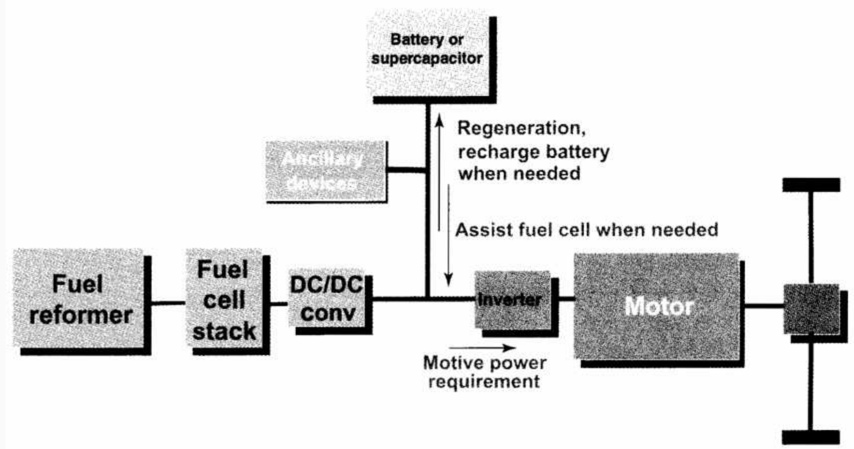

Figure 11.6 Fuel cell parallel hybrid power train configuration.

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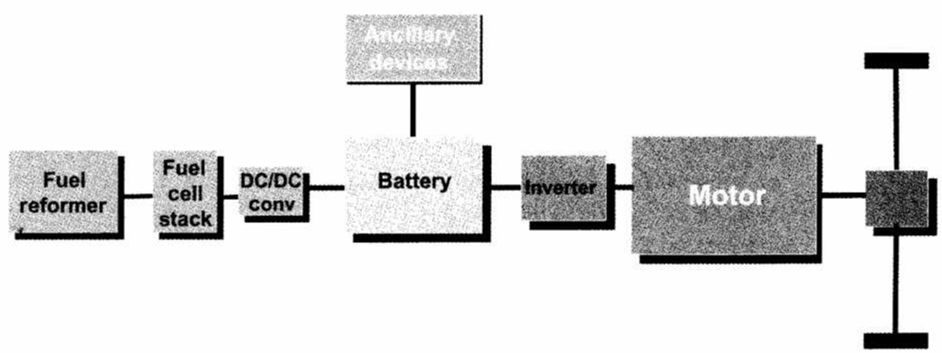
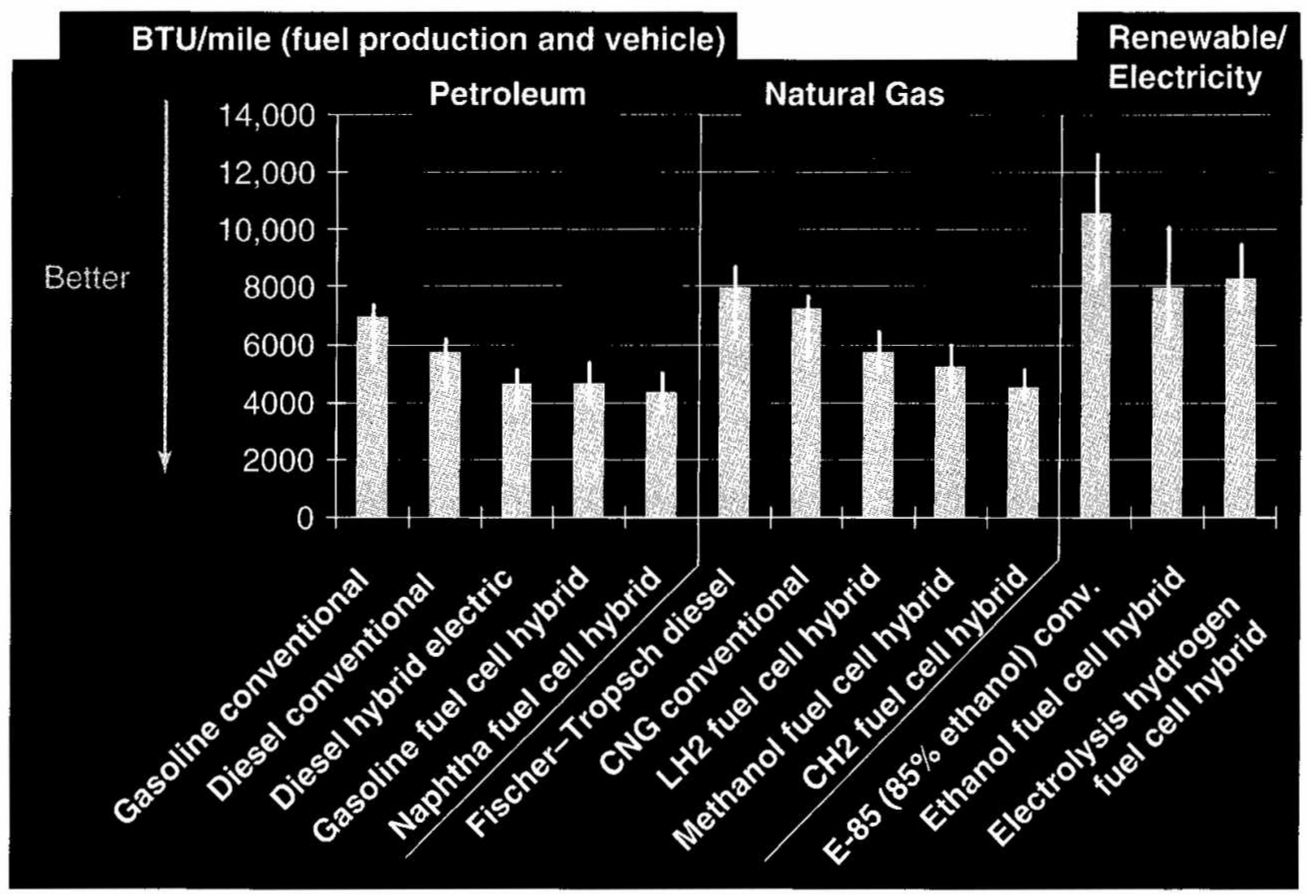


