FUEL CELLS

Emission-free, safe and super efficient

Air pollution. It's an unfortunate part of our daily lives. And most of us know that the tailpipe exhaust produced by internal combustion engines – especially those powering automobiles – is a major reason why. Internal combustion engines, or ICEs, create energy by burning fuel/air mixtures at high temperatures, producing expanding gases whose force within a confined space provides mechanical power. In the process, however, ICEs emit a variety of pollutants and greenhouse gases, including hydrocarbons (HCs), carbon monoxide (CO), carbon dioxide (CO_2) and assorted oxides of nitrogen (NO_x).

For years, battery powered cars have been championed as the environmentally-friendly alternative to internal combustion engines. General Motors recently announced that North America's first mass production electric vehicle, the EV-1, would be launched in the fall of 1996. Yet while this and all other battery-powered vehicles automatically qualify as zero-emission vehicles (ZEVs) under environmental legislation, none of them currently offer the driving range, refuelling capability or operating economies of the internal combustion engine.

The fuel cell solution

Is a commercially practical, emission-free source of energy possible? The answer until recently appeared to be no. But an important and rapidly evolving technology is radically challenging that assumption. Fuel cell technology – a technology in which Canada has a world-leading product – converts energy into power through an electro-chemical rather than thermo-mechanical process.

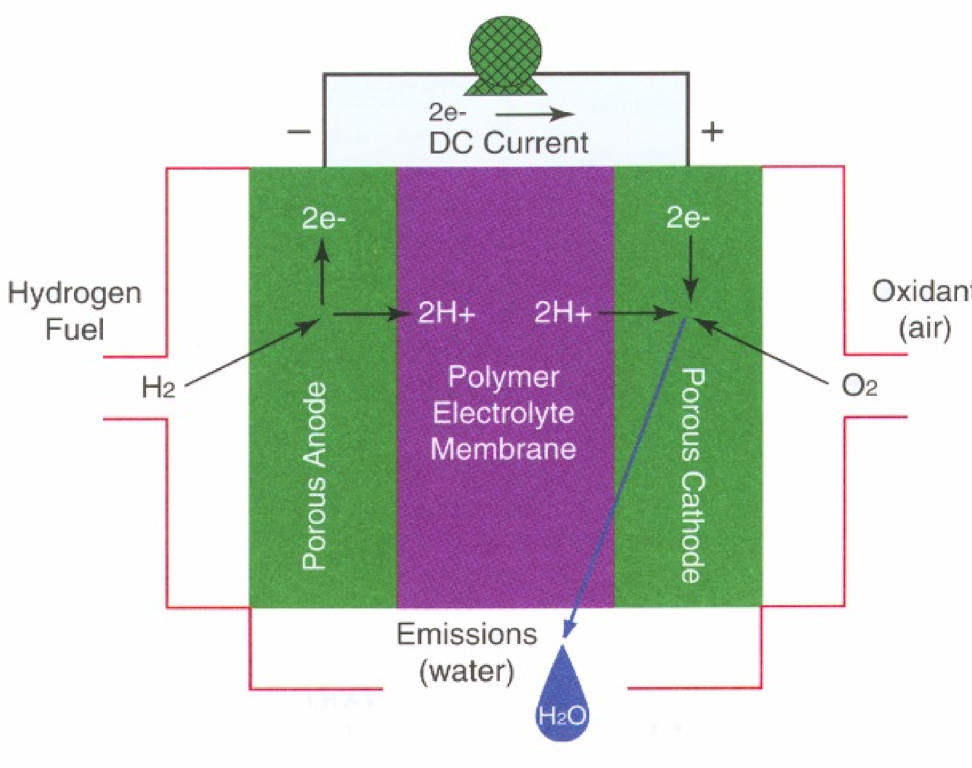
Simply put, fuel cells offer the best of both worlds: the zero emissions of electric power with the performance and range advantages of fuel powered, internal combustion systems. Because fuel cells operate at relatively low temperatures and can use clean fuels like hydrogen from renewable energy sources, the pollutant emissions associated with internal combustion can be eliminated. And since stored fuel is used to create electricity, rather than a battery, refuelling (which takes minutes) replaces recharging (which can take hours).

