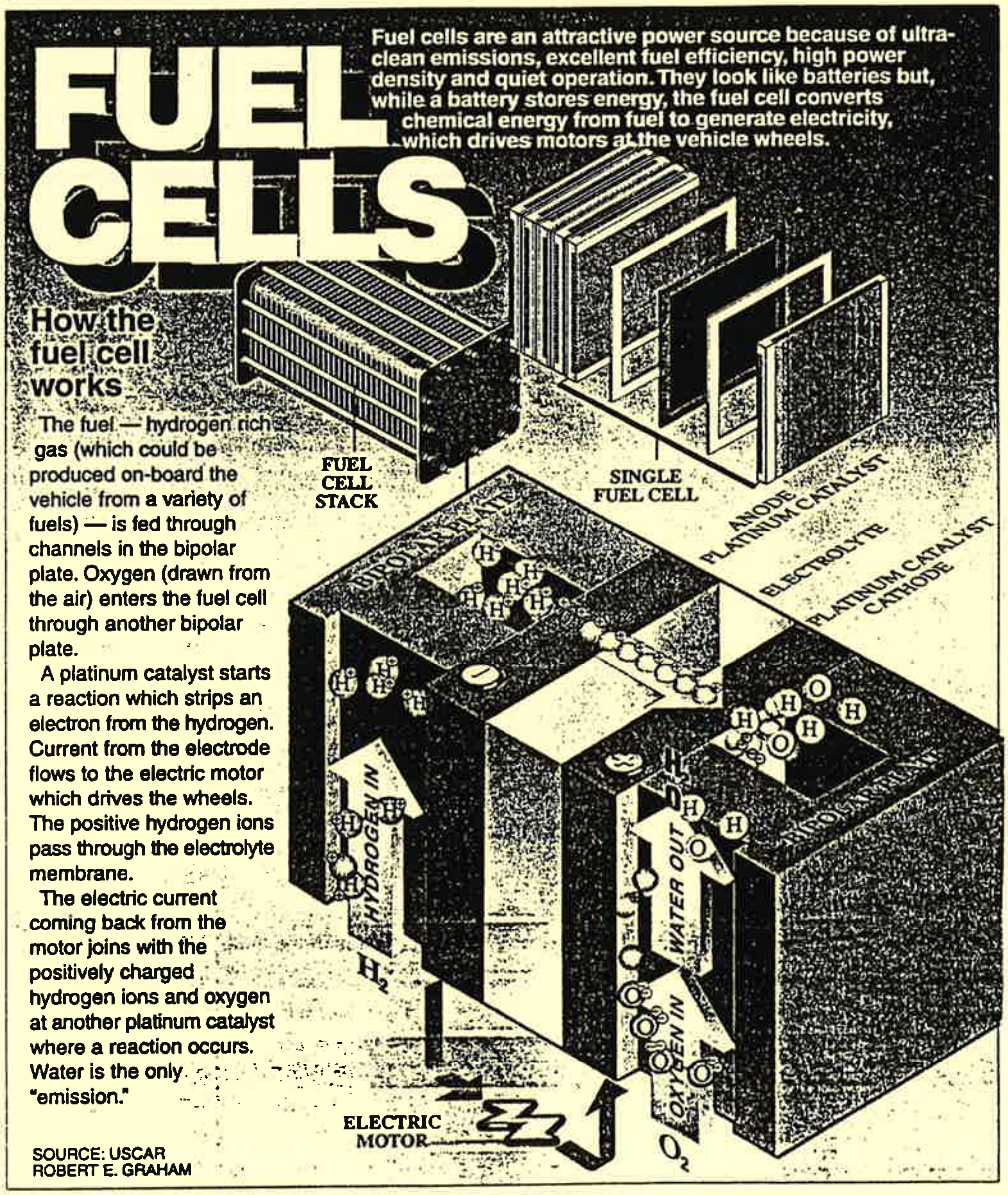

DEPARTMENT OF ECONOMIC AND COMMUNITY DEVELOPMENT

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INTRODUCTION

This document has been written by Frederick J. Munster Jr. for the Maine Department of Economic and Community Development, as an informational guide regarding fuel cell technology.

Fuel cell technology has been used routinely in the U.S. Space program for the last 30 years. A fuel cell operates like a battery but does not needs to be recharged. Instead, it uses fuel like an engine. As long as fuel is supplied it will produce electricity, heat and water. The first widespread civilian use of fuel cells will appear commercially in automobiles as a replacement for the internal combustion engine. The automotive fuel cell design is geared to take advantage of the existing fossil fuel infrastructure (gas pumps/pipelines) and can utilize other renewable fuels as well. Eventually the infrastructure will be changed to incorporate direct hydrogen fueled systems.

The primary focus of this document is use or planned use of this and related technologies in civilian and commercial sectors. The widespread implementation of this technology will result in substantial economic, environmental and national security benefits.

The author would like to expressly thank the following: The Maine Department of Economic and Community Development; The United Technologies family of companies, including Hamilton Standard, International Fuel Cells and ONSI; The U.S. Department of Energy, Ballard Power Systems, The American Hydrogen Association (AHA) and Mr. Roy McAlister P.E., President of AHA.

Edited by: Mr. Christopher Carroll, Maine Department of Economic and Community Development.

Chapter 1

HYDROGEN

Hydrogen was first observed by Paracelsus, (1493-1541). He noted that when iron reacts with sulfuric acid that "an air arises which burst forth like the wind." In 1700, Lemery demonstrated combustion of this invisible "rising wind" when it was ignited with another flame. By 1766 Henry Cavendish (1731-1810) called the rising wind "inflammable air" and determined many of its true physical properties. He published many of the findings from his long term research on hydrogen in 1781 noting that hydrogen and air (oxygen) combine to "produce nothing but water." In 1783, Antoine Laurent Lavoisier (1743-1794) named the element "hydrogen" meaning water producer in Greek.

The prevalent hydrogen isotope has an atomic mass of 1 (atomic mass is defined as the number of electrons an atom has), and is the simplest atom consisting of one proton and one electron. In nature hydrogen exists as a diatomic molecule consisting of two hydrogen atoms (H_2). Hydrogen is about 14 times lighter than air. It moves faster than any other element at standard pressure and temperature and is smaller than any other atom, even in its normal diatomic molecular state. Like metals, it gives up electrons in reactions with other non-metals such as oxygen and halogens. These energy releasing reactions are the basis of hydrogen combustion and fuel cells. At temperatures above its boiling point of 20.4^0K, hydrogen is a gas. From 20.4^0K to about 13.8^0K, hydrogen is a liquid. Cooling below 13.8^0K produces solid hydrogen. Hydrogen exists in two isomeric forms, *orthohydrogen* and *parahydrogen*. As orthohydrogen

the two atomic nuclei are spinning in the same direction (parallel spin) while in parahydrogen the two nuclear spins are in the opposite (antiparallel) directions. At and above ambient temperature the equilibrium composition is about 75% orthohydrogen. As hydrogen is cooled, the equilibrium shifts toward increased parahydrogen. At liquid nitrogen temperature (77.4^{0}K), about 52% orthohydrogen would exist at equilibrium. At the boiling point (20.4^{0}K), the equilibrium composition is 99.8% parahydrogen. Because equilibrium takes time to develop, it is common to liquify hydrogen with about 75% orthohydrogen present which is called *normal* H_2.

Orthohydrogen in normal H_2 liquid will slowly change to the parahydrogen isomer in an exothermic process. This process releases about 168 cal/g and will cause considerable evaporation of the liquid hydrogen even if it is isolated from all external heat sources. In order to preserve storage of hydrogen as a cryogenic substance it is imperative to convert the orthohydrogen into parahydrogen. Catalysts such as ferric oxide gel, ruthenium and nickel silicate are effective in promoting equilibrium conditions by converting orthohydrogen to parahydrogen. In instances where long term storage of cryogenic liquid or solid hydrogen is desired, catalysts are utilized to assure that only parahydrogen enters storage. In instances that relatively rapid release of gaseous hydrogen from cryogenic normal H_2 storage is desired, such catalysts can be used with great reduction in the requirement for application of external heat and have served the aerospace industry throughout the U.S. Space Program. [1,2]

Uses of hydrogen are too numerous to mention: Some of the more

familiar is the food industry adding hydrogen to margarine, cooking oils and peanut butter as a hardening agent and indicated by the terms hydrogenated or partially hydrogenated, in the manufacturing and refining process of petroleum, chemicals and medicine, alloying metals, as a coolant, as fuel in the space program, in converted automobile engines (internal combustion engines) and in fuel cells used for automotive, stationary and portable power applications.

Table 1 shows the physical and chemical properties of hydrogen.[2]

TABLE 1

PHYSICAL AND CHEMICAL PROPERTIES OF HYDROGEN

1. Electron Structure	S^1
2. Covalent Radius	0.37 A (He = 0.93 A)
3. Electronegativity (Pauling)	2.1
4. Specific Heat	(C_p) 3.44 Cal/Gram
	(C_v) 2.46 Cal/Gram
	(C_p/C_v) 1.40 Cal/Gram
5. Gas Specific Gravity	(Air=1.0) 0.0695 Gram/Liter)
6. Gas Self Diffusion Constant	^0C, 1 Atmosphere 0.61Cm^2/sec.
7. Boiling Point	-252.7^{0}C
8. Melting Point	-259.2^{0}C

Chapter 2

HYDROGEN SAFETY

The safety aspects of hydrogen are the most common concern of the general public when it is first introduced as an energy carrier or fuel concept. Many organizations are concerned with hydrogen safety. The National Fire Protection Agency publishes guidelines for storage systems; The U.S. Department of Transportation regulates distribution of hydrogen over the nations roads; The American National Safety Institute and American Society of Mechanical Engineers publish standards for components used in hydrogen equipment; The Compressed Gas Association sets standards covering gas production, handling and use. The National Hydrogen Association in conjunction with the U.S. Department of Energy periodically hold workshops addressing codes and standards. The International Standards Organization created a hydrogen technologies committee, ISO TC 197. This committee along with its working groups are in the process of identifying and developing necessary standards to assure uniformity of hydrogen systems, components, design, specifications and guidelines around the world.

Industry has consistently demonstrated the safe production, shipping and handling of hydrogen in gas and liquid form. NASA's experience with the safe handling of hydrogen over many decades continues to prove this as well.[3]

Table 2 shows ignition/combustion comparisons [4] and Table 2.1 compares safety of fuels from 1 to 3, 1 being the safest and 3 least safe. The ranking has been summed up for each fuel in order to arrive at an overall ranking. The total rankings have been

prorated to obtain the safety factors, defined as the ratio of the total ranking of hydrogen to that of a given fuel. [5]

TABLE 2

IGNITION/COMBUSTION COMPARISONS

Properties Units	Hydrogen	Methane (Natural Gas)	Gasoline
Self-ignition Temp.(^{0}C)	585	540	228-501
Ignition limits in Air (Vol.%)	4-75	5.3-1.5	1.0-7.6
Min. ignition energy (mWs)	0.02	0.29	0.24
Flame speed (cm/s)	265	40	40
Flame temperature (^{0}C)	2045	1875	2200
Lower heating value (kWs/g)	120	50	44.5
Detonation limits (Vol.%)	13-65	6.3-13.5	1.1-3.3
Detonation velocity (km/s)	1.48-2.15	1.39-1.64	1.4-1.7
Explosive energy (kg TNT/m^3 gas)	2.02	7.03	44.22
Diffusion coefficient (cm^2/s)	0.61	0.16	0.06

TABLE 2.1 [5]

SAFETY RANKING of FUELS

Characteristic	Fuel Ranking[a]		
	Gasoline	Methane	Hydrogen
Toxicity of fuel	3	2	1
Toxicity of combustion (CO,SO_x,NO_x,HC,PM)	3	2	1
Density	3	2	1
Diffusion Coefficient	3	2	1
Specific Heat	3	2	1
Ignition Energy	2	1	3
Ignition Temperature	3	2	1
Flame Temperature	3	1	2
Explosion Energy	3	2	1
Flame Emissivity	3	2	1
TOTALS	30	20	16
SAFETY FACTOR ϕ_s	0.53	0.80	1.00

[a] 1, safest; 2, less safe; 3, least safe

CO = Carbon Monoxide

SO_x = Sulphur Dioxide

NO_x = Oxides of Nitrogen

HC = Unburned Hydrocarbons

PM = Particulate Material

Millions of pounds of hydrogen are used safely every day nationwide. With energy and fueling concepts now under consideration, its use will increase.