Figure 11.7 Fuel cell series hybrid power train configuration.

Sustainable Energy Science and Engineering Center

Fuel Cell Performance



Fuel Cell Powered Automobile - Progress

TABLE 10.1 Progress of General Motors Stack Hardware

Stack	Gen 3	Gen 4	Gen 7	Stack 2000	Stack 2001
Year developed	1997	1998	1999	2000	2001
Stack power (kW)	37–41	23–40	80–120	94–129	102–129
Power density (kW/l)	0.26	0.77	1.10	1.60	1.75
Specific power (kW/kg)	0.16	0.31	0.47	0.94	1.22[a]
Cells	220	106	200	200	640
Active area (cm^2)	500	500	800	800	?
Pressure (bar)	2.7	2.7	2.7	1.5–2.7	?
Temperature (°C)	80	80	80	80	?
Dimensions (mm)	—	—	590 × 270 × 500	472 ×251 × 496	140 × 820 ×500
Other features	—	—	—	No external humidification	No external humidification
Used in	—	1998 Zafira ?	HydroGen 1	HydroGen 3	—

Note: Figure 10.1 shows photographs of these stacks.

[a] Calculated by the author.

Source: Data from Opel and from the Web sites of Fuel Cell Today and General Motors.

Fuel Cell Powered Automobile - Progress

Daimler-Chrysler NeCar:

TABLE 10.16 Technical Data of NeCar 4 — Advanced

Fuel cell vehicle name (date)	NeCar 4 — advanced (2000)
Vehicle base	Mercedes-Benz A class
Dimensions	—
Seating capacity	5
Maximum speed	145 km/h (90 mi/h)
Fuel cell type/power rating	Ballard Mark 900/75 kW
Motor type/power rating/torque	—
Fuel processing	Direct hydrogen
Fuel storage	2.5 kg of hydrogen compressed at 35 MPa
Backup battery	None
System	—
Drive range	200 km (125 mi)

Source: U.S. Office of Transportation Technologies, Department of Energy, January 2002.

TABLE 10.17 Technical Data for DaimlerChrysler's NeCar 5

Fuel cell vehicle name (place and date exhibited)	NeCar 5 (Berlin, November 7, 2000)
Vehicle base	Mercedes-Benz A class
Dimensions	—
Seating capacity	5
Maximum speed	150 km/h (95 mi/h)
Fuel cell type/power rating	Ballard Mark 900/75 kW
Motor type/power rating/torque	—
Fuel processing	Methanol reformer
Fuel storage	Methanol tank
Backup battery	None
System	—
Drive range	—

Source: Ballard home page and Fuel Cells 2000 Information Service, 2002.