How fuel cells work

Fuel cells create power, evenly and efficiently, without combustion, without moving parts and without emissions. Fuel cells create electricity through a process in which oxygen and hydrogen (or a hydrogen-rich fuel) are introduced in a controlled manner into an electrochemical cell. With the help of electrocatalysts, fuel cells convert the chemical energy in hydrogen and oxygen into an electric current that is channeled to a load (for example, an electric motor). The only by-product emitted from this process is pure water.

Since each cell produces about 0.6 volts under load conditions, many cells are stacked together in series to provide the voltage necessary to run a

Having the right chemistry



car or power a factory. Fuel is stored in a separate storage tank, just like gasoline. Oxygen from the air is used as the oxidizing agent – unlike in batteries, where the oxidant is chemically stored within the battery itself.

The fuel cell system

The fuel cell is just one element in a fuel cell system. In a fuel-cell powered bus, for example, the complete system consists of a fuel cell stack which produces the electricity, a storage container for the fuel, and auxiliary subsystems which supply and process the fuel and cool and maintain the system. If the fuel used is not pure hydrogen, a reformer would be required to convert the fuel into hydrogen and CO_2.

FUEL CELL ENGINES

vs. Internal combustion engines	vs. Battery engines
Emission-free	Low weight
High energy efficiency	Superior driving range
Quiet operation	Quick refuelling
High torque (increased power at lower speeds)	
Reduced maintenance	

Performance comparisons: fuel cell types

FUEL CELL TYPE	Proton Exchange Membrane	Alkaline	Solid Oxide	Molten Carbonate	Phosphoric Acid
Operating temperature (Celsius)	80°	80°	1000°	650°	200°
Power/density (watt/kg.)	340-1500	35-105	15-20	30-40	120-180
Efficiency	40%-60%	40%-60%	45%-50%	50%-57%	40%-47%
Time to operation	Seconds	Minutes	>10 hours	>10 hours	2-4 hours
Fuel source	Pure H_2, reformed methanol, nat. gas	Pure H_2	Nat. gas, syn-gas	Nat. gas, syn-gas	Reformed nat. gas
Platinum used	Yes	No	No	No	Yes

Fuel cell types

Fuel cells come in many different shapes and sizes, depending on the material used for the electrolyte. They include: Alkaline Fuel Cells (AFC) and Phosphoric Acid Fuel Cells (PAFC), which use liquid electrolytes; Molten Carbonate (MCFC), in which the electrolyte is molten salt; Solid Oxide (SOFC), which employs a ceramic electrolyte; and Proton Exchange Membrane (PEM) Fuel Cells, in which the electrolyte is a thin, solid polymer membrane. The chart above illustrates their various operating characteristics.

PEM (Proton Exchange Membrane) fuel cells are superior in several key areas. They operate at a relatively lower temperature than most other fuel cells (70 to 90 degrees Celsius). They are highly efficient, possess high power density and load following capabilities, and offer high reliability and long operating life. Prototype PEM fuel cells are already operating in public-transit applications and are currently being developed for stationary power plants.

Key applications

Power plants

Fuel cells can be a clean and highly efficient energy alternative in stationary power applications outside of large utility electrical plants. Currently, two technologies dominate: diesel engines, and natural gas turbines, which are used at larger power generation stations. As the industry becomes increasingly deregulated, new entrants are looking for smaller, safer, cleaner power plants to generate energy cost-effectively at point of use, while large gas utilities are searching for ways to extract higher value from the natural gas they sell. Commercial opportunities for stationary fuel cell systems are numerous, especially in small and medium size power plant installations and in remote locations off the grid.