There are several common misconceptions about hydrogen safety. The first issue is the Hindenberg disaster of 1937 at Lakehurst, New Jersey. The airship did not explode, it did however tragically catch on fire. For decades the prevailing theory (without evidence) blamed the event on free hydrogen. Recent research by NASA and Mr. Addison Bain, NASA Hydrogen Program Manager (retired) have concluded that a serious flaw in the outer covering of the airship is the most likely cause of the fire. The cellulose acetate butyrate-powdered aluminum-iron oxide coating used to waterproof and tighten the fabric was found to be not only extremely flammable but conducive to formation of electrostatic activity on the airship. The hydrogen did burn after each of the 16 hydrogen filled cotton gelatin-latex gas cells were progressively breached by the outer airship fabric fire. Evidence from Germany supports this. Confirmation of the engineering flaw was publicly suppressed for political and liability reasons. A handwritten letter June 28, 1937 by Hindenberg crew member and electrical engineer Otto Beyersdorf states " The actual cause of the fire was the extreme easy flammability of the covering material brought about by discharges of an electrostatic nature..." Mr. Bain concluded that even if the Hindenberg would have used helium gas it still would have burned. [3,6,7]

Another issue is that of the hydrogen bomb. There is no connection whatsoever between the chemical reaction potential of hydrogen fuel and the thermonuclear explosive potential of hydrogen as it is used in "hydrogen bombs". The term comes from the use of deuterium and tritium, both special isotopes of hydrogen. To

produce a thermonuclear or fusion reaction, extreme conditions of temperature and pressure which are necessary can only be achieved by the detonation of a fission (atomic) device. Hydrogen used in the marketplace has no probability of forming a fusion reaction. [3]

Hydrogen is not poisonous: The first thing all plants do during the photosynthetic process is produce hydrogen from water. Humans are also naturally exposed to free hydrogen. Up to 40% of the intestinal gasses can be measured as free hydrogen.[7]

Hydrogen exposed to oxygen will not spontaneously combust. In fact hydrogen requires an ignition temperature of 585°F (1085°F) to initiate combustion in ambient pressure air.[8]

Chapter 3

ELECTROLYSIS

Water is our most plentiful resource, and is also made up of a combination of hydrogen and oxygen (H_2O). One of the simplest methods of extracting hydrogen from water is done through a process called *electrolysis*. Michael Faraday (1791-1867) was one of the first scientists to investigate electrolysis. To better understand this process I will first discuss a process known as *ionization in electrolytes*.

An electric current can pass through non-metal conductors such as gases, certain liquids and polymers. The amount of electricity passing through such materials (electrolytes) depends on the number of ions (free electrons) that move through it. In ionized solutions, the ions fulfill the same role as electrons in conducting electricity through a wire. In an electrolytic cell, a positively charged electrode (anode) and a negatively charged electrode (cathode) are placed in the electrolyte. By passing an electric current through it, the positively charged ions drift to the cathode and negatively charged ions to the anode.

Electrolysis of water is done by adding a sufficient electromotive potential (voltage) across water. As the current flows through the electrolytic cell, chemical changes occur at the surface of the electrodes. At the cathode (negative electrode) the electrolyzed liquid combines with electrons supplied by a DC power source. This process is called reduction. At the anode (the positive electrode), the liquid gives electrons to the anode. This process is called oxidation. During the electrolysis process, the

water combines with electrons at the cathode and is reduced to hydrogen gas. At the anode the water gives up electrons and is oxidized into oxygen gas as shown in equation 3. [21]

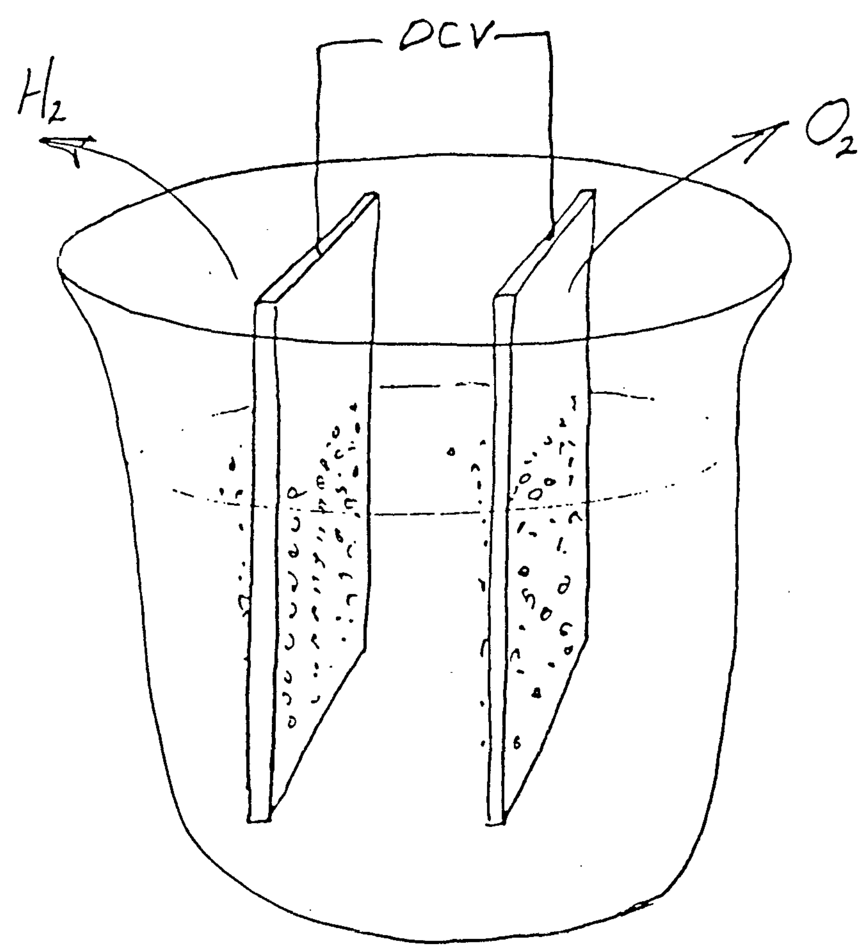
EQUATION 3

$$2H_2O \rightarrow 2H_2 \uparrow + O_2 \uparrow$$

Figure 3.1 shows a simple electrolytic "cell". Hydrogen bubbles appear at the cathode and oxygen gas appears as bubbles at the anode. [11]

FIGURE 3.1

The simple electrolysis of water



Chapter 4

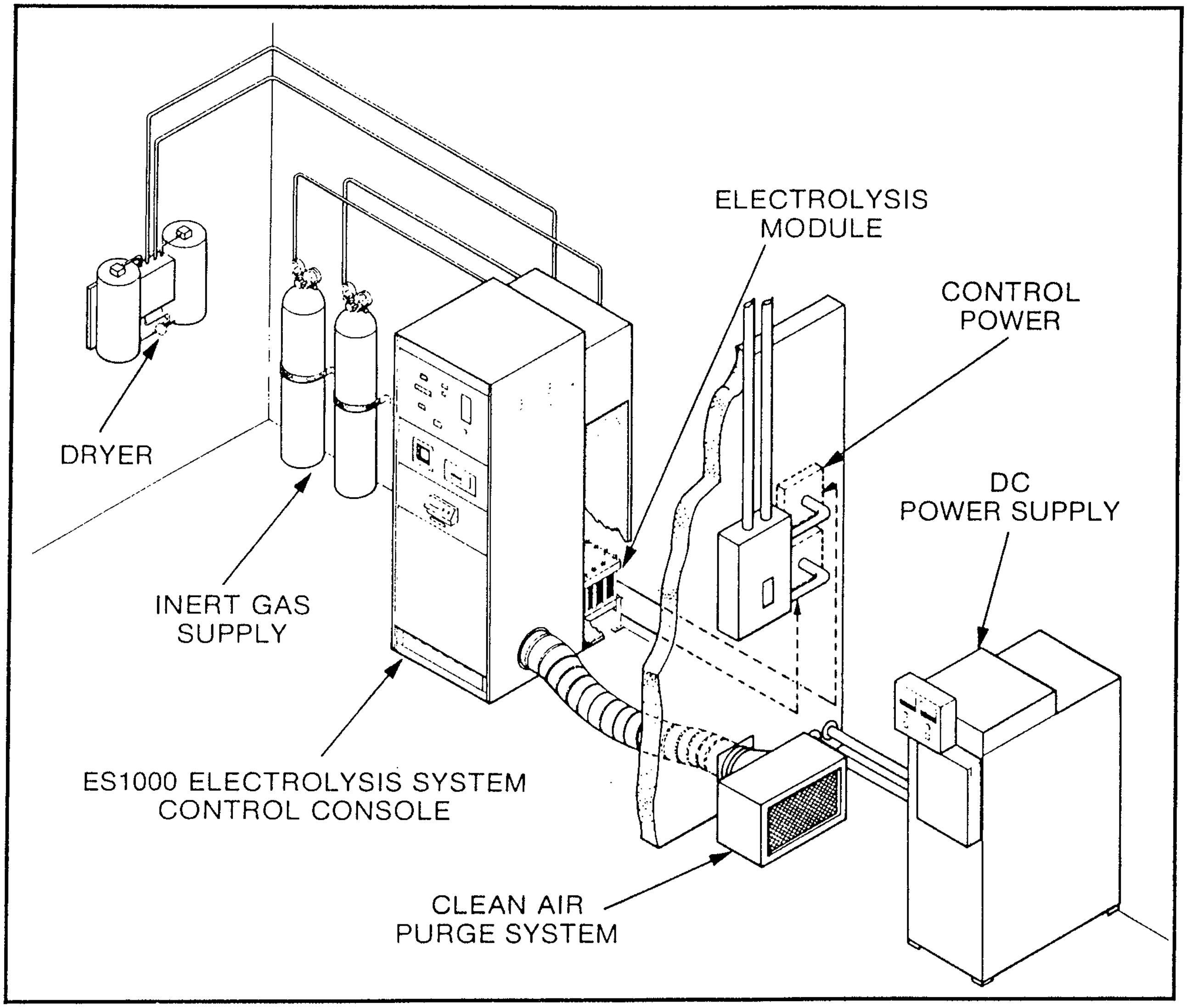
ELECTROLYZERS

Current electrolysis systems are more complex and look much different than the electrolysis cell shown in figure 3.1. Figure 3.2 shows a commercially available electrolysis system

FIGURE 4.2

ES 1000 ELECTROLYSIS SYSTEM

TYPICAL INSTALLATION

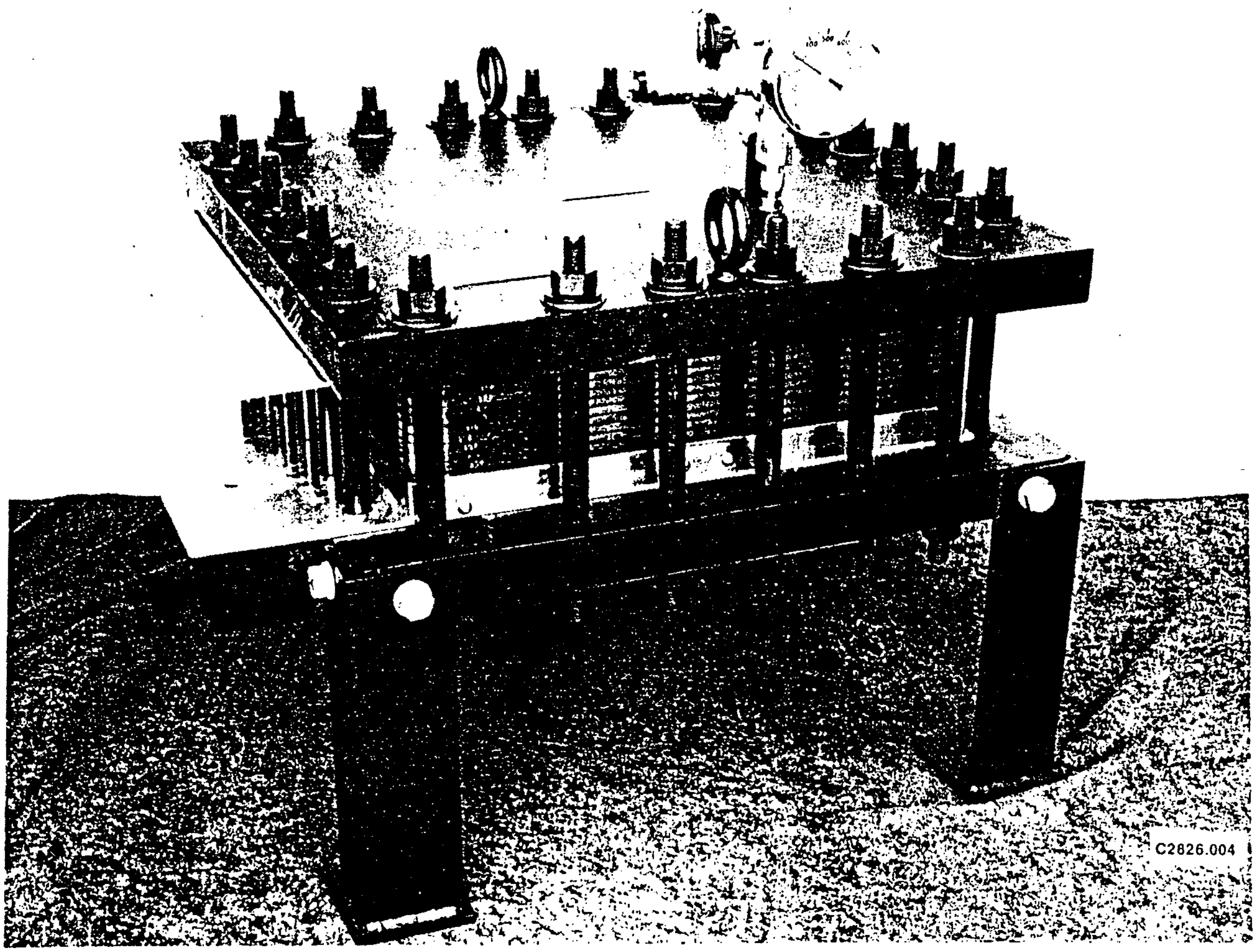


courtesy: United Technologies/ Hamilton Standard)

The key to the electrolysis system is the electrolysis module. The module, or "cell stack", is made of many individual cells "stacked" together like a deck of cards as shown in figure 4.1