Fuel Cell Powered Automobile - Progress

Ford Focus Hydrogen -powered fuel cell vehicle

TABLE 10.20 Technical Data for Ford's Focus FCV Hydrogen-Powered Fuel Cell Vehicle

Fuel cell vehicle name (date)	Ford Focus FCV (2001)
Vehicle base	Ford Focus
Dimensions/weight	4338 mm (l) × 1758 mm (w)/1727 kg (3800 lb)
Seating capacity	5
Maximum speed	>80 mi/h (>128 km/h)
Fuel cell type/power rating	Ballard Mark 901/75 kW
Motor type/power rating/torque	67 kW (90 hp) AC induction motor from Ecostar, 190 N.m maximum torque
Fuel processing	Direct hydrogen
Fuel storage	1.4 kg of hydrogen at 24.8 MPa (3600 psi)
Backup battery	?
System	?
Drive range	100 mi (160 km)

Sources: Ford's Think Web site, 2002; Ballard press release, 2001; Fuel Cells 2000 Information Service; L-B-Systemtechnik, 2002.

Fuel Cell Powered Automobile - Progress

Honda fuel cell car

TABLE 10.30 Technical Data for Honda's FCX-V4

Fuel cell vehicle name (date)	Honda FCX-V4 (September 2001)
Vehicle base	Honda EV Plus
Dimensions/weight	4045 mm (l) × 1810 mm (w)/1740 kg
Seating capacity	4
Maximum speed	140 km/h (87 mi/h)
Fuel cell type/power rating	Ballard Mark 900/78 kW
Motor type/power rating/torque	Permanent magnet AC synchronous/60 kW (82 hp)/238 N·m
Fuel processing	Direct hydrogen
Fuel storage	Compressed hydrogen, 35 MPa, 130 liters; located under rear seat
Backup battery	Ultra-capacitors
System	—
Drive range	330 km (205 mi)

Source: Fuel Cell Today, 2001; Ballard, press release, 2001; Hydrogen & Fuel Cell Letter, November 2001; L-B-Systemtechnik fuel cell car listing, 2002.

Methanol Fuel Cell Powered Automobile

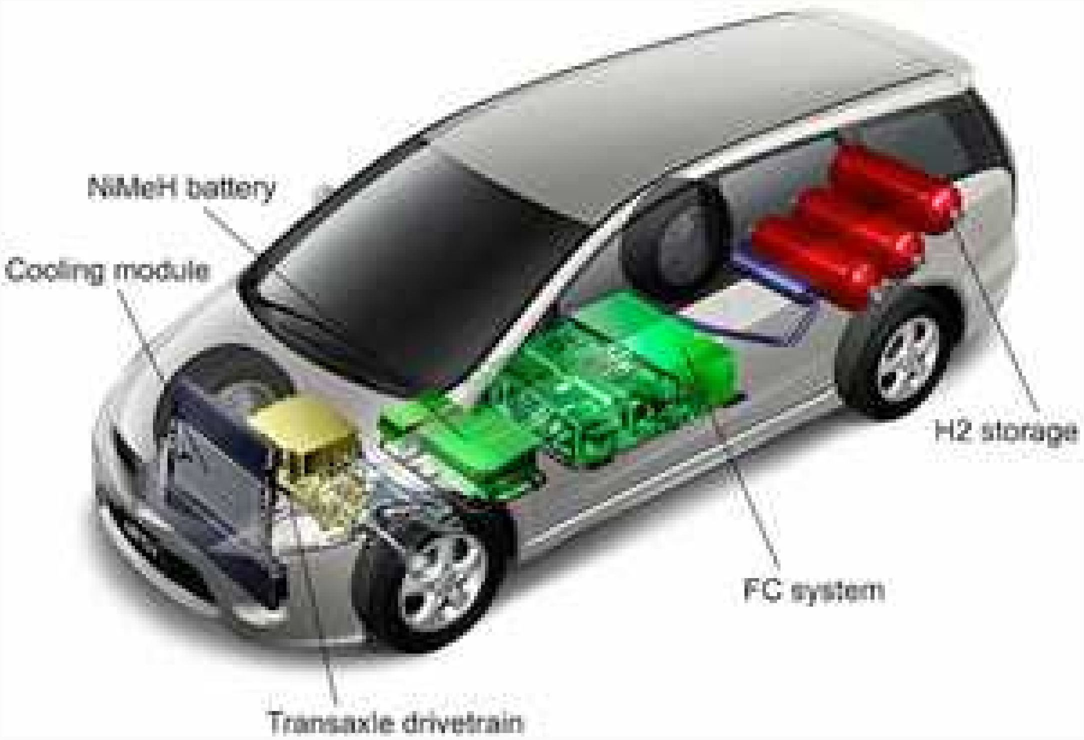
Toyota's Methanol-powered Fuel cell Electric Vehicle