Public transit

The demand for low pollution transit vehicles continues to increase. The world's first hydrogen fuel cell bus has been on the road in Vancouver and many parts of Canada since 1993. Using PEM fuel cell technology and compressed hydrogen fuel, Ballard Power Systems of North Vancouver is leading the way in fuel-cell powered buses. In 1995, the Chicago Transit Authority announced the purchase of three second-generation prototype buses from Ballard for a three-year trial.

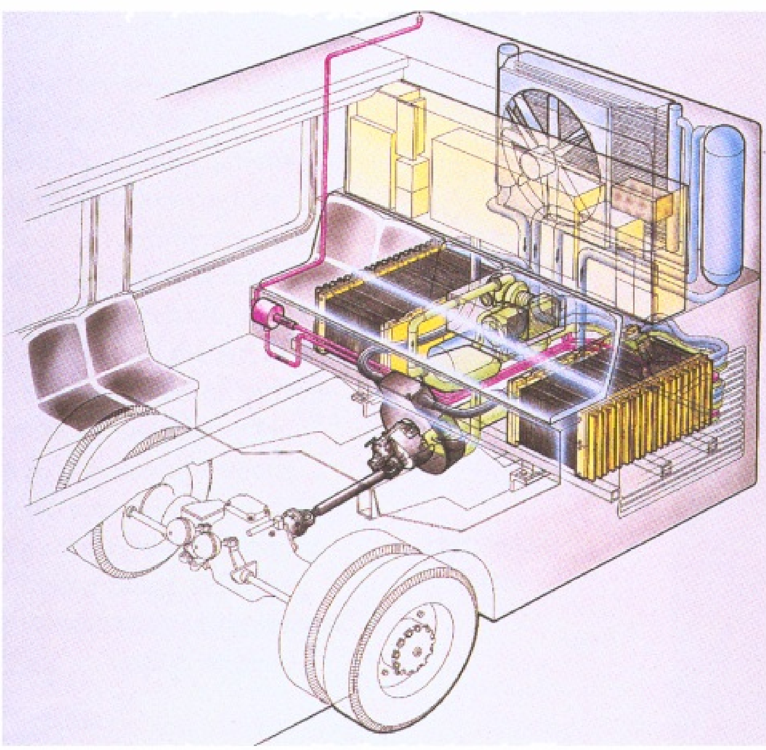
These buses are equipped with 275 horsepower PEM fuel cell engines integrated into a fully functional transit bus with a top speed of 95 km/h (60 mph) and a 400 km (250 mile) range. In 1996/97, a third-generation bus will be introduced having 500% more power than the first generation fuel cell and capable of carrying an industry-standard 75 passengers with a range of up to 560 km (350 miles).

Motor vehicles

Fuel cells combine the zero emissions, high efficiency, and quiet operation of a battery-powered car with the long range and refuelling time approaching that of a gasoline-powered car. PEM has become the fuel cell of choice for light transport applications such as automobiles. Recent advances have achieved the power density necessary for commercial use in an automobile. In fact, power density is now more than five times higher than for earlier generation fuel cells.

Driving range is in the order of 400 to 500 kilometres – comparable to today's internal combustion engines and far ahead of battery powered systems. At the point where an automobile operates at its average power (15% load), a fuel cell system is roughly twice as efficient as a spark ignition engine. Today, fuel cell technology is strongly supported in the U.S. through a recent American Presidential initiative, the Partnership for a New Generation Vehicle (PNGV).

