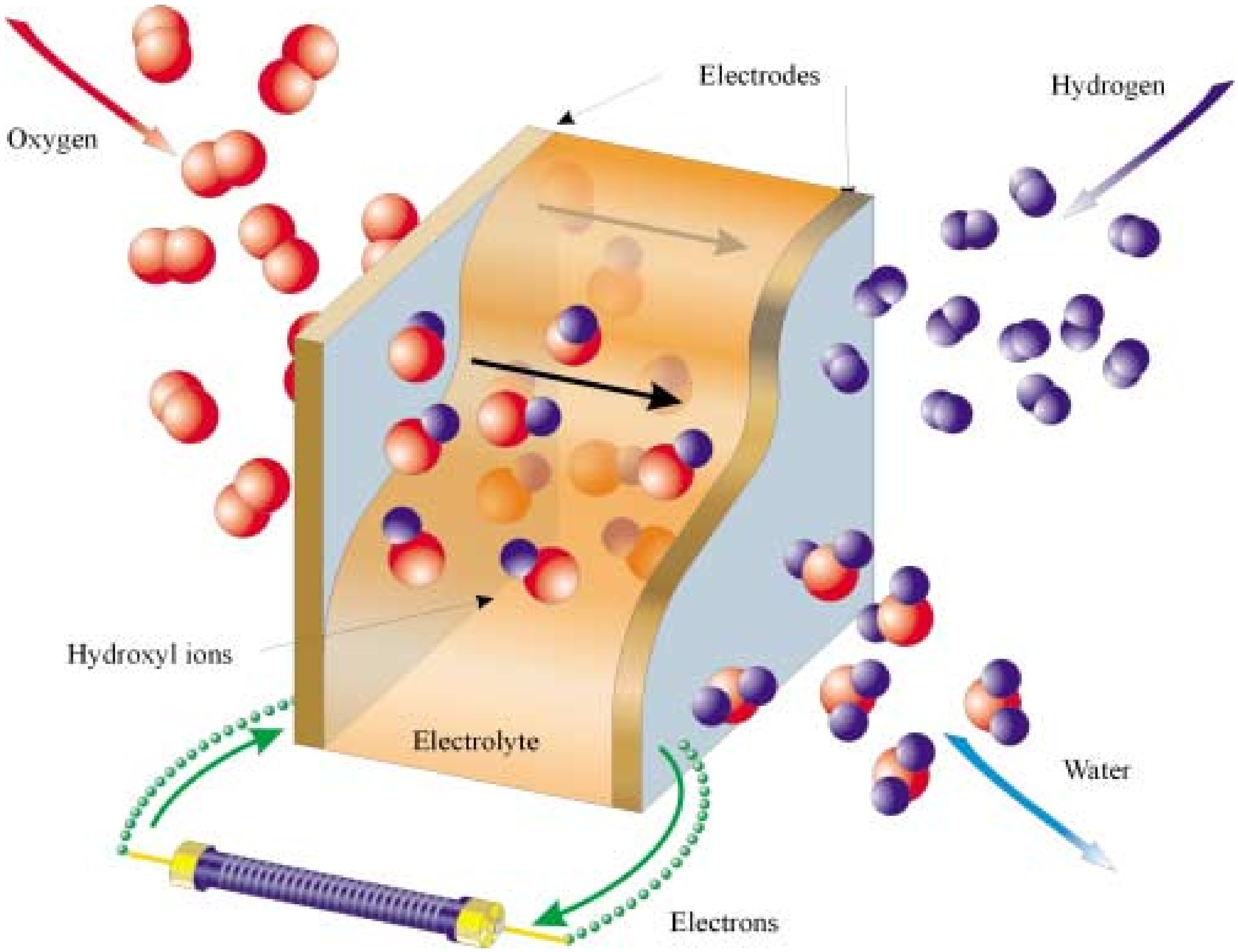
Introduction

Fuel cell research has recently become a high-profile endeavor due to the promise of pollution-free efficient energy production. According to experts the 100-year petroleum era is almost over. Global oil production is expected to peak sometime between 2004 and 2008. Petroleum geologists continue to search for new fields but no significant reserves have been found since the 1970s. Billions of dollars have been poured into new drilling technology but this investment is not expected to make a significant difference to the gloomy prediction. Traditional fossil fuel conversion relies on combustion methods that are subject to the thermodynamic laws that limit conversion efficiency, whereas a fuel cell is a device that generates electricity by a chemical reaction that is not subject to these limits. Increasing energy demands will require more efficient conversion of the dwindling oil reserves and so the race is on to commercialize fuel cell technology. Unfortunately, building inexpensive, reliable and efficient fuel cells is a complicated business. Impurities in the fuel (i.e. sulfur) and secondary reactions in the process (carbon monoxide) can poison expensive catalysts. Preferred low-temperature operation often requires a "reformer" to convert the fossil fuel into pure hydrogen. In many cases, accurate process gas analysis plays an important part in the development of improved devices. This application note will describe the various fuel cell technologies and highlight the role that Thermo analyzers can play in their development.