FIGURE 4.1

EM-1000 ELECTROLYSIS MODULE

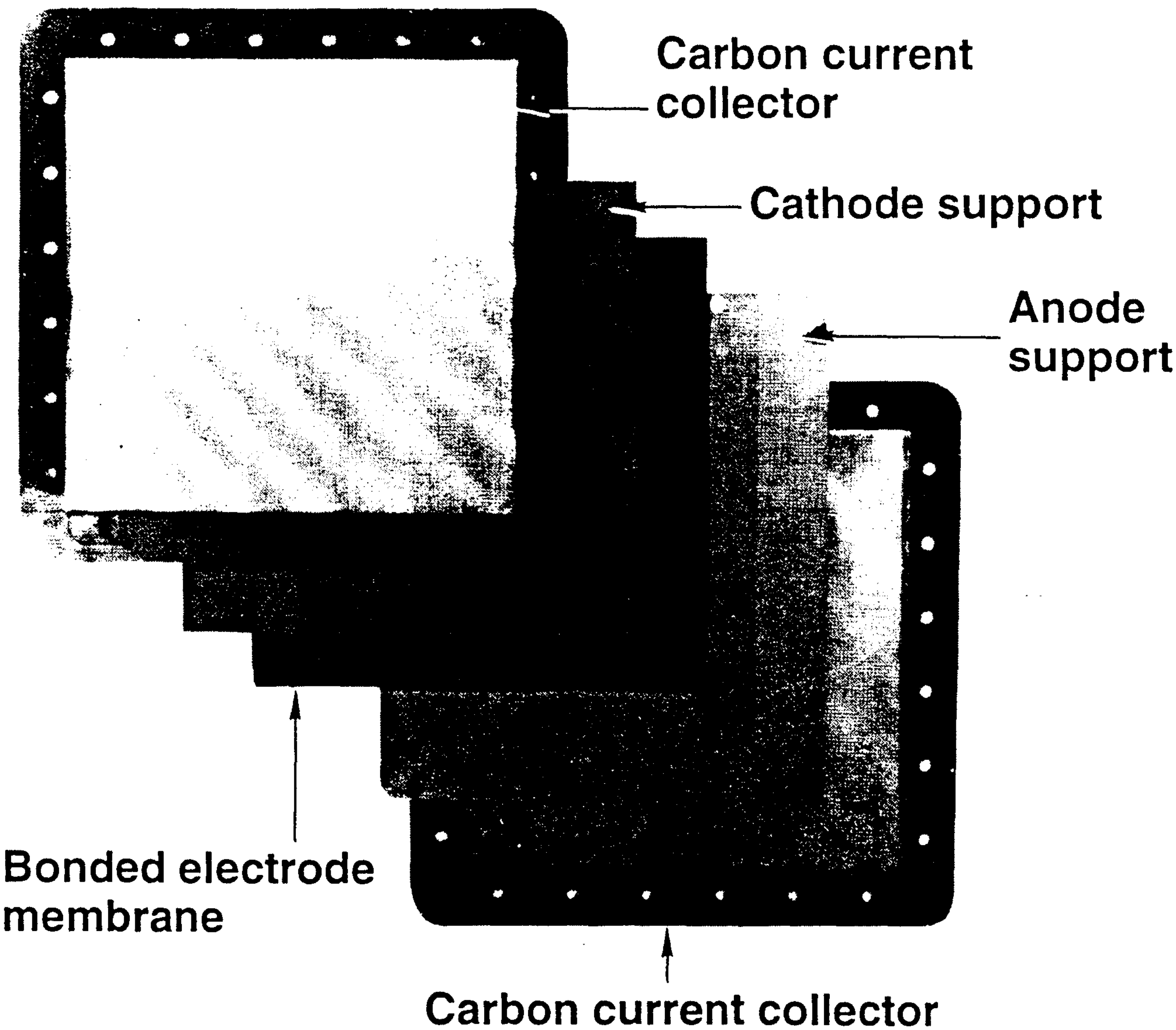


courtesy: United Technologies/Hamilton Standard

Each individual cell has 5 main components as shown in figure 4.2

FIGURE 4.2

SINGLE ELECTROLYSIS CELL



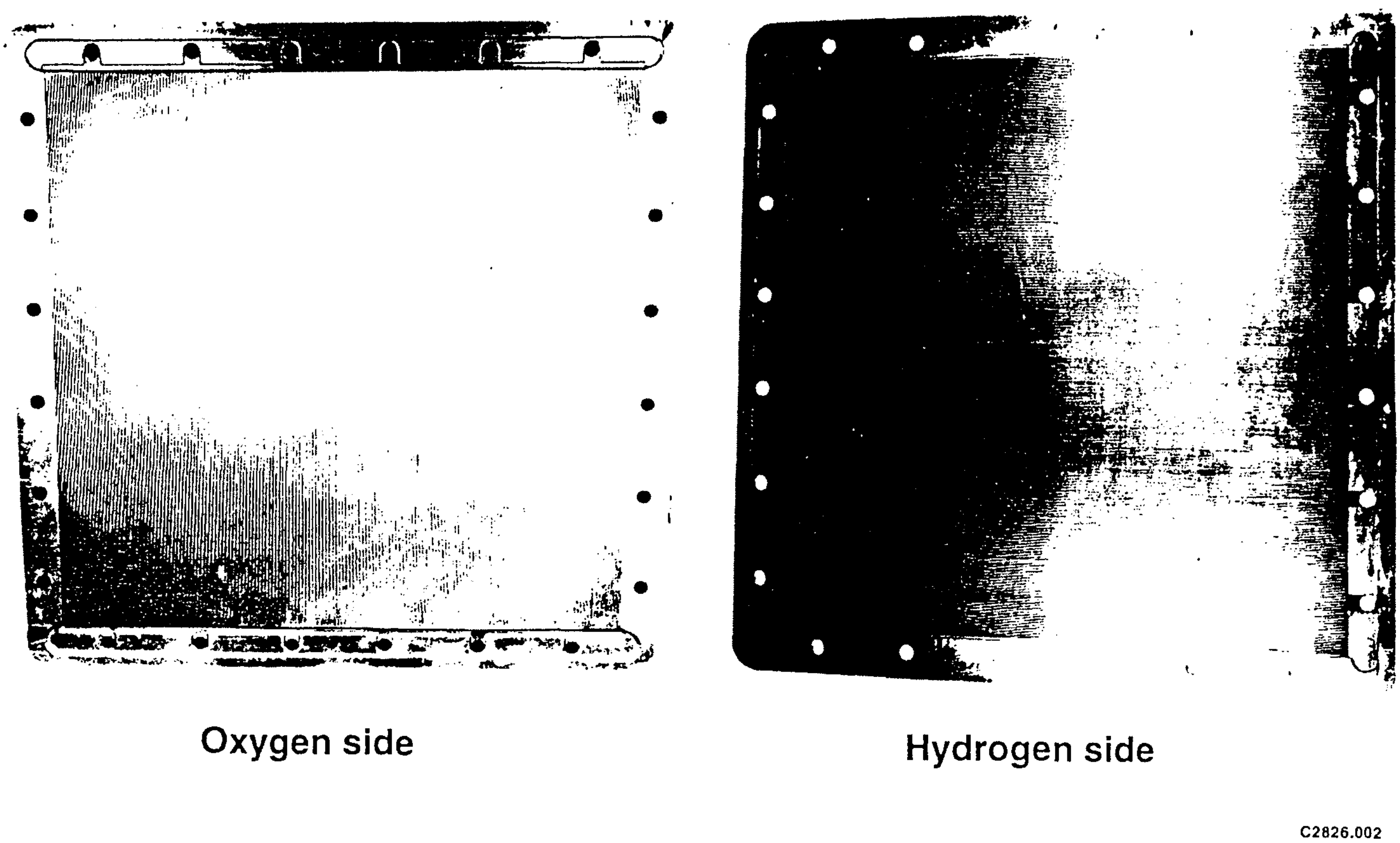
Courtesy: United Technologies/Hamilton Standard

The bonded electrode membrane (perfluorocarbon ion exchange membrane) acting as the electrolyte is made of a polymer known as Nafion® (similar to teflon). This solid polymer electrolyte technology is trademarked SPE™.

Each cell has 2 molded carbon current collectors. One is the oxygen side and the other is the hydrogen side as shown in figure 4.3

FIGURE 4.3

CARBON CURRENT COLLECTORS

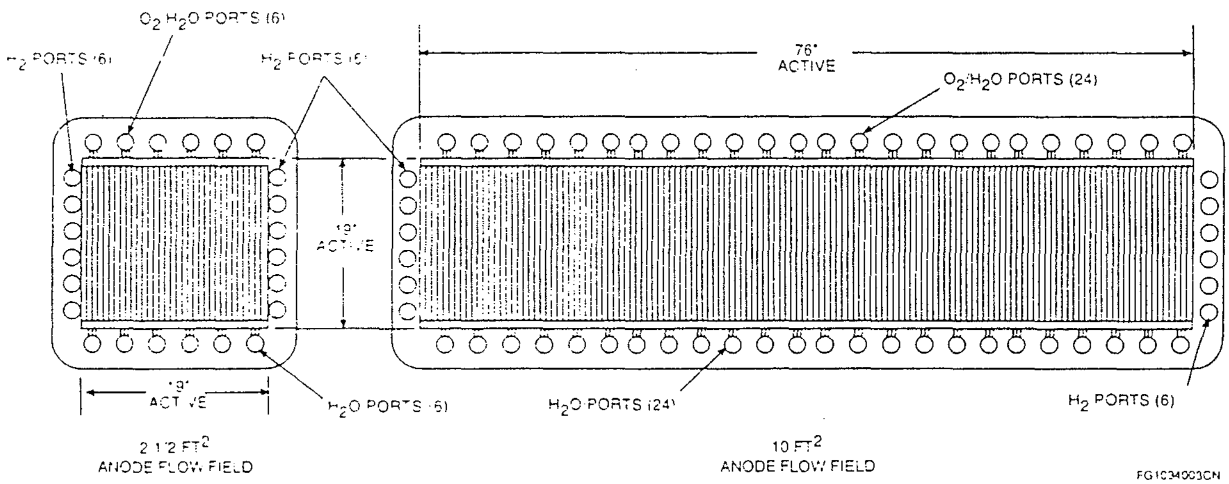


courtesy: United Technologies/Hamilton Standard

The carbon current collectors are designed to channel the hydrogen, oxygen and water through the cell assembly by special ports as demonstrated in figure 4.4

FIGURE 4.4

SPE WATER ELECTROLYZER MOLDED SEPARATORS

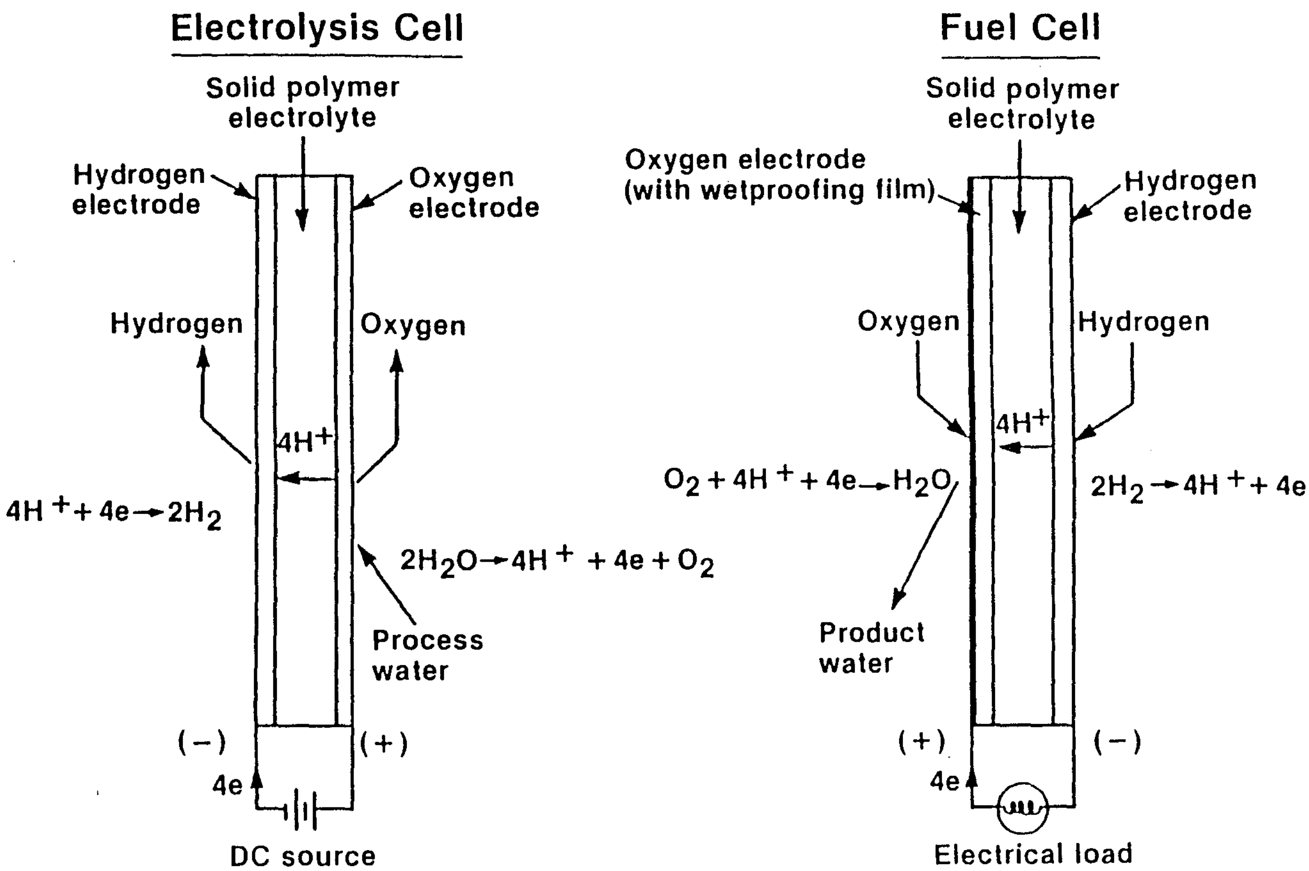


Courtesy: United Technologies/Hamilton Standard

Electrolysis also works in reverse. When hydrogen and oxygen are combined, water and electricity are produced. The device which is similar in makeup is known as a fuel cell. Figure 4.5 shows SPE™ electrochemical cell reactions in both.