TABLE 10.6 Technical Data for Toyota's Methanol-Powered RAV4 FC EV

Fuel cell vehicle name (date)	RAV4 FC EV (September 1997)
Vehicle base	Toyota RAV4
Dimensions	3980 mm (l) × 1695 mm (w) × 2410 mm (h)
Seating capacity	5
Maximum speed	125 km/h (80 mi/h)
Fuel cell type/power rating	25 kW PEMFC, 400 cells, 1.05 × 0.5 × 0.24 m 0.2 $kWdm^{-3}$
Motor type/power rating	Synchronized permanent magnet/50 kW
Fuel processing	Methanol with reformer — 600 mm (l) × 300 mm (diameter)
Fuel storage	Methanol tank
Backup battery	NiMH, regenerative braking
Drive range	Approximately 500 km (310 mi)

Source: L-B-Systemtechnik fuel cell car listing, February 2002.

Fuel Cell Powered Automobile



An x-ray view of Mitsubishi's new fuel cell Grandis minivan.

Portable Application

Typically well under 100W of power with significantly higher power densities or larger energy storage capacity than those of advanced batteries.

Power generation on a larger scale , say 1 kw continuous output to replace gasoline or diesel generators or supply quiet electric power on boats, caravans or trucks.

Solar Powered Airplane

Helios

Instead of jet fuel, Helios has about 62,000 solar cells across the wing. The solar cells collect energy from the Sun and convert it to electricity, which runs the 14 small motors, which turn the 14 propellers. The propellers are specially designed to pull the aircraft aloft even in the very thin air that's 18 miles high. The next project for the Helios is to use fuel cells to store enough of the sun's energy during the day to continue flying through the night. When this happens, Helios will be able to stay up for weeks and months at a time.

The Helios, developed by Paul McCready, CEO of Aerovironment Corp.,

March 11, 2002

DIGITAL PHOTOS FROM SOLAR AIRPLANE TO IMPROVE COFFEE HARVEST

Funded by NASA

Electric Powered Airplane

The new Electric Plane, or E-Plane, is a high-speed, all-carbon French DynAero Lafayette III, built and donated by American Ghiles Aircraft. The E-Plane is being converted from a combustion engine to electric propulsion in three stages. The first flights, planned for next year, will be on lithium ion batteries. The next flights will be powered by a combination of lithium ion batteries augmented by a fuel cell. Finally, the aircraft will be powered totally by a hydrogen fuel cell, with a range of more than 500 miles.

Supported by Foundation for Advancing Science and Technology Education (FASTec) showed off the plane it is developing as the world's first piloted fuel-cell-powered aircraft.