Basic Principles

A fuel cell consists of a positive electrode (cathode), a negative electrode (anode), an electrolyte and a catalyst. The electrolyte carries electrically charged particles between the electrodes and the catalyst increases the reaction rate at the electrodes. The electrolyte permits only the appropriate ions to pass between the electrodes. The basic fuel is hydrogen, which is oxidized using oxygen in air (or a specially formulated oxidant) to provide the electrical charge and produce water as a byproduct. There are essentially five different types of electrolyte, namely, Alkali, Phosphoric Acid, Solid Oxide, Proton Exchange Membrane and Molten Carbonate. Each has its own set of performance parameters, strengths and weaknesses that direct it towards a particular part of the energy market. Current fuel cell research is aimed at addressing the complete energy spectrum from micro-cells operating in hand-held electronic devices to 200MW+ systems for city power generation.

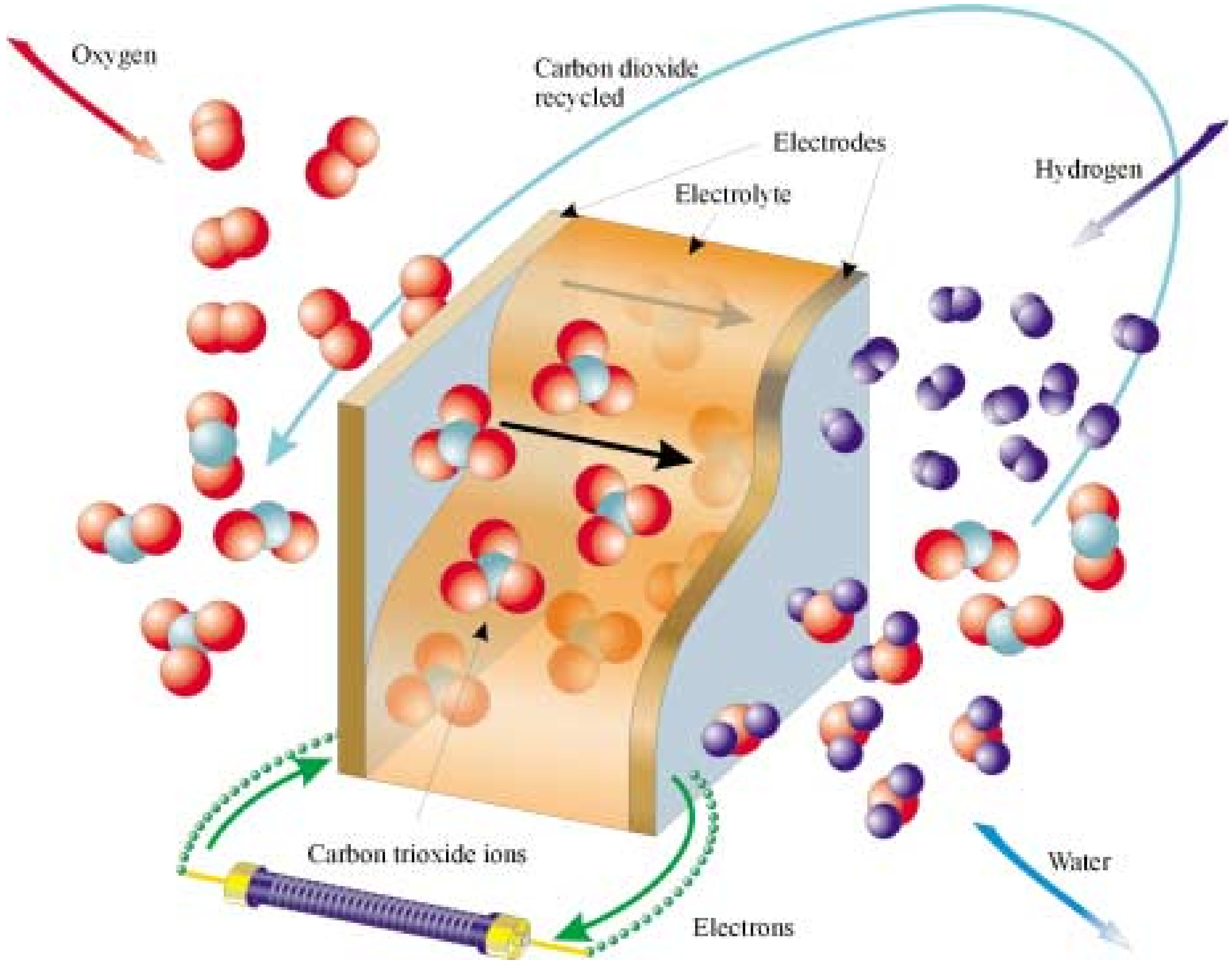
Alkali Fuel Cell



Alkali fuel cells operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide in water as the electrolyte. They require pure hydrogen fuel and the platinum electrode catalysts are expensive. Their high efficiency has made them a favorite of NASA but they are too expensive for many applications. Cobalt has been used successfully as an alternative to platinum however, and this has rejuvenated research. One company, Zevco (in association with Shell Hydrogen), has developed a series of commercial vehicles using alkali fuel cells that employ a cobalt catalyst.

Efficiency:	*70%*
Operating Temperature:	*150 - 200 C*
Output Range:	*300W - 5KW*