FIGURE 4.5

SPE ELECTROCHEMICAL CELL REACTIONS



Courtesy: United Technologies/Hamilton Standard

Other methods of hydrogen production or technologies used in

fuel cells (described later) include but are not limited to:

A. *Endothermic electrolysis*. This is electrolysis done in elevated temperature systems that substitute heat for voltage. Heat is added to overcome voltage expenditures due to various resistive losses, thus reducing the voltage requirement for splitting the water molecules. The result produces more chemical potential energy as hydrogen, than the process consumes as electrical energy. On an electrical analysis the efficiency of electrolysis is the ratio of hydrogen energy units divided by the electricity units consumed in the process.

Efficiency = (hydrogen energy/electrical energy)100. [11]

B. *Thermochemical dissociation*. If enough heat is added to water it will boil and vaporize. Adding more heat will cause the water to reach the temperature of dissociation and hydrogen will be separated from the oxygen.[11]

C. *Catalytic dissociation*. Hydrogen that is contained in hydrogen rich fuels such as gasoline, diesel, kerosene, methanol, ethanol and natural gas will dissociate in the presence of a catalyst such as platinum. [13]

Other sources of hydrogen or hydrogen rich compounds can be derived from agricultural operations (methane CH_4, ethanol C_2H_5OH and methanol CH_3OH); municipal wastewater systems (methane); landfills (methane) and as a by product of many other manufacturing/refining processes.

Chapter 5

HISTORY OF FUEL CELLS

The fuel cell was invented In 1839, by Sir William Robert Grove. [15,16,17] At that time Grove was a professor of experimental philosophy at the now defunct London Institute, a good friend of Michael Faraday and an early student of electrolysis. During one of his experiments he disconnected the electrolyzer and discovered that it worked in reverse (when oxygen and hydrogen combine they form water and electricity). This is the basis for the fuel cell. [17]

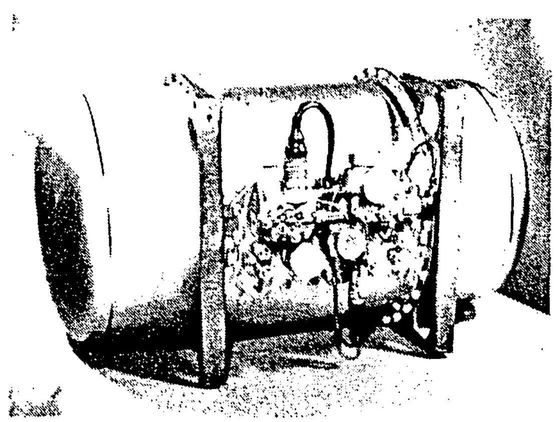
Sir Robert William Grove

Although the principles of fuel cell operation were conclusively demonstrated by Grove, it was not until the 1950's

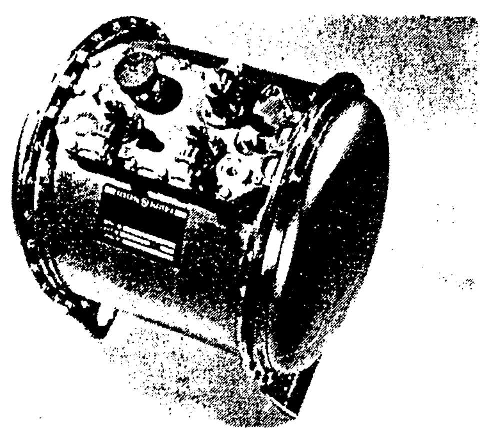
that engineer Francis T. Bacon succeeded in building a device that could generate practical amounts of electricity over prolonged periods. This device produced 6 kilowatts (kW) of power. Building upon this success, Pratt and Whitney Aircraft began a program sponsored by the U.S. Government for the development of a fuel cell for the Apollo Space Program.[19]

By 1965 fuel cells were in routine use in space flight as shown in figure 5 [18] and are used today on the space shuttle orbiter in figure 5.1. Other current applications will be discussed later in this document.

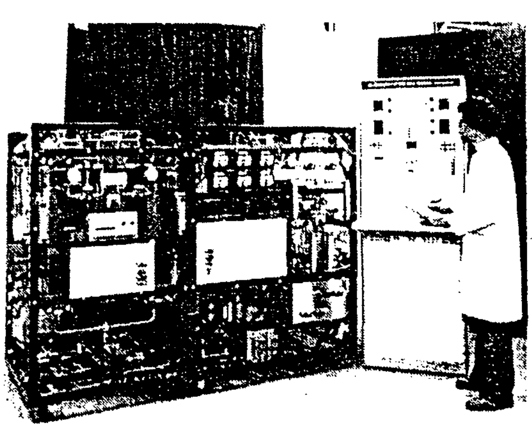
FIGURE 5



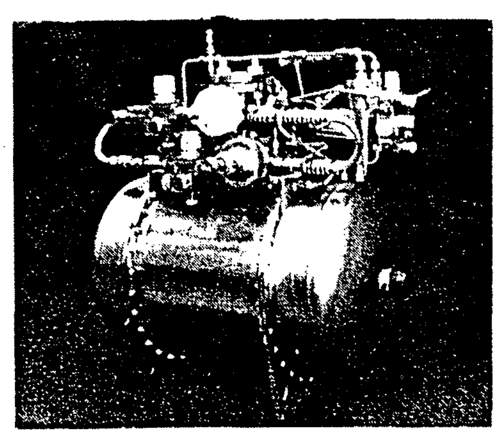
1 kW fuel cell
for Gemini spacecraft



350 watt fuel cell
for biosatellite
spacecraft

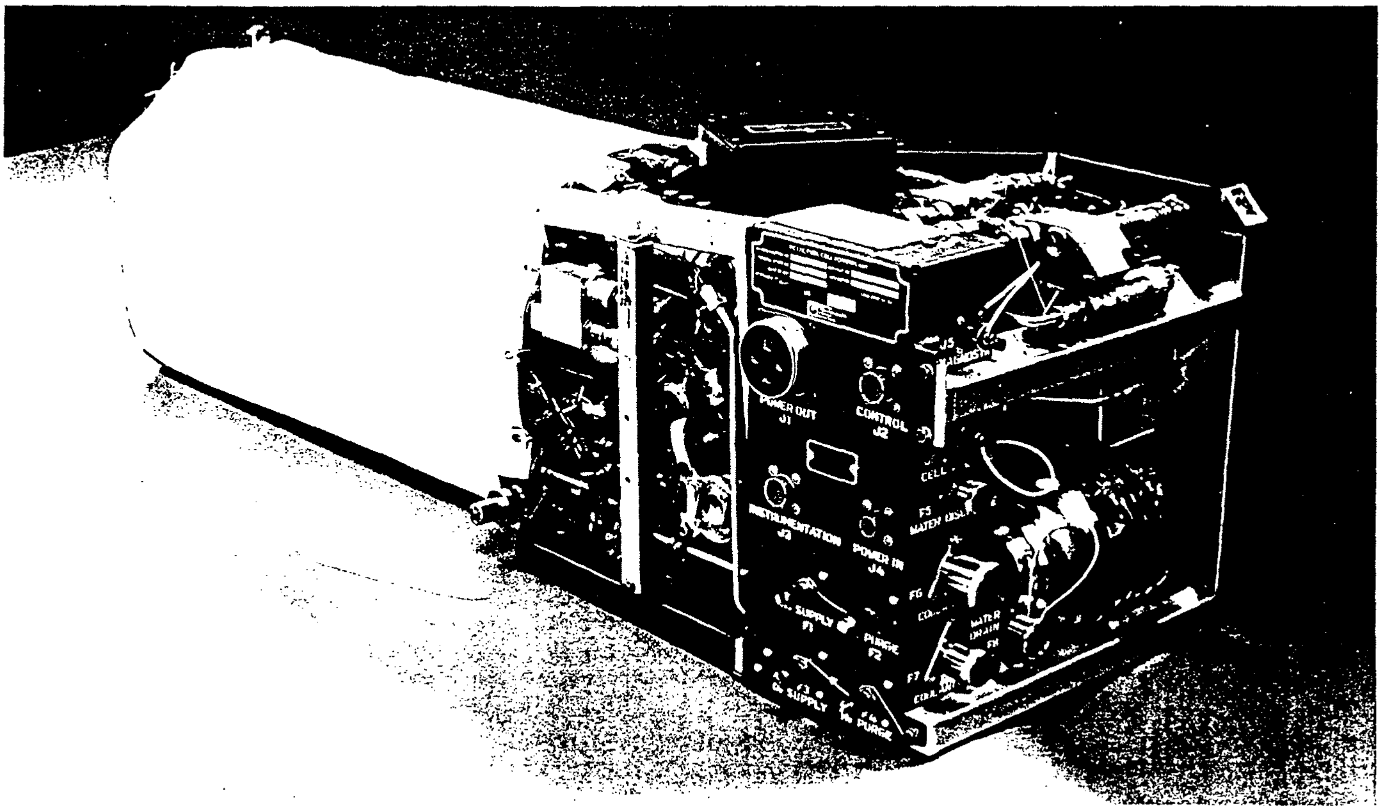


Regen. O_2/H_2 fuel cell
B/B system for NASA
orbital energy storage



3 kW fuel cell
system for Navy
Aerostat

FIGURE 5.1



International Fuel Cells

SPACE SHUTTLE ORBITER FUEL CELL

WCN 10462

courtesy: United Technologies/International Fuel Cells

Chapter 6

HOW FUEL CELLS OPERATE

A fuel cell produces electricity without using moving parts. It cleanly, quietly and efficiently converts the stored chemical energy of its fuel into electrical energy. It can be used to power, heat and cool homes; utilities and factories and also power automobiles; buses and locomotives. The fuel cell combines hydrogen with oxygen from air to produce electricity. In a vehicle hydrogen can be stored as a gas or a liquid. By using a reformer fuels such as gasoline; ethanol; methanol and other hydrogen rich fuels can be used. The only emission from the fuel cell itself is water [22,24].

Physically the fuel cell resembles a sandwich with each cell producing a certain amount of voltage. The total output of a fuel cell is determined by the number of cells contained in the "stack". Each cell is comprised of two electrodes, a negative anode and a positive cathode which are separated from each other by an ion conducting electrolyte. The anode is where the hydrogen atoms from the fuel react to form positive hydrogen ions (H^+) and negative electrons (e^-). The hydrogen ions migrate through the electrolyte to the cathode where they combine with oxygen from air to form water. The flow of electrons from the anode to the cathode produces an electric current as is demonstrated in figure 6 [39].

FIGURE 6

FUEL CELL OPERATIONS

Load → e^-

H_2 ↓ | \/\/\/\/\/\/\/\/\/\/\/\/\ | O_2 ↓

Proton Ion Exchange		
$H_2 \rightarrow 2H^+ + 2e^-$	$H^+ \rightarrow$	$O_2+4H^++4e^- \rightarrow 2H_2O$
Alkaline		
$H_2+2OH \rightarrow 2H_2O+2e^-$	$\leftarrow OH^-$	$O_2+2H_2O+4e^- \rightarrow 4CH^-$
Phosphoric Acid		
$H_2 \rightarrow 2H^+ + 2e^-$	$H^+ \rightarrow$	$O_2+4H^++4e^- \rightarrow 2H_2O$

Chapter 7

FUEL CELL TYPES

There are several types of fuel cells which are differentiated by their operating characteristics. The major fuel cell types are:

Alkaline Fuel Cells-AFC

Molten Carbonate Fuel Cells-MCFC

Phosphoric Acid Fuel Cells-PAFC

Proton Exchange Membrane Fuel Cells-PEMFC

Solid Oxide Fuel Cells-SOFC

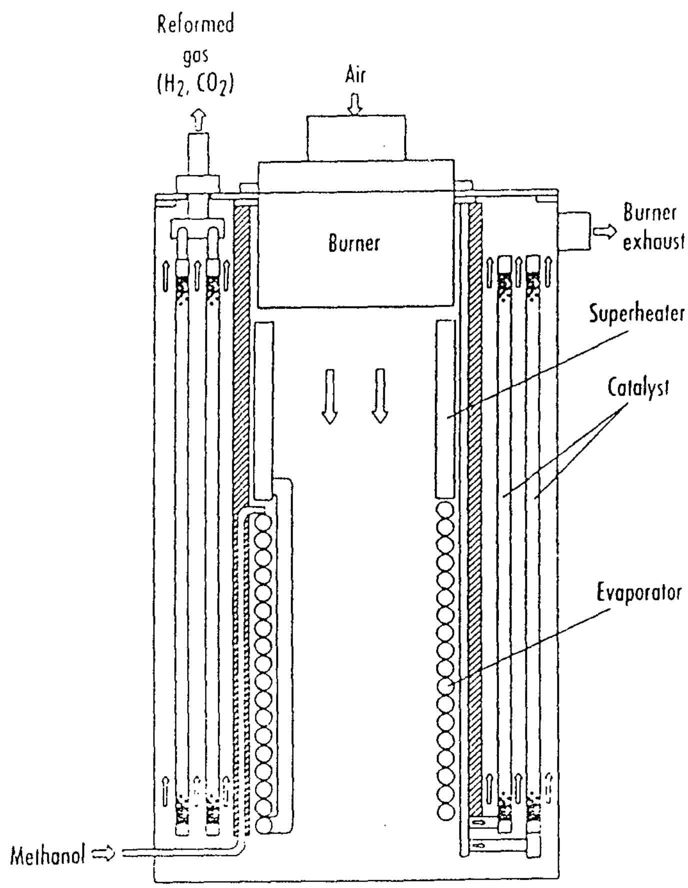
The names are derived from the electrolyte component of the fuel cell. The PAFC has a phosphoric acid electrolyte, the MCFC a molten carbonate electrolyte and the SOFC a solid oxide electrolyte. In the PEMFC, the electrodes are submerged in an aqueous, water-based, medium and a special polymer membrane produces the electric current as the ions pass through it. The AFC (figure 5.1 on page 21) uses potassium hydroxide as the electrolyte.