Fuel-cell powered bus



Marine applications

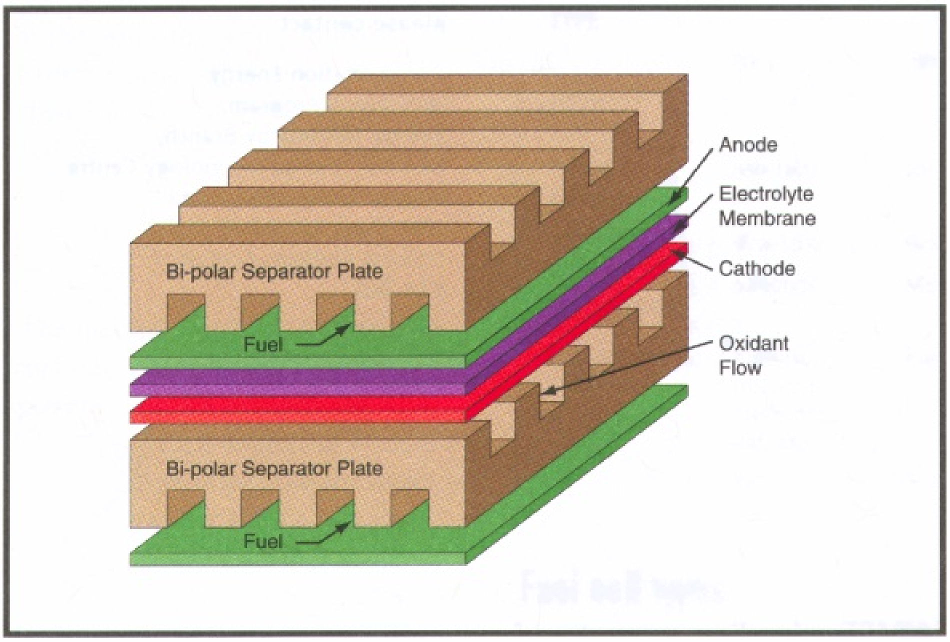
Submarines powered by fuel cells gain at least two important operating advantages over conventional diesel-electric vessels: low noise and low heat emissions. In addition to these stealth-enhancing attributes, it is estimated that the technology will produce a ten-fold increase in endurance over the best diesel-electric powered submarines in service with NATO – approaching that of nuclear submarines but at a fraction of their cost.

Space program

Because of their high efficiency and energy capacity, and because pure drinking water is the by-product, NASA has used fuel cells to help power its spacecraft since the 1960s. The Gemini space program used hydrogen-oxygen PEM fuel cells with ion exchange membranes. The Apollo space program used alkaline fuel cells in which the electrolyte was made of immobilized potassium hydroxide. Today, alkaline fuel cells are used to power the operations of the space shuttle.

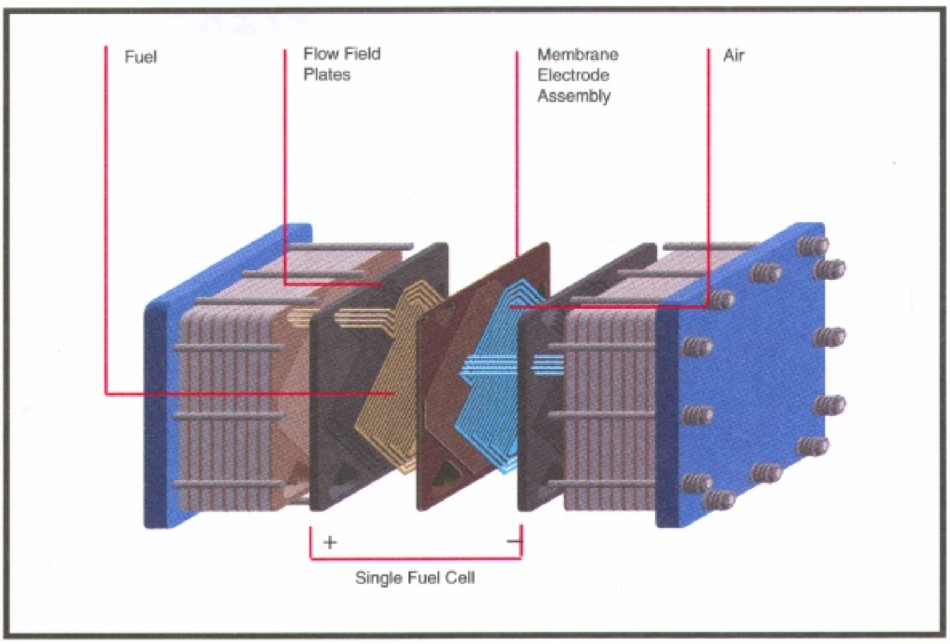
The "ins" and "outs" of fuel cells: hydrogen and oxygen in; electricity and pure water out.