Molten Carbonate Fuel Cell

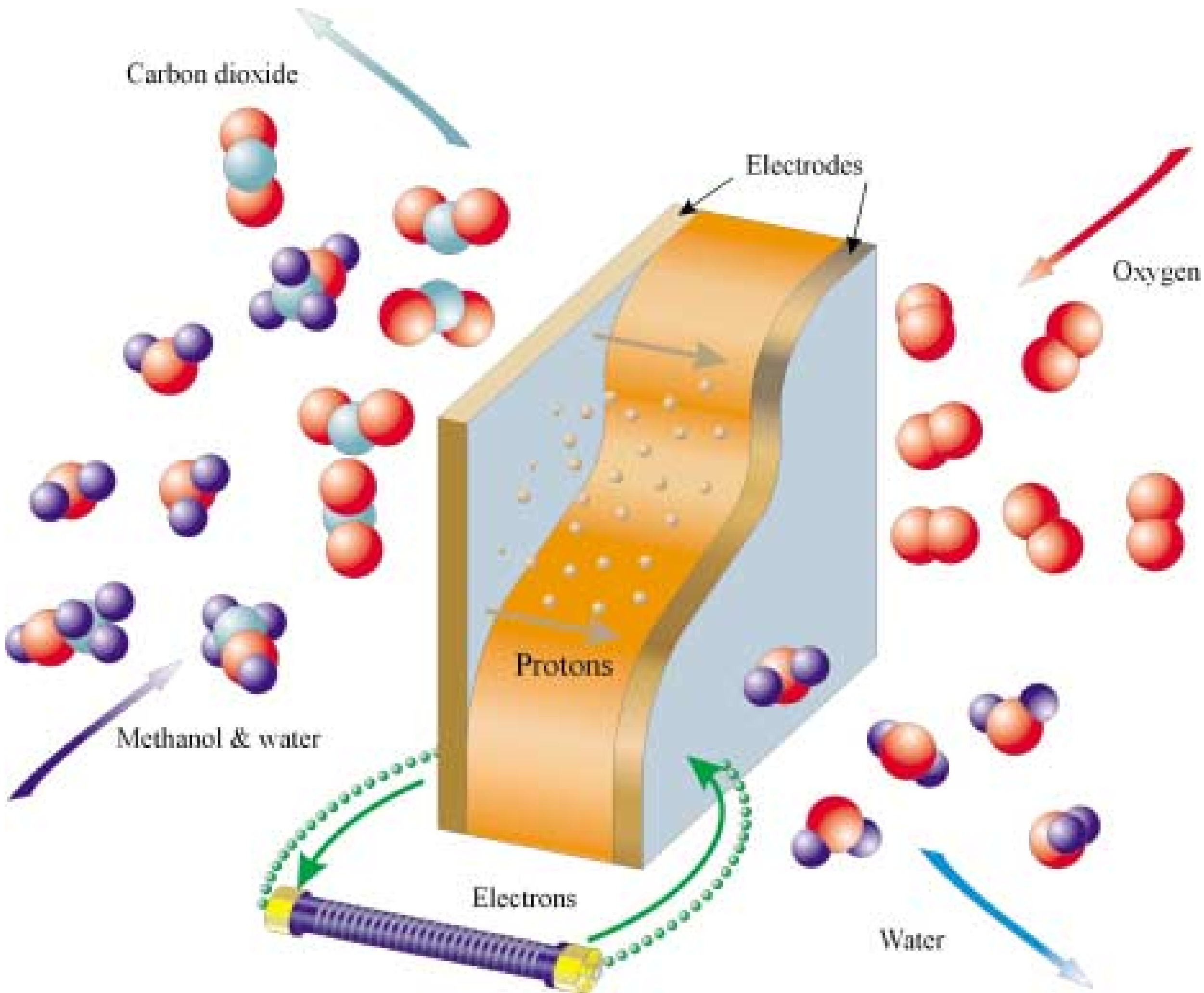


In a molten carbonate fuel cell (MCFC), the electrolyte is made up of carbonate salts which melt at the operating temperature of 650C. The electrolyte conducts carbonate ions (CO3) from the cathode to the anode where they react with hydrogen to form water and carbon dioxide. This reaction releases electrons. The CO3 ions are replenished by reacting oxygen (from air) with recycled carbon dioxide. Principle advantages: work with a variety of fuels and use low-cost nickel catalyst.

The high temperature operation makes these units ideally suited to cogeneration plants (where the waste heat is used to make steam for space heating). They have also been proposed for