Fuel Cell Based Aircraft Propulsion

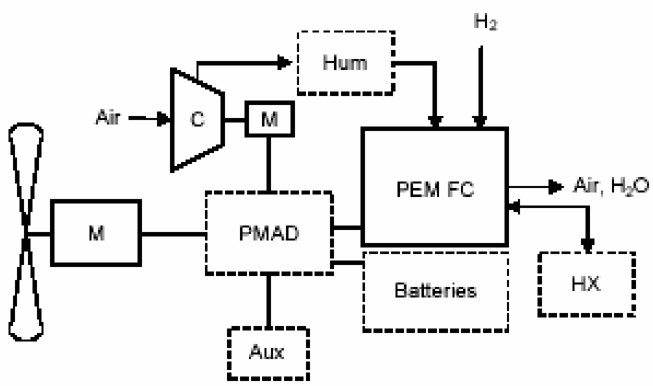


Figure 1.—Fuel cell propulsion system diagram

Table 1.—General assumptions used for technology level projections

	Off-the-Shelf Technology	Intermediate Technology	Advanced Technology
	Based on commercially-available products	*Based on current government and industry research and development*	*Based on government and university laboratory demonstrations*
Fuel Cell Stack	Automotive-derivative PEM fuel cell stack (~1.0 hp/lb)	Higher operating temperature PEM fuel cell stack; higher power densities (~2.0 hp/lb)	New type of fuel cell with different chemistry, higher power densities, more efficient operation (~3.0 hp/lb)
Fuel Cell System	Automotive-derivative compressor, heat exchangers, humidifiers, separator (~0.6 hp/lb)	Integrated heat exchangers, humidifiers, separator into fuel cell; lightweight, more efficient compressor (~1.1 hp/lb)	Humidification, separation, extensive cooling not required (~1.6 hp/lb)
Electric Motor	Automotive-derivative permanent magnet electric motor (~0.7 hp/lb)	Electric motor with advanced cooling and more efficient design (~1.5 hp/lb)	Superconducting electric motor with very efficient and lightweight design (~5.0 hp/lb)
Power Electronics	Automotive-derivative power management and distribution (~0.5 hp/lb)	Higher temperature materials (SiC) and components; advanced cooling; more efficient design (~0.6 hp/lb)	Superconducting electronics for a very efficient and lightweight design (~0.9 hp/lb)
H_2 Storage	Mid-pressure (5000 psi) compressed gas; liquid storage for long-duration missions	Improved high pressure composite tanks; lightweight metal hydrides; lightweight, low-temperature chemical reformation	Liquid system design with low boiloff, high safety; or fuel cell able to use common liquid fuels directly
Batteries	Currently available Li-Ion batteries	Advanced Li-Ion or similar chemistry batteries with higher power density	New battery chemistry with longer life and higher energy density

Source: NASA TM-2003-212393

Fuel Cell Powered Aircraft

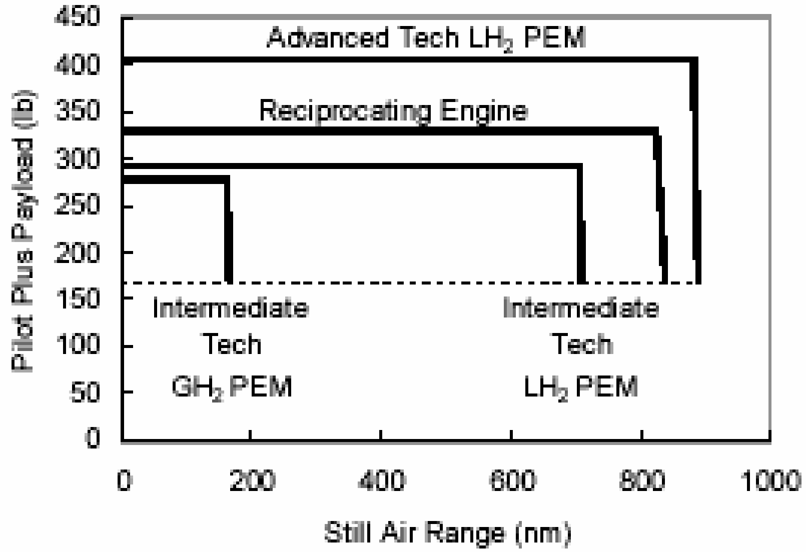


Figure 12.—Intermediate and advanced technology 81 bhp system projections

Fuel Cell Motorbike to Hit US Streets

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Top Speed: 50 mph (80 kmh)

Range: 100 miles (160 km)