The PAFC, MCFC and SOFC are high temperature fuel cells operating at 190-210^{0}C, 630-650^{0}C, and 900-1000^{0}C respectively. The PEMFC and AFC are low temperature fuel cells both operating at 50-100^{0}C.

A fuel cell runs on hydrogen or hydrogen rich fuels. Most of the fuels we are familiar with contain hydrogen including: gasoline, diesel fuel, propane, natural gas, methanol, ethanol, landfill gas and pure hydrogen. A fuel cell may utilize any of these fuels with some fuel cleaning and pre-processing. Fuel

cleaning is needed to remove contaminants such as heavy metals or sulphur that may reduce fuel cell performance or damage its components. Fuel pre-processing is done by a device known as a reformer shown in figure 7 [25]

FIGURE 7

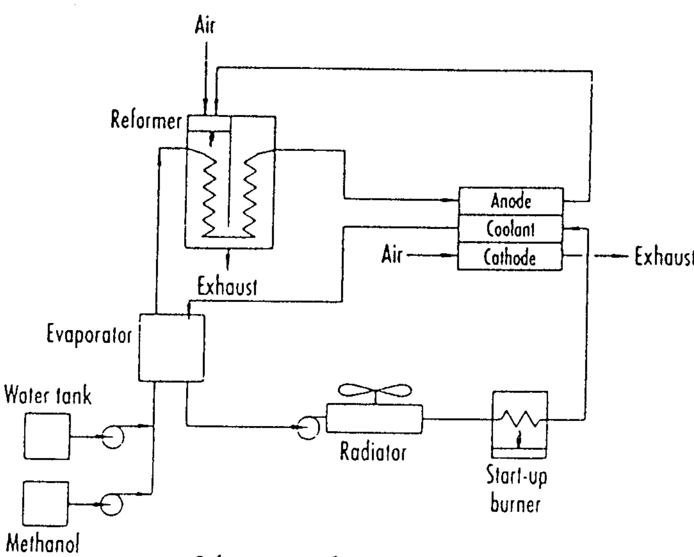


Cross Section of a Methanol Reformer

The reformer extracts hydrogen from fuels which can then be fed directly to the fuel cell. Natural gas is the most commonly reformed fuel, but methanol and gasoline can also be reformed as well.

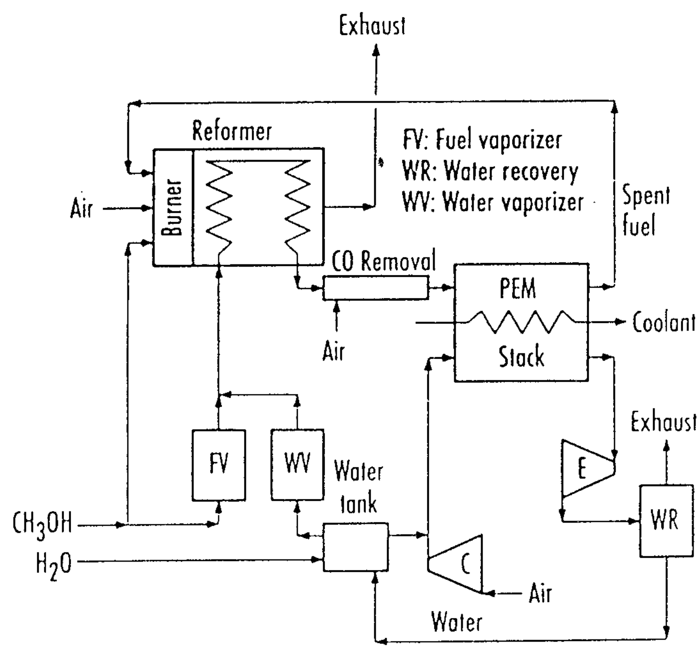
The PAFC (figure 7.1), PEMFC (figure 7.2) and AFC (space shuttle fuel cell) require pure hydrogen fuel which can be either direct hydrogen or hydrogen from reformed fuel. The SOFC (figure 7.3) and MCFC (not shown) can utilize natural gas, propane, dilute ethanol and methanol directly without reforming. This is due to high fuel cell operating temperature and specialized reforming plate contained on top of the cell stack. [26]

Figure 7.1



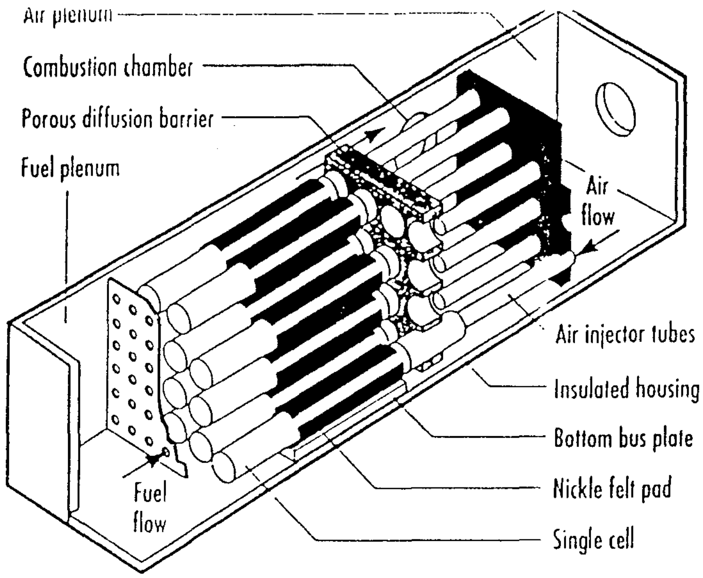
Schematic of a PAFC System

Figure 7.2

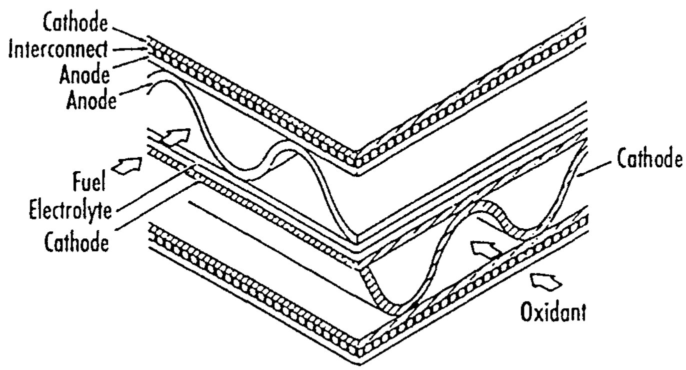


A PEM Fuel Cell System

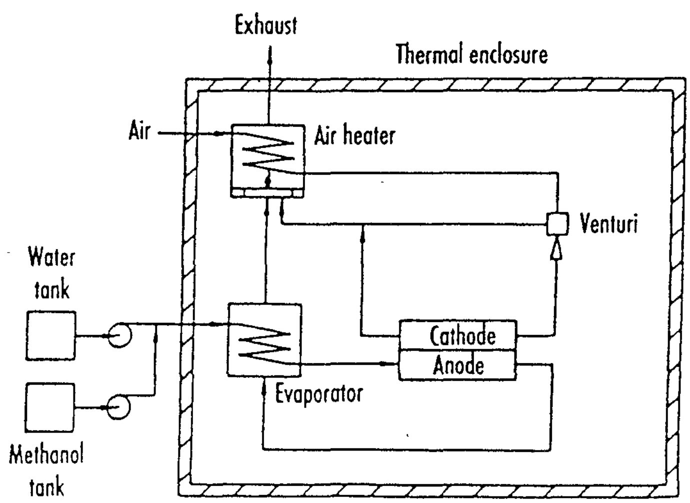
FIGURE 7.3



Tubular SOFC Design



Monolithic SOFC Design



Schematic of a SOFC System

Chapter 8

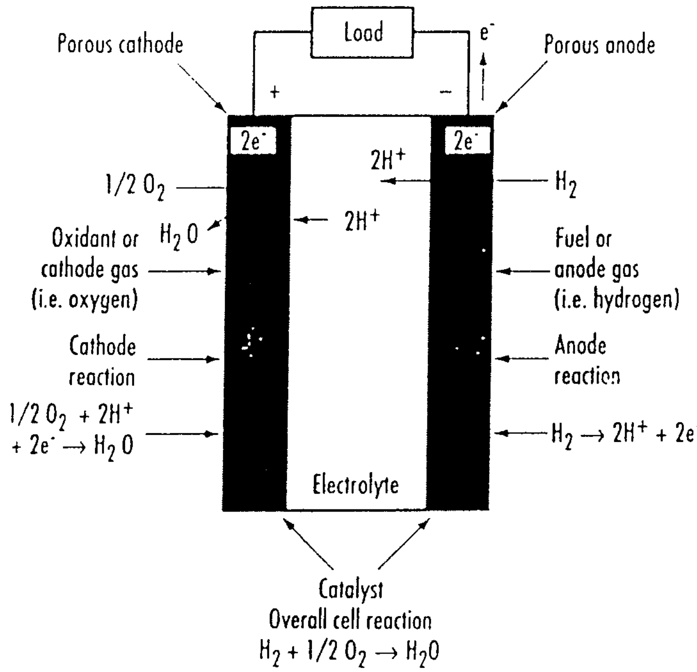
FUEL CELL ELECTROCHEMISTRY

Except for the molten carbonate fuel cell, all of the fuel cells described operate in the reverse direction of the electrolysis of water in which electricity is used to dissociate water to produce gaseous hydrogen and oxygen. Although the electrochemical reactions at the electrodes vary with the nature of the electrolyte, fuel cells combine hydrogen and oxygen ions to form water, and in the process, produce a flow of electrons from the anode to the cathode.

When an acid electrolyte is used, hydrogen gas dissociates at the negative electrode (anode) to form hydrogen ions (H^+) and an equivalent number of electrons (e^-): $H_2 \rightarrow 2H^+ + 2e^-$ The electrons flow through the external load to the positive electrode (cathode) where the electrons react with oxygen (O_2) from the air and water (H_2O) from the electrolyte to form negatively charged hydroxyl ions (OH^-): $1/2\ O_2 + H_2O + 2e^- \rightarrow 2OH^-$ The hydrogen and hydroxyl ions then combine in the electrolyte to form water: $H_2 + 1/2\ O_2 \rightarrow H_2O$ as shown in figure 8. The electrochemical conversion of energy in fuel cells takes place at much higher efficiency than that of the combustion of heat engines, which is limited by the Carnot cycle [22] described in equation 8.1 [23].

FIGURE 8

TYPICAL FUEL CELL REACTIONS



EQUATION 8.1

CARNOT EQUATION

$$W = Q\ (T_H - T_L)/T_H;\ \text{Therefore } E = W/Q = (T_H - T_L)/T_H$$

Where:

W = Useful work

Q = Heat energy

T_H = Temperature at which Q is delivered to the working fluid

T_L = Temperature at which the engine can reject heat

E = Engine efficiency

The theoretical efficiency for the conversion of heat energy into electrical energy is 83%. Efficiencies of practical cells using pure hydrogen and oxygen range from 50 to 60%. Cells using hydrogen derived from hydrocarbon sources and oxygen from air have somewhat lower efficiencies. [22]

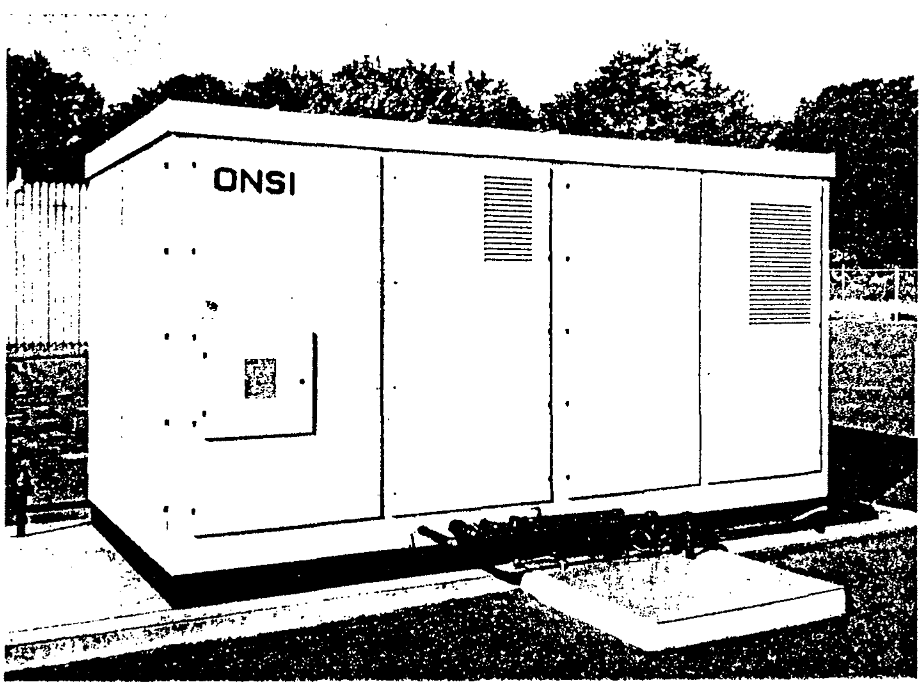
Chapter 9

POWER SYSTEMS

Fuel cell power systems are currently in use worldwide. One company ONSI, has commercially available stationary fuel cell power plants (PC25™ and PC25C™) which are rated at 200kW as shown in figure 9.