Efficiency:	*60-80%*
Operating Temperature:	*650 C*
Output Range:	*1-100 MW*

Proton Exchange Membrane

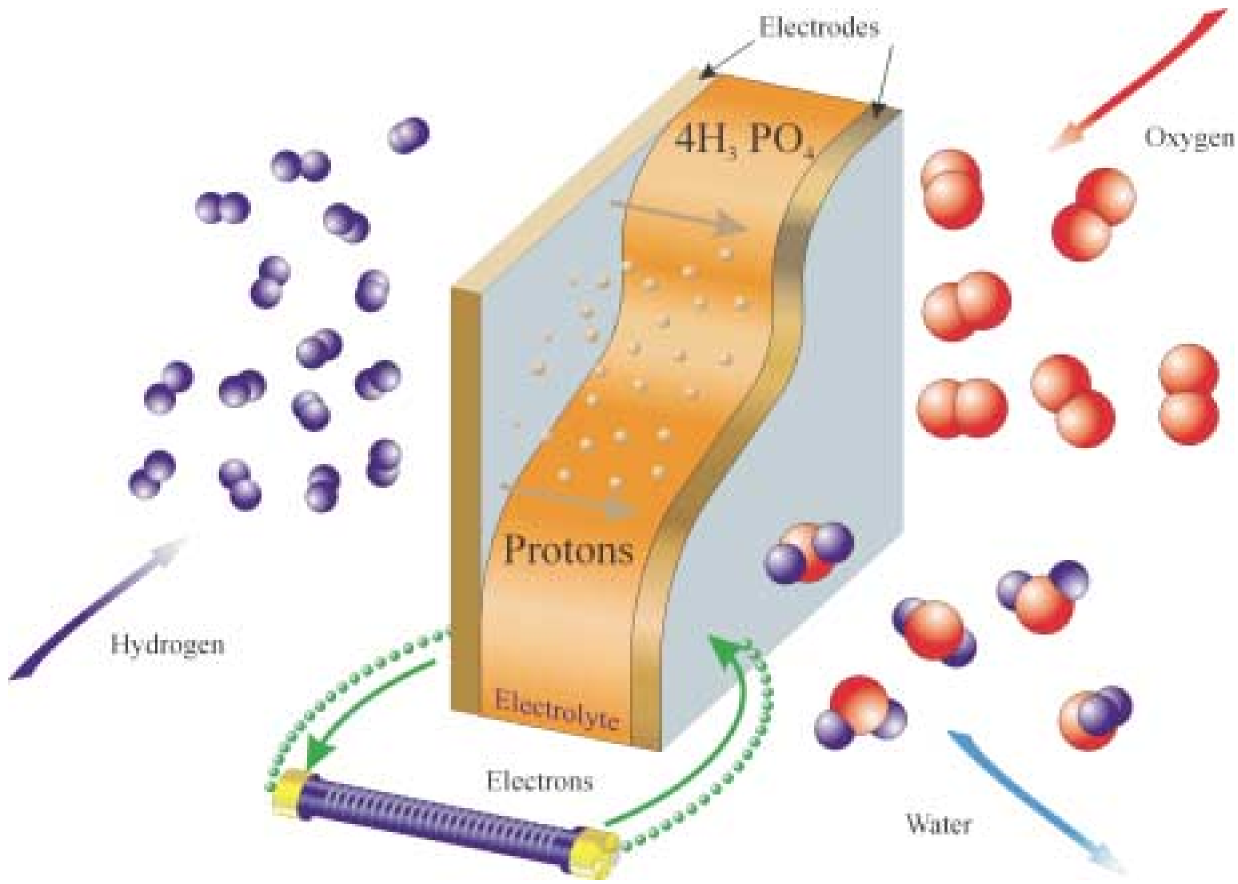


Proton Exchange Membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin permeable sheet. The solid, flexible membrane allows operation at relatively low temperatures and they can be used with diluted methanol as well as compressed hydrogen. Principle disadvantage: expensive platinum catalyst used on both sides of the membrane.

This type of fuel cell is emerging as the favorite technology for use in automobiles. Daimler Chrysler, Ford and Volkswagen are all testing PEM hybrid vehicles. Motorola and Samsung are actively developing micro fuel cells using semiconductor fabrication techniques with the PEM assemblies laid side-by-side.

Efficiency:	*40-50%*
Operating Temperature:	*15-80 C*
Output Range:	*0.1W (micro cell) - 250KW*