Hydrogen Storage tank capacity: 1 kg

Cost: $6,000 - 8000

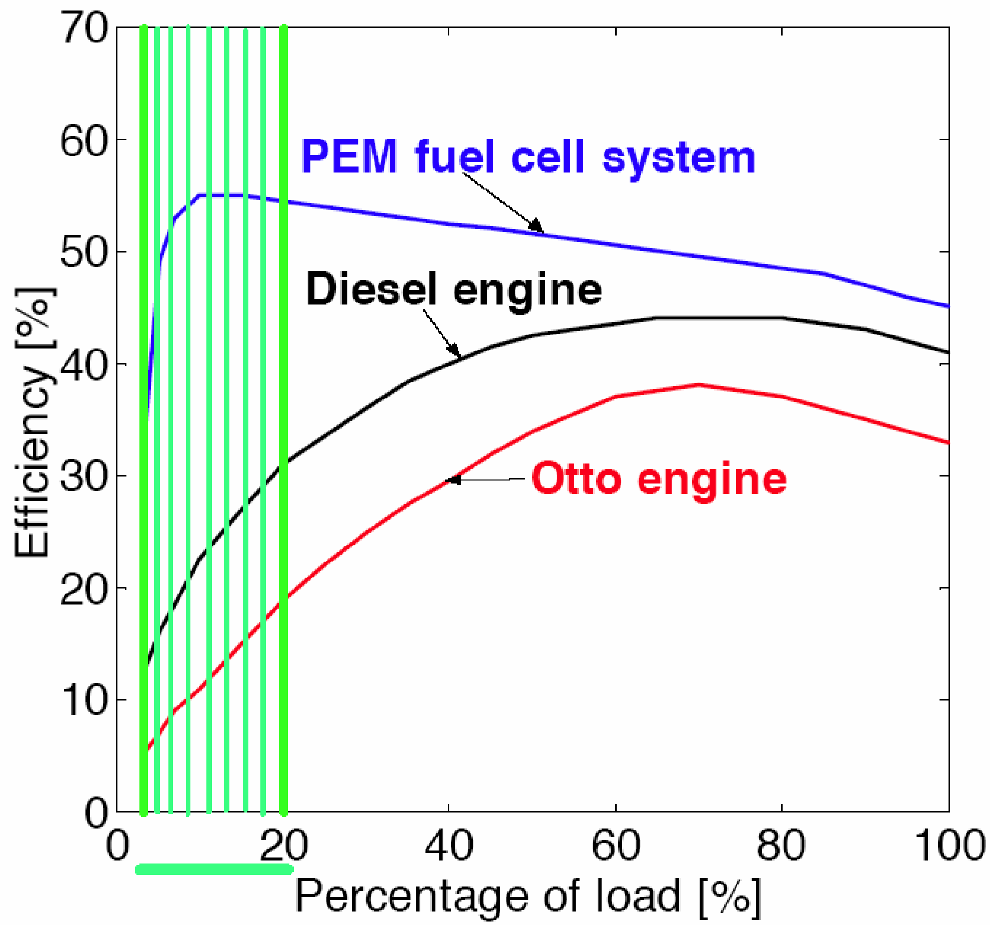
Manufacturer: Intelligent Energy, London, UK

ENY: Emission Neutral Vehicle

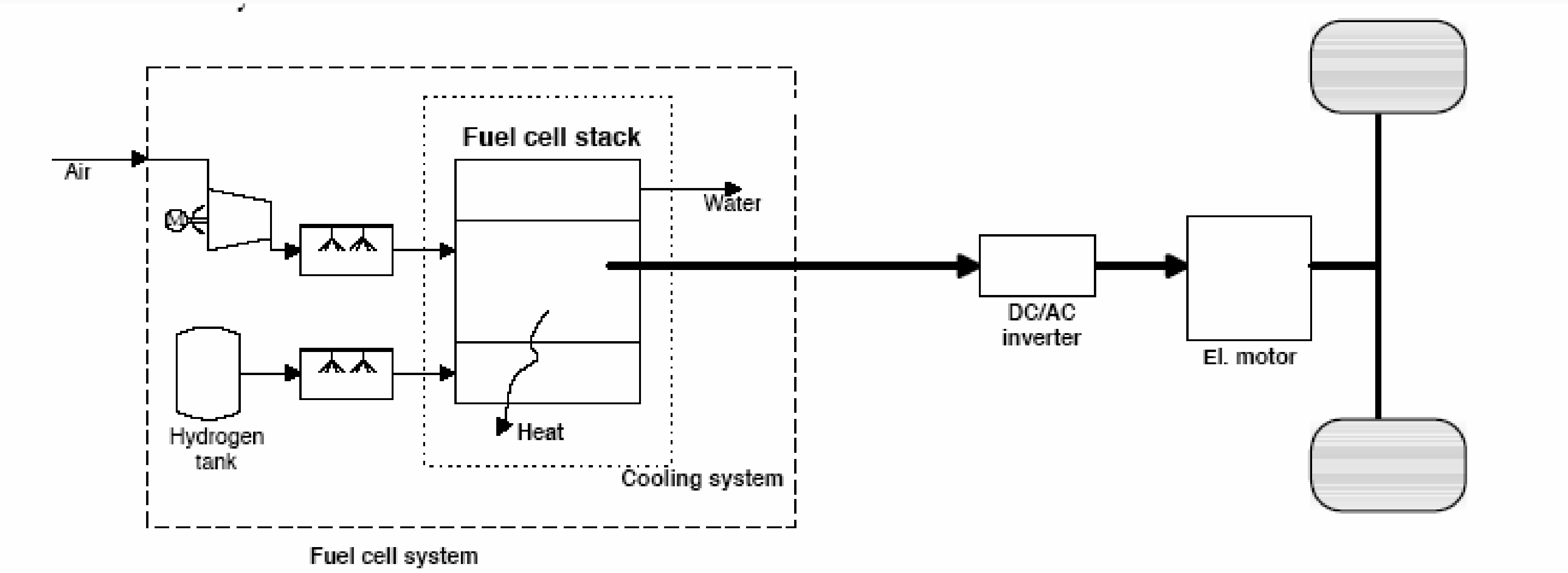
Intelligent Energy is currently developing devices called reformers that extract hydrogen from biodiesel fuels (typically made from vegetable oils or animal fats) and ethanol (generally made from grain or corn). The units would sell for around U.S. $1,500 and could produce enough hydrogen to fill up the ENV for about 25 cents per tank.