FIGURE 9

ONSI PC25™

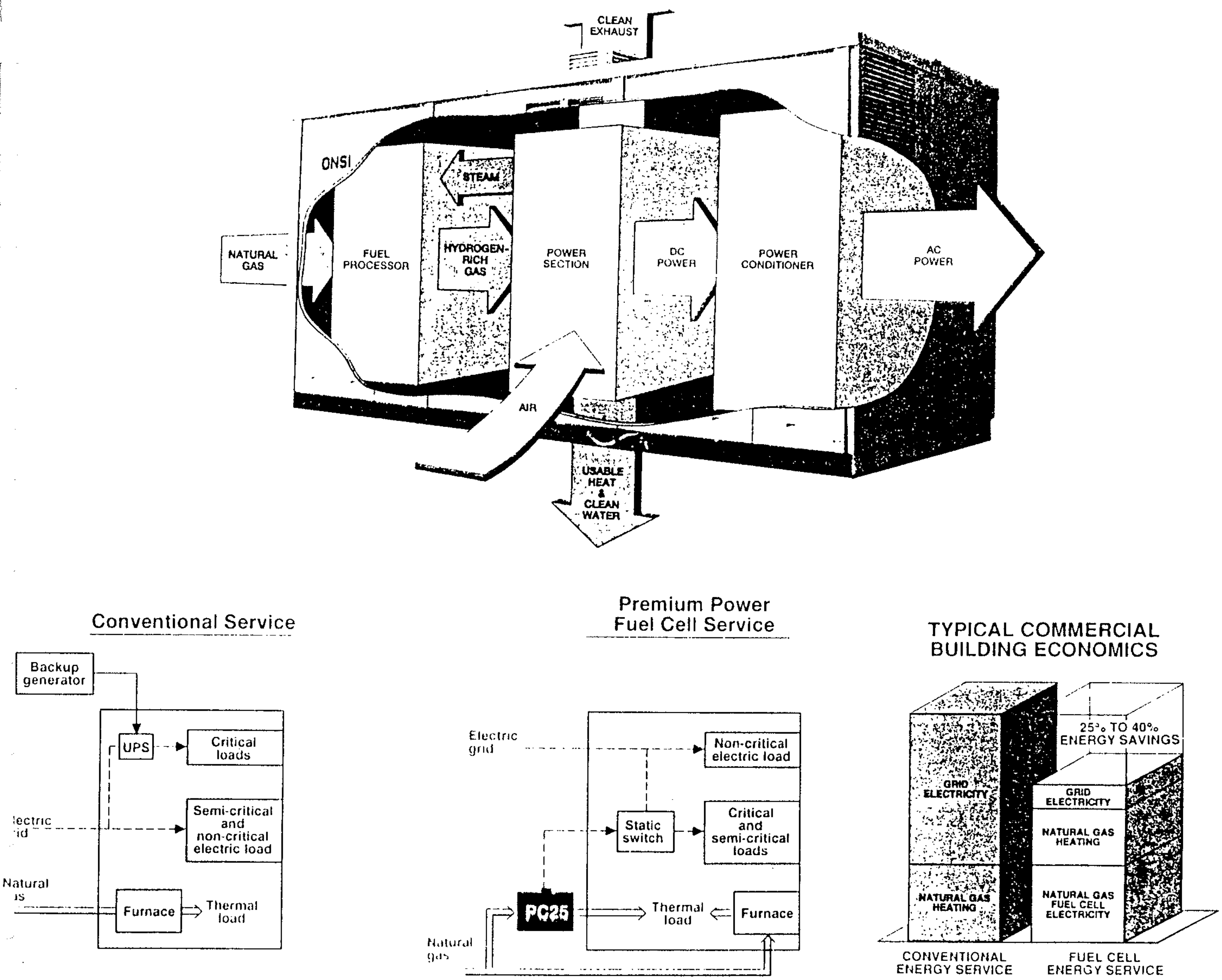


- 10'H X 10'D X 18'L
- 40,000 lbs.
- The PC25C is 30% smaller and lighter than ONSI's earlier models

Courtesy: International Fuel Cells

The PC25™ and PC25C™ plants utilize the Phosphoric Acid Fuel Cell (PAFC) configuration and are fueled by natural gas or optionally other fuels like propane. Not only do they produce electricity, the heat by-product can be used for water and space heating and cooling at 140°F to 250°F as shown in figure 9.1.

FIGURE 9.1



Courtesy: International Fuel Cells

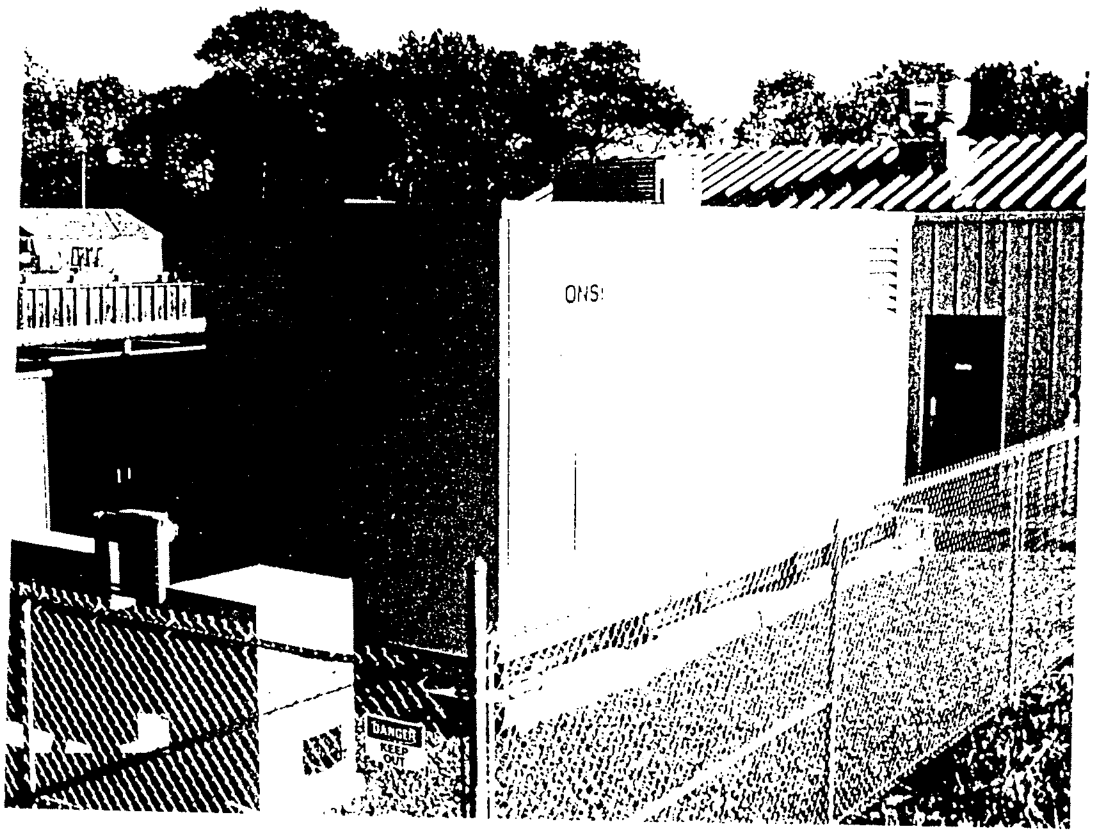
These units are available in grid-connected (the utility provides supplemental power) and grid-independent (The grid is used as a backup, or, the unit can operate entirely independent from the grid) configurations. The units are also very quiet. Noise levels are below 60 dBa at 30 feet or about that of a window air conditioner.

With over 1,000,000 operating hours, availability of 96%, 20 year operating life, 5-7 years before major maintenance and 4000 hours between forced outages proves that such systems are quite reliable. The cost of this systems can range from $600,000 to $800,000 depending upon installation [28] (about the same or less than the cost of a comparable photovoltaic system). In other developments ONSI has produced a 200kW fuel cell that operates using pure hydrogen fuel. The unit was purchased from ONSI by a partnership of electric utility Electricitats -Werke AG (HEW) and gas utility Hamburger Gaswerke (HGW). The unit was installed in Hamburg, Germany. Similar to the PC25™, this unit differs in that it uses pure hydrogen thus negating the use of fuel processing equipment and thus increases efficiency [29]. This plant provides electricity to the grid and hot water to an adjacent apartment complex. [29]

Another innovative fuel cell configuration was demonstrated at a landfill in Groton, Connecticut. This demonstration project involved the unprecedented partnership of the town of Groton, Northeast Utilities, International Fuel Cells, and the U.S. Environmental Protection Agency. The purpose was to clean the landfill gas (methane), then efficiently convert it into grid

electricity with essentially no air pollution. [30] Figure 9.2 shows this particular plant. [32]

FIGURE 9.2



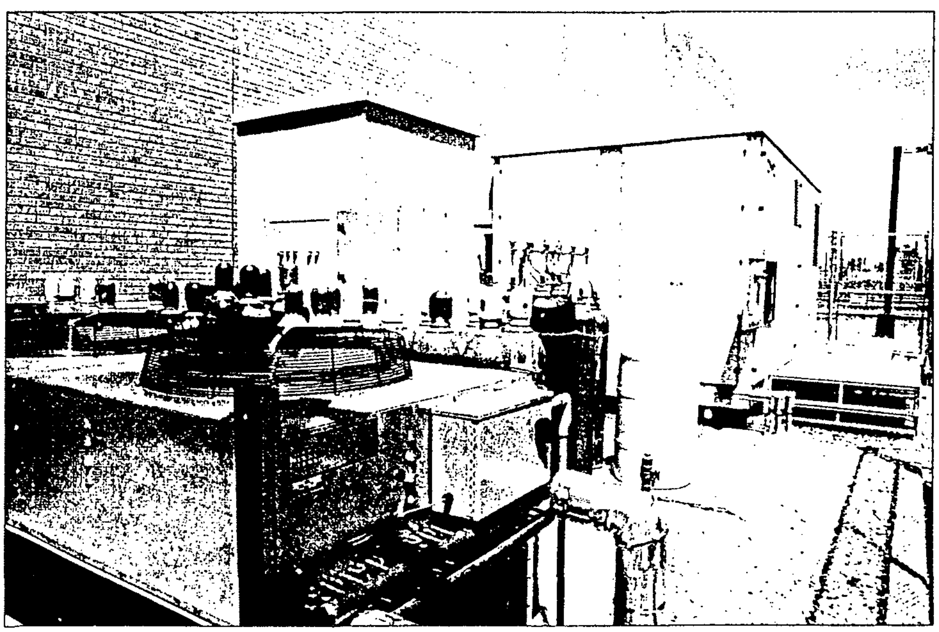
Courtesy: International Fuel Cells

Another interesting project involved the Yonkers waste water treatment plant. Located in Westchester County New York, this

project was funded by the U.S. Department of Energy, the Electric Power Research Institute and the New Your State Electric Research and Development Authority. Also involved was Westchester County, owner and operator of the plant. The plant utilized anaerobic digester gas (ADG) as the fuel. ADG is a by-product from the bacterial and biologic processes which occur at the waste water treatment plant during the treatment of waste water. The PAFC is a 200kW system made by ONSI, a joint venture IFC and Toshiba. Figure 9.3 shows this particular plant and figure 9.4 shows the schematic of fuel cell plant layout [31].

FIGURE 9.3

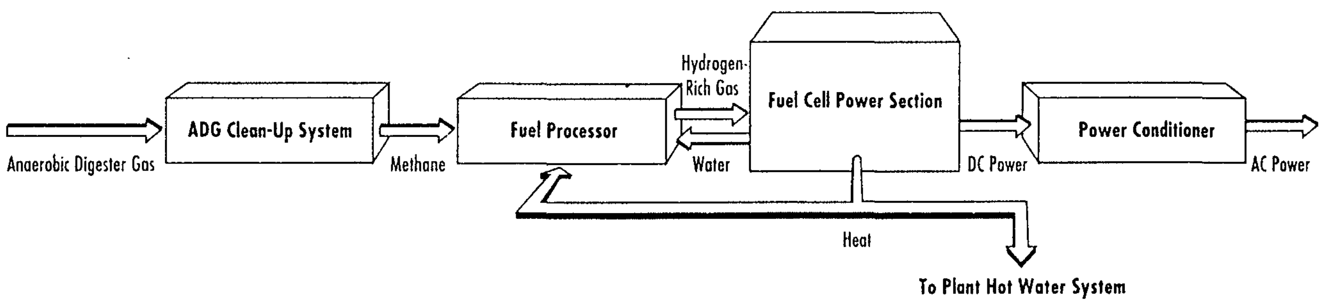
ADG FUEL CELL AT YONKERS.