Phosphoric Acid Fuel Cell

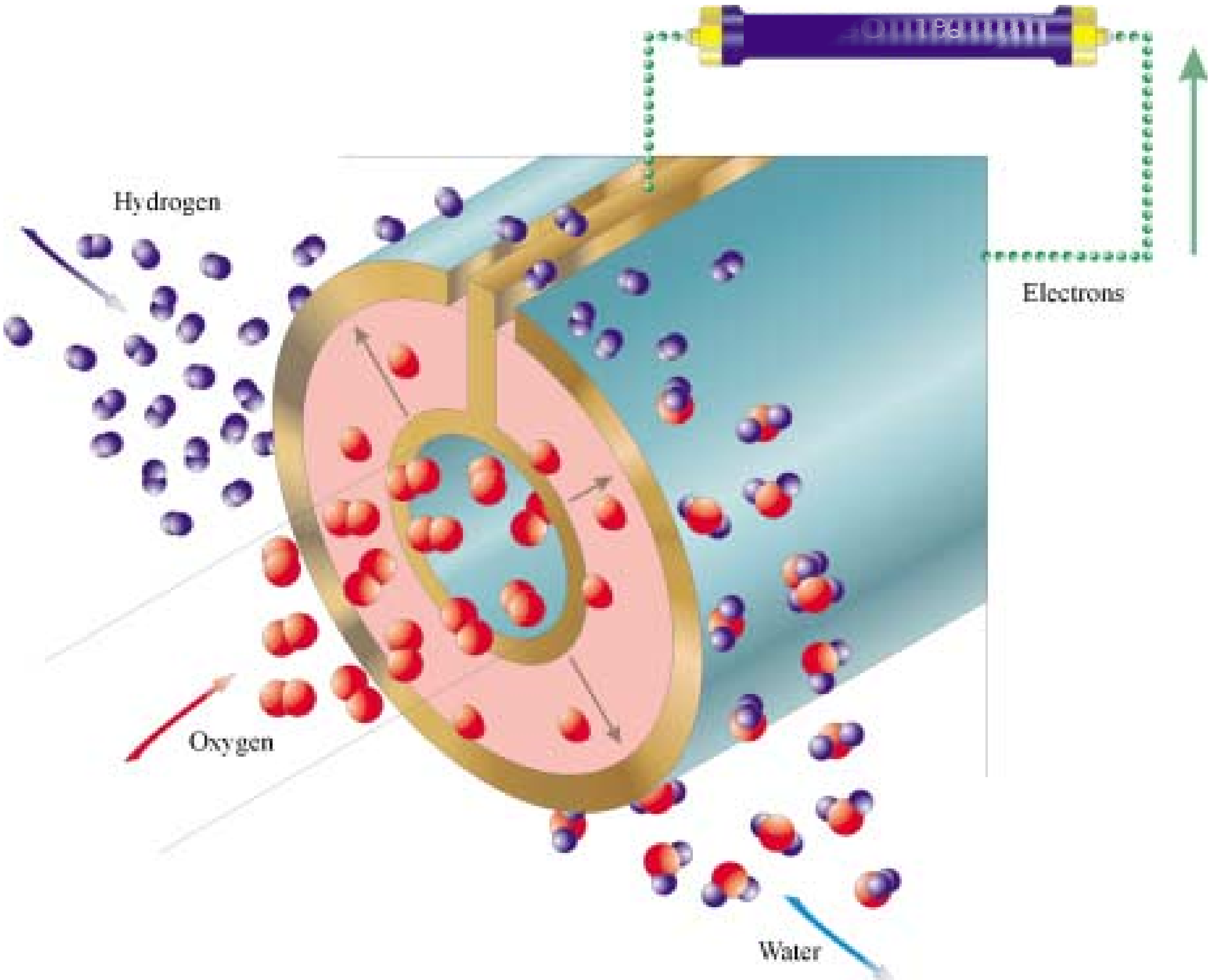


Phosphoric acid fuel cells work on the same principle as PEM devices but the membrane is replaced with a phosphoric acid electrolyte. They can tolerate up to 1.5% CO which broadens the choice of fuel that they can use. If gasolene is used as a source of hydrogen (via a reformer), then it is necessary to remove all the sulfur otherwise the platinum catalyst will be damaged.

This type of fuel cell has been deployed in a number of public service vehicles but they are unlikely to see service in private vehicles due to extended warm-up times. They have been deployed as supplemental power systems for office buildings and have been tested on

Efficiency:	*40-80%*
Operating Temperature:	*150-200 C*
Output Range:	*200KW - 11MW*