MEA: Membrane Electrode Assembly



Single cells are stacked back to back in series electrically by means of bi-polar plates. The plates connect the anode of one MEA to the cathode of the next.

PEM Fuel Cell Stack



When many MEAs are stacked in series, the power of the cell becomes sufficient to support a large electric load such as a motor.

PEM fuel cells: technical overview

In water electrolysis, an electric current is passed through water containing an electrolyte in order to split the water (H_2O) into its constituent parts, hydrogen and oxygen. With a fuel cell, the process is reversed: hydrogen and oxygen are combined to form water, and in so doing, generate an electric current within an electrochemical cell. The electrolyte can be either liquid or solid, depending on the type of fuel cell employed. Proton Exchange Membrane (PEM) fuel cells are considered by many experts to be the best solution for applications where high power density and portability are critical.

Hydrogen PEM fuel cells consist of two electrodes – an anode and a cathode – separated by a polymer electrolyte membrane. Each electrode is coated on one side with an electrocatalyst. Hydrogen (the fuel) enters the porous anode and, helped along by the electrocatalyst, disassociates into free electrons and positively charged hydrogen ions (protons). The negatively charged electrons are drawn towards the positively charged cathode. But along the way the electrons are diverted, passing through an external circuit connected to the load. Meanwhile, the protons migrate directly through the polymer membrane electrolyte to the cathode, where they combine with the oxygen and the energy-depleted electrons from the external circuit. The result is electricity, and a remarkable by-product: pure water.

Hydrogen fuel: clean and ubiquitous

Clean, occurring in water and all organic compounds, hydrogen is virtually inexhaustible in supply and safe to use. In the future, hydrogen is expected to be produced from the electrolysis of water, powered by renewable sources such as solar, wind and hydro energy. From its production through to its consumption in fuel cell engines, the cycle of producing and consuming hydrogen will be sustainable, safe and clean.

With support from Natural Resources Canada (NRCan), a commercial demonstration of electrolytic hydrogen production has been established at the liquid hydrogen plant in Bécancour, Quebec, operated by HydrogenAL, a joint company of Hydro-Québec and Canadian Liquid Air. Support has been provided for further R&D towards reducing process costs by evaluating different electrocatalysts and separators, and by developing more efficient polymer separators for water electrolysis.

Some key technical challenges must still be resolved before hydrogen can become a practical and ubiquitous source of transportation energy. In its natural state, hydrogen is lighter than air. Its lower density means it is bulky and awkward to store and transport. As a result, it must be compressed or else stored as a cryogenic liquid or as a metal hydride. All these options require bulky, heavy or complex storage systems.

Support of R&D towards light-weight fuel storage for hydrogen-fuelled vehicles is a continuing activity at the CANMET Energy Technology Centre. A promising new technique involves storing hydrogen in a liquid carrier such as methanol, which is reformed on-board the vehicle into a hydrogen-rich gas, or used unchanged in a Direct Methanol Fuel Cell. By combining continuing advancements in fuel cell technology with increasingly economical production and storage techniques, hydrogen is likely to become an integral part of the world's transportation system early in the 21st century.

CANMET: a leading supporter of Canadian science and technology development

CANMET is a key science and technology arm of Natural Resources Canada. Its mandate is to support the development of private and public research into new technologies and help enhance Canada's technological expertise in environmentally-friendly technology. CANMET's Energy Technology Branch oversees and encourages growth in the development of cleaner and more efficient transportation technologies (such as electric vehicles) and alternative fuels including natural gas, propane, methanol, ethanol and hydrogen.

For information

please contact:

Transportation Energy Technology Program,
Energy Technology Branch,
CANMET Energy Technology Centre
Natural Resources Canada
13th Floor, 580 Booth Street
Ottawa, Ontario, Canada
K1A OE4

Tel (613) 996-6220
Fax (613) 996-9416