Courtesy: International Fuel Cells

FIGURE 9.4

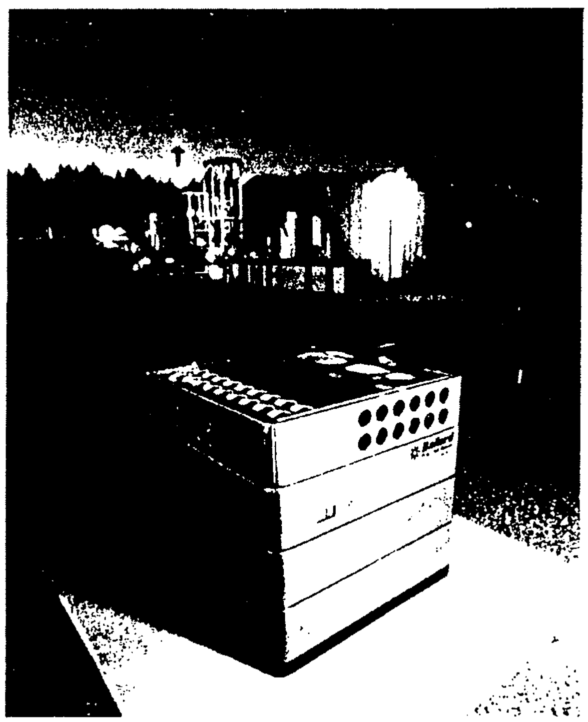
SCHEMATIC OF YONKERS FUEL CELL LAYOUT



Courtesy: International Fuel Cells

Another company involved in all facets of fuel cell technology is Ballard Power Systems. Currently Ballard and GPU International (Ballard Generating Systems) are testing a 250kW PEMFC that will be their entry into the power generation market for units under 1 megawatt in size. In 1994 Ballard had successfully demonstrated a 30kW PEM fuel cell which operated on by-product hydrogen from a nearby chemical plant as shown in figure 9.5. [33]

FIGURE 9.5



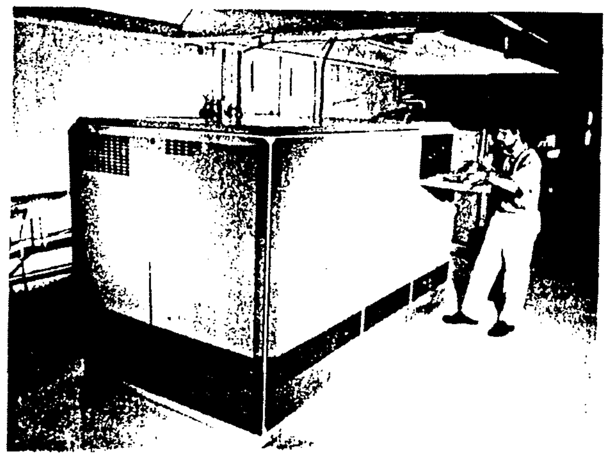
30 kW Power Plant Specifications

Net Power Output: 30 kW, 460 volts AC
Fuel: Industrial Hydrogen
Dimensions: 729 ft³ (20.6 m³)
Length: 9 ft (2.7 m)
Width: 9 ft (2.7 m)
Height: 9 ft (2.7 m)
Weight: 14,700 lb (6,700 kg)

Courtesy: Ballard Power Systems

Another Ballard project is its 10kW PEM natural gas plant. This demonstrated the ruggedness of a PEM fuel cell utilizing a natural gas reformer and is the basis for the 250kW unit as shown in figure 9.6. The prototype commissioning was completed in August 1997 and after thorough testing is expected to become available commercially in 2001.

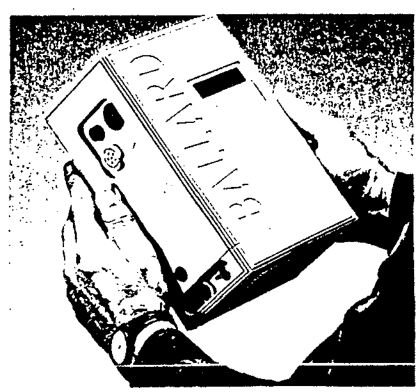
FIGURE 9.6



Ballard has also developed portable power systems. Figure 9.7 shows a recently developed 100 watt portable system.

FIGURE 9.7

Ballard's portable fuel cell power system was tested powering a radio during an ascent of Mount Logan in Yukon Territory, Canada.



Ballard's latest portable fuel cell power system provides 100 Watts of power.

Courtesy: Ballard Power Systems

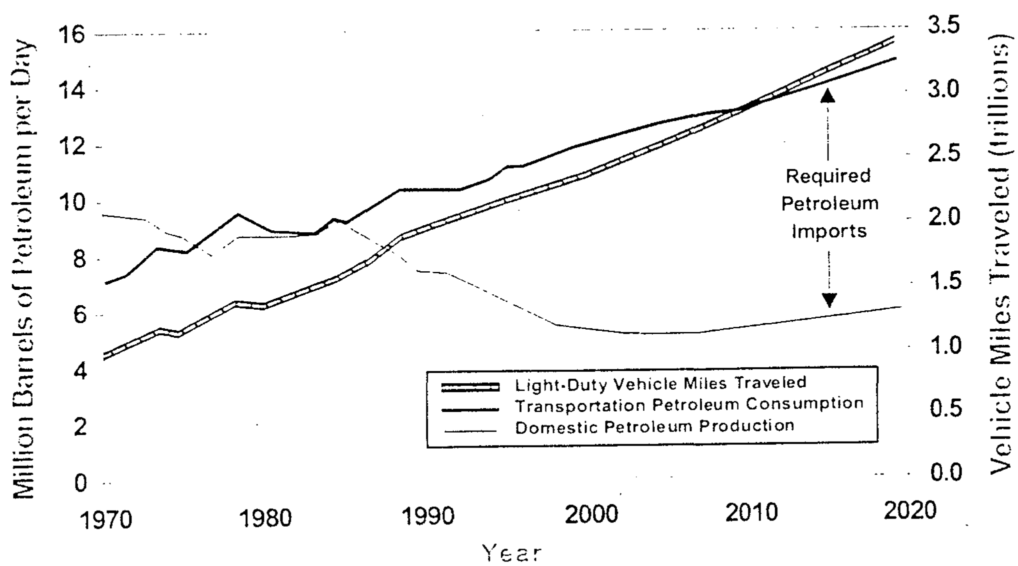
Chapter 10

FUEL CELLS IN TRANSPORTATION

Fuel cells have emerged as a potential replacement for the internal combustion engine (ICE) in vehicles. This is because of their demonstrated high efficiency, low emissions, fuel flexibility, quiet and continuous operation and modularity. The fuel must be hydrogen rich and includes fossil derived fuels such as: natural gas; methanol and petroleum distillates (gasoline, diesel etc), and also renewable fuels such as: ethanol; methanol and hydrogen (produced from renewable resources).

The transportation sector is the single largest user of petroleum in the United States consuming about 2/3 the total. Nearly half of all petroleum consumed in this country is imported. Oil consumption by automobiles and light-duty trucks alone now exceeds domestic production. [24] as shown in figure 10.

FIGURE 10



Source: U.S. Department of Energy

Americans have always enjoyed the freedom associated with automobiles. Just being able to go for a ride on sunday or going to the store on a moments notice because you ran out of milk, is a freedom and convenience most of us take for granted. Most of us drive to work every day without thinking twice about it. However, things were quite different on two occasions in recent American history. Some of you who read this might remember these events and those who were not yet born should be aware of them.

Reliance on imported oil especially from the Middle East has the potential of being a very serious threat to the economic well being and security of this nation as was demonstrated by the energy crisis of 1973 and again in 1978.[36] While reductions in U.S. oil supplies were less than 5% during both shortages, the dependency of the American economy on imported oil was so strong and rigid that it created economic upheaval; long lines at gas stations, prices doubling during each shortage, a $60 billion dollar drop in GNP, rapid inflation and large balance-of-payments deficits. These events demonstrated that our domestic economy can be significantly affected by oil supplies and prices. As long as America was dependent for a significant share of imported oil, and those imports hinge on oil from the Middle East, the U.S. would face serious and severe national security risks. Hundreds of billions of dollars was spent on military and other measures addressing this strategic threat. To reduce our dependence on imported oil, Congress passed a series of laws which sought to expand domestic gas and oil production, increase efficiency and promote renewable energy production. Shortly thereafter cheap oil was once again available. Funding for development of these technologies and tax

credits were significantly reduced or eliminated.[27]

In 1991 worldwide reliance on imported oil again became evident when 40 countries deployed troops and equipment to the Persian Gulf region. Iraq which holds more oil than any other country except Saudi Arabia, invaded Kuwait. By doing so Iraq was in control of 1/5 of the worlds oil supply. Had Saudi Arabia been taken, Iraq would have controlled 40% or nearly 1/2 of the worlds oil supply [37].

Events such as these are directly responsible for the United States and other countries in recognizing the benefits of fuel cell technology by accelerating development and implementation. The Fuel Cells for Transportation Program, which supports the U.S. Department of Energy Research and Development Plan for the Office of Advanced Automotive Technologies, is a strategy for the acceleration and implementation of fuel cell technology for transportation. This program will provide significant energy, environmental (figure 10.1), and economic benefits at the national, regional and local levels. These include:

A. Reducing dependance on foreign oil, thereby reducing trade deficits and increasing economic, political and military security.

B. Minimizing environmental impacts of transportation while maintaining a high level of mobility.

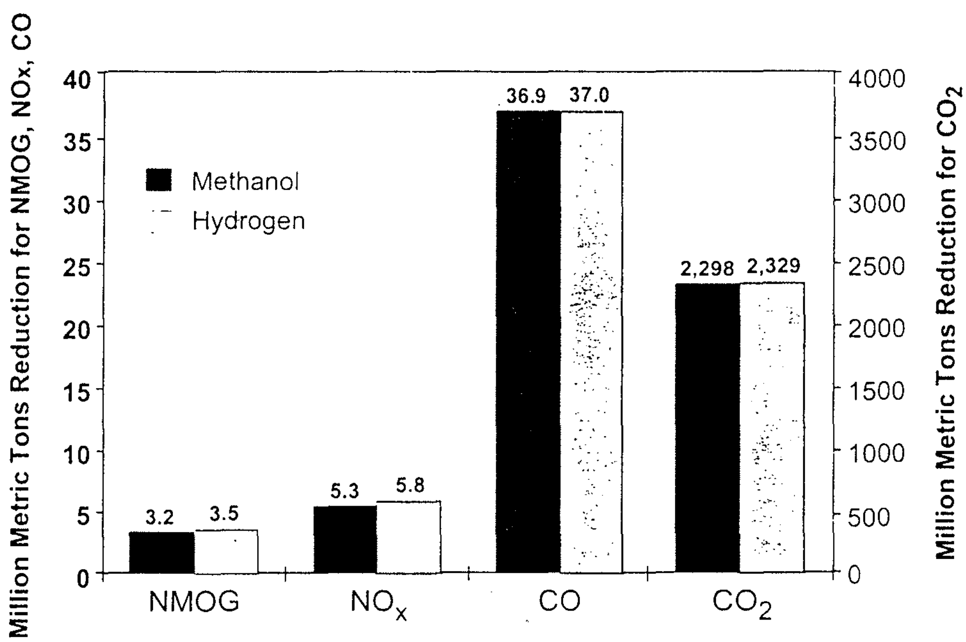
C. Increased jobs in the automotive industry and strengthening the competitiveness of the U.S. in international markets including

the utility, construction and industrial sectors.

D. Providing benefits to the entire domestic economy while include savings to consumers in the form of reduced fuel expenditures.

The value in reduced air emissions could total $23 billion by 2030 (1991 dollars), and a savings of 6.3 billion barrels of oil between 2000 and 2030. [24]

FIGURE 10.1



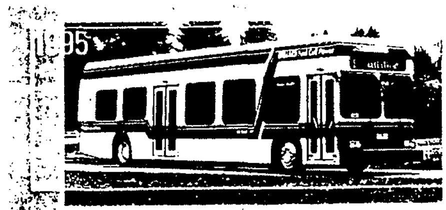
Cumulative Emissions Reductions from the Use of FCVs for the Period 2010-2030 (Base Case Market Penetration)

Source: U.S. Department of Energy.

Fuel cell technology is currently being used in the transportation sector. One of the industry leaders is Canadian based Ballard and affiliated companies. In 1995 Ballard demonstrated a fuel cell powered bus

as shown in figure 10.2.

FIGURE 10.2



Ballard Prototype Zero-Emission Fuel Cell Bus.

Courtesy: Ballard Power Systems.

In 1996 Ballard demonstrated a passenger vehicle in a joint venture with Daimler-Benz as shown in figure 10.3

FIGURE 10.3

Courtesy: Ballard Power Systems.