Solid Oxide Fuel Cell

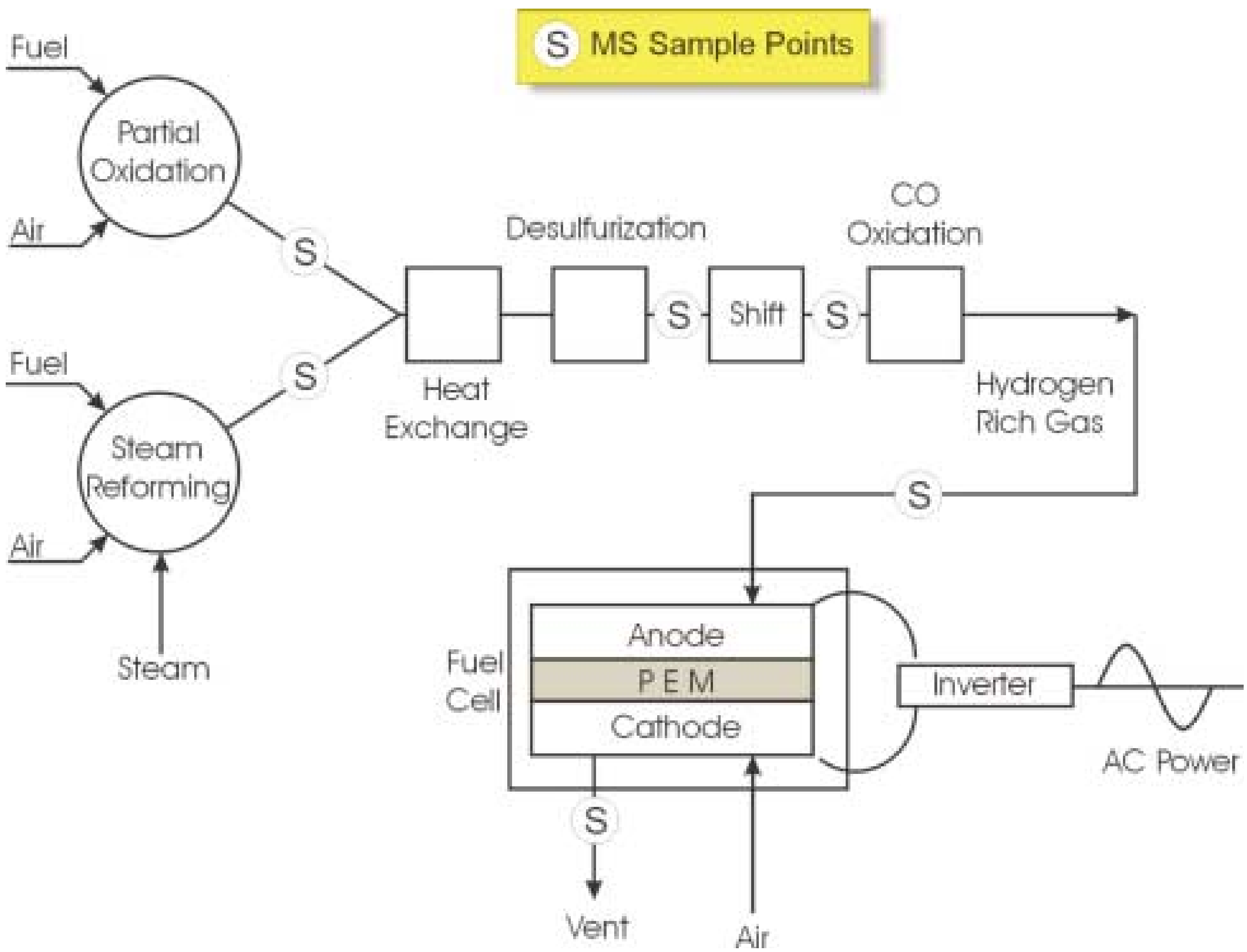


Solid oxide fuel cells use a ceramic compound of metal oxides (often zirconium or calcium) as the electrolyte. Negatively charged oxygen ions migrate through the solid crystal lattice and exit through the porous electrode material. When a fuel gas containing hydrogen is passed over the anode, the flow of negatively charged oxygen ions oxidize the fuel. A typical fuel cell assembly consists of an array of tubes. The high operating temperatures provide the advantage that a reformer is not required to extract hydrogen.

About 40 companies are presently working on this technology, mostly in the stationary power generation fields. The high operating temperatures make this type of device ideally suited for cogeneration plants.

Efficiency:	***60%***
Operating Temperature:	***1,000 C***
Output Range:	***10-100 KW***

Integrated Fuel Cell



Partial Oxidation