National Geographic News, August 2, 2005

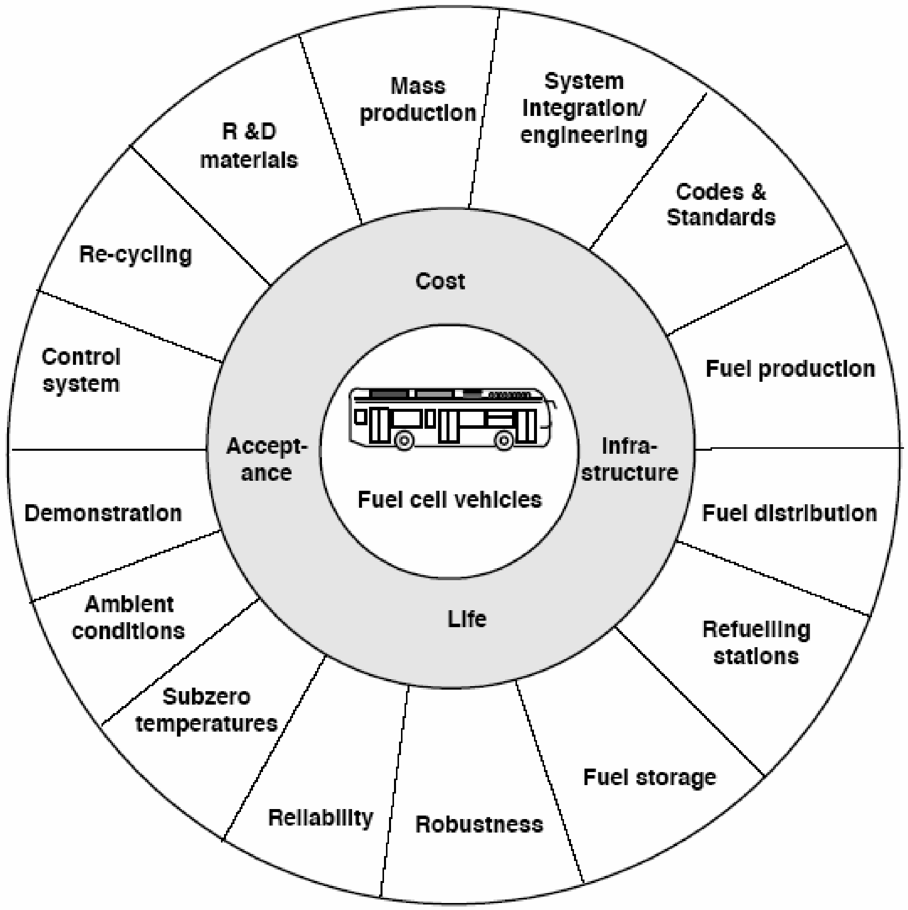
PEM Fuel Cell Performance



Fuel Cell System



FC Implementation Requirements



GM Zero Emission Vehicle - 2006

Source: NY Times, September 22, 2006