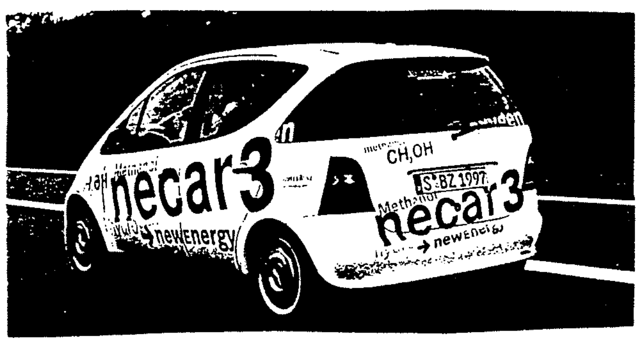
In 1997 Ballard delivered 3 fuel cell powered buses to the Chicago Transit Authority shown in figure 10.4 and completed three others for the British Columbia Transit Authority. During this time Ballard secured automotive partners Daimler-Benz AG and Ford Motor Company for the development and commercialization of fuel cell buses, cars and trucks. Ballard also obtained orders from automotive customers Chrysler, Ford and Nissan. Shown in figure 10.5 is the NECAR 3, a Mercedes-Benz A-class subcompact powered by Ballard fuel cells. Figure 10.6 shows 3 generations of Daimler-Benz

cars powered by Ballard fuel cells.

FIGURE 10.4

Courtesy: Ballard Power Systems.

FIGURE 10.5



Courtesy: Ballard Power Systems.

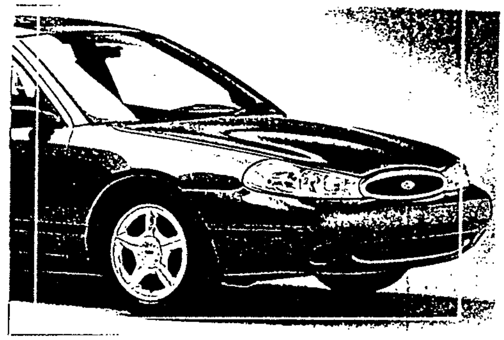
FIGURE 10.6

Courtesy: Ballard Power Systems.

In 1999 Ford Motor Company will complete its P2000 fuel cell concept car shown in figure 10.7 which resembles the Taurus in phase one of its fuel cell development activities.

FIGURE 10.7

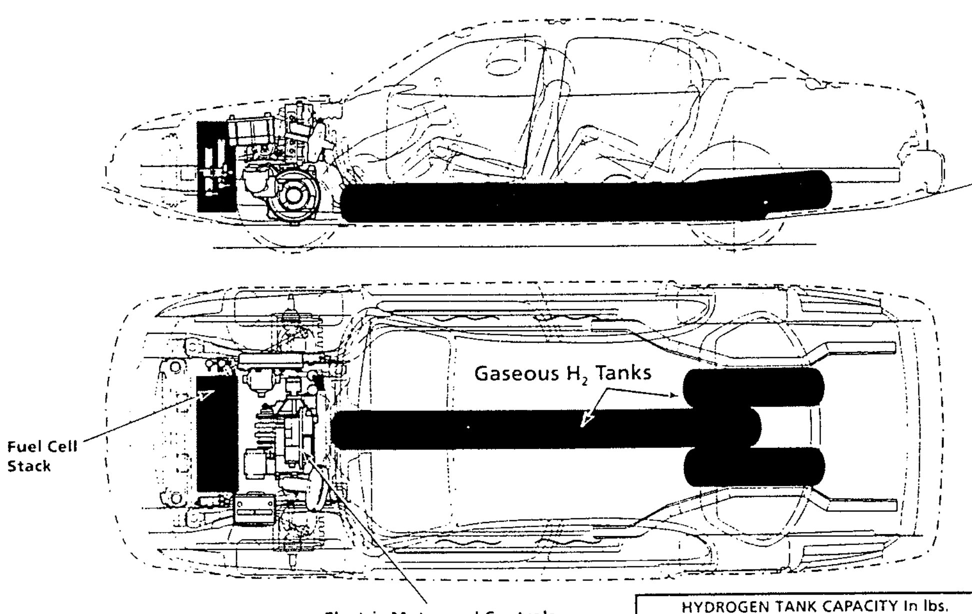
THE BALLARD POWERED FORD P2000 CONCEPT CAR



Courtesy: Ballard Power Systems.

Ford Motor Company is also working on a direct hydrogen fueled vehicle shown in figure 10.8 as part of its Phase 2 activities. The fuel cell is a 50kW PEM unit.

FIGURE 10.8



HYDROGEN TANK CAPACITY In lbs.		
	Per	Total
9.0" x 105" Long	4.9	4.9
9.0" x 35" Long	1.5	3.0
		7.9

Source: U.S. Department of Energy.

The subcontractors involved are: Directed Technologies of Arlington Virginia; Power Plug LLC, Latham, New York and International Fuel Cells Corp, South Windsor, Connecticut.

The automotive fuel cell operating characteristics are the same as its stationary power plant counterparts as is demonstrated in figure 10.9.[24]

FIGURE 10.9

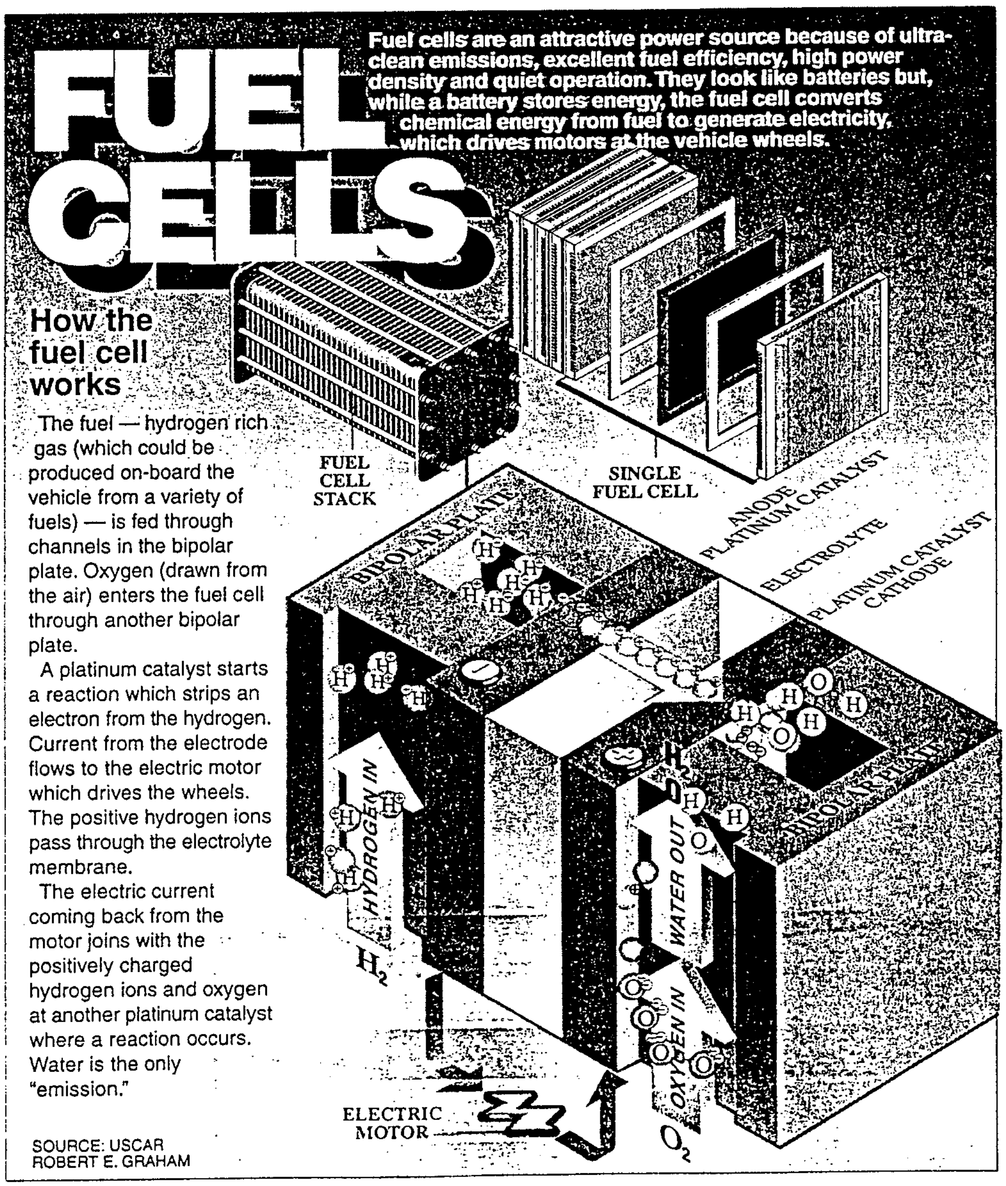
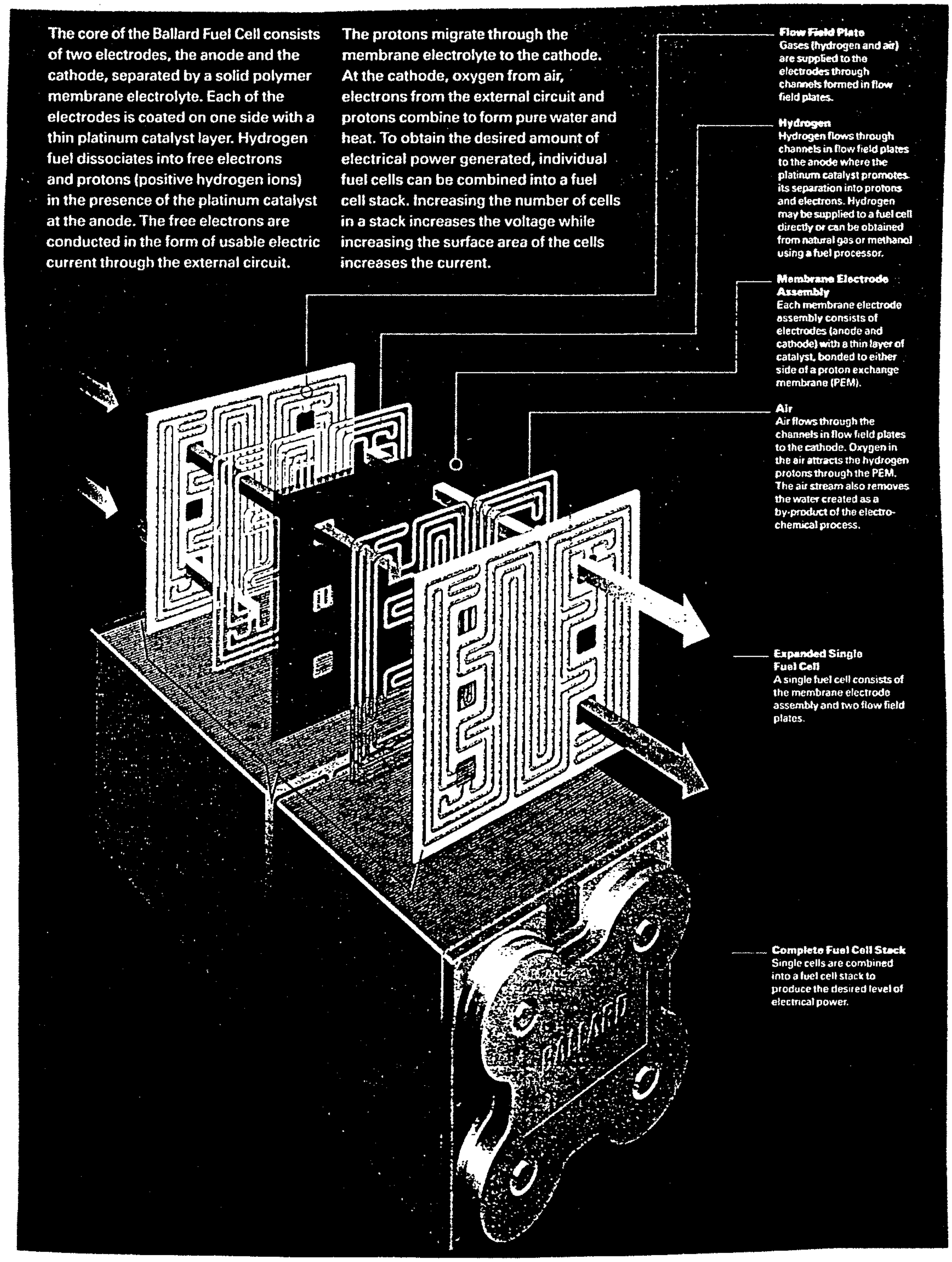


Figure 10.10 demonstrates the operating characteristics and makeup of the Ballard fuel cell.

FIGURE 10.10



Courtesy: Ballard Power Systems.

Chapter 11

HYDROGEN POWERED INTERNAL COMBUSTION ENGINES [40,41]

The successful conversion of standard internal combustion engines (ICE) to operate on hydrogen gas has been accomplished by the American Hydrogen Association and its affiliated chapters. A converted 1979 Dodge D-50 pickup originally developed for Dr. Robert Zweig*, is in service to demonstrate the viability of converting a standard ICE to operate on hydrogen without emissions associated with its fossil fueled counterpart. [40] Figure 11 shows specifications of the converted 1979 Dodge D-50.

FIGURE 11

FUEL STORAGE TANK: 11,390 CU.IN. composite; 12,000 PSI design; 5,000 PSI test; 3,000 PSI DOT approved hydrogen storage pressure for road use.

PRESSURE REGULATORS: MECO (first stage), IMPCO model E (second stage).

FUEL METERING: Special metering valve in hydrogen delivery manifold. Direct delivery to each cylinder.

AIR CONTROL: Normal intake valve