Partial Oxidant Reformers are used to convert a variety of fuels into hydrogen-rich gas mixtures for use in light-duty fuel cell power systems. The common fuels employed in these catalytic reformers include gasoline, diesel, methanol, ethanol, propane and natural gas. When operated at temperatures around 750 degrees Centigrade hydrogen concentrations in the 30-40% range can be achieved for a range of fuels.

Steam Reforming

Steam Reformers operate at a higher temperature (1,000 degrees Centigrade when reforming gasoline) but they are better developed than their partial oxidation counterparts. They also tend to be larger, run at higher pressures (4 Bar) and have longer startup times.

Both types of reformer can be used with naphtha, which is a low-cost alternative to gasoline. Octane levels are too low for internal combustion engines but naphtha is ideal for fuel cells and it can be distributed using existing infrastructure.

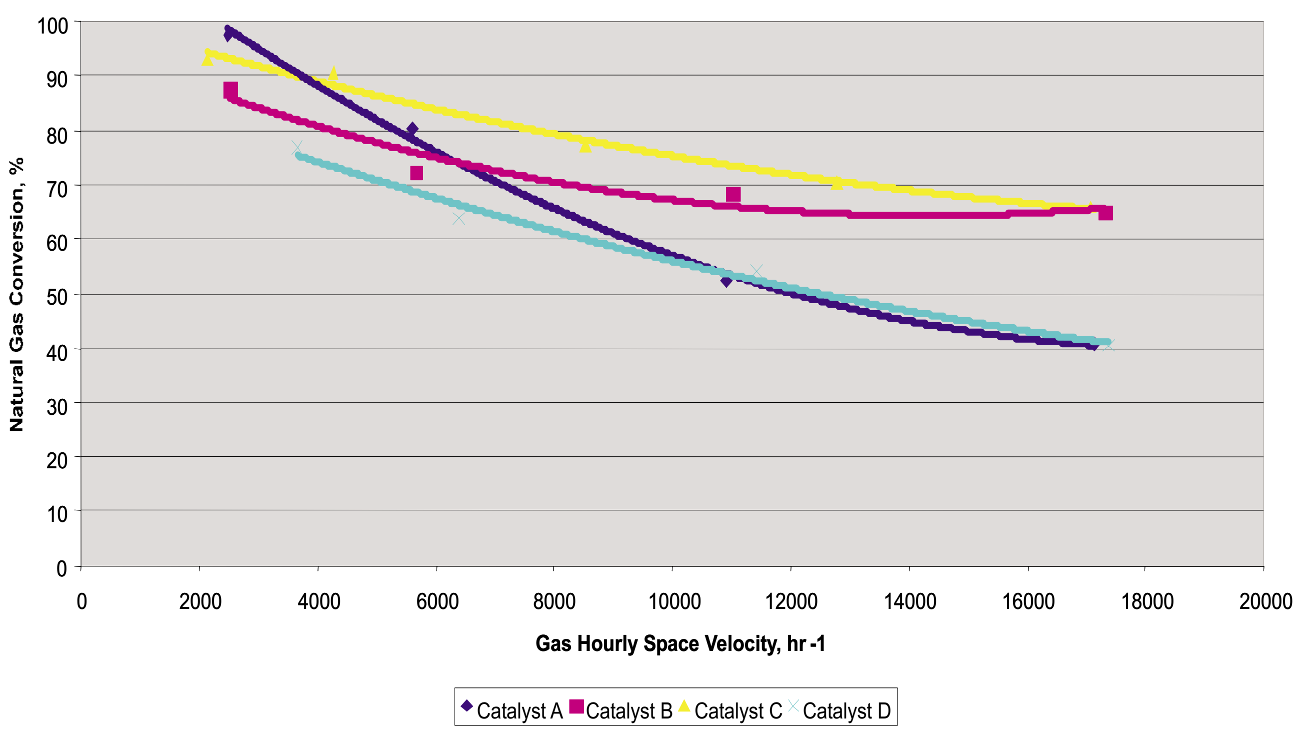
Shift (CO Shift Converter)

Carbon monoxide is a poison to the catalyst to a greater or lesser extent, depending on the fuel cell technology being employed. The shift reaction of CO to CO_2 takes place over a catalyst and is designed to reduce CO from 10% to below 50 ppm for PEM cells or 1.5% for PAFC units.

Catalysis Research

One of the keys to the development of economically viable fuel cell technology lies in the development of the various catalysts used in the device. Fast, precise gas analysis using a process mass spectrometer provides the necessary data to identify the improvements that result from changes to the chemical composition of the materials. The graph below illustrates the performance differences for 4 similar catalyst materials.

Natural Gas Conversion Vs Gas Hourly Space Velocity



Process Instruments Division Products

SOLA

The SOLA (Sulfur On-Line Analysis) reliably measures low ppm total sulfur in fuels without requiring a pure oxygen supply. Pulsed UV Fluorescence technology yields longer lamp life and lower detectable levels than non-pulsed systems. This analyzer is ideal for quality control in ultra-low-sulfur fuel cell applications.

XVI G

The XVI Total Sulfur laboratory analyzer combines the interference-free lead acetate tape detection technology with microprocessor-based electronics to provide fast and precise measurements of total sulfur content in liquid, gaseous, and LPG laboratory applications. This unique analyzer system is capable of measuring extremely low total sulfur concentrations (< 50 ppb) as well as high concentrations (up to 1500 ppm).

Tracker

The Tracker also measures total sulfur in hydrocarbon streams using lead acetate tape technology but it employs a rugged process cabinet configurable for use in hazardous areas. Total sulfur is measured using a specially designed Pyrolyzer that converts all sulfur species in the sample to H2S. This ensures that the reported measurement reflects the actual concentration of only the total sulfur present in the fuel stream.

VG Prima δB

The VG Prima δB is a multistream, multicomponent scanning magnetic sector mass spectrometer ideally suited to fuel-processor research and fuel cell development. The combination of superior analytical performance, backed up by VG application knowledge and powerful Gasworks and Prima Wizard software packages, established the Prima as the world's top selling process mass spectrometer system. The new Prima δB now sets new standards for process mass spectrometer performance and reliability.

VG ProLab

The VG ProLab is a compact Mass Spectrometer designed around our patented contamination resistant enclosed ion source and triple-filter quadrupole. The ProLab provides the flexibility of a scanning mass spectrometer in a laboratory bench-top configuration. This analyzer also benefits from the powerful GasWorks software suite.

Technologies Offered for Fuel Cell Research

Pulsed UV Fluorescence
Lead Acetate Tape
Scanning Magnetic Sector Mass Spectrometry
Triple-Filter Quadrupole Technology
Gas Chromatography
None-dispersive Infrared
Process FTIR

Thermo Electron Corporation provides an un-matched array of technologies for Process Analysis and Quality Control in the area of Fuel Cell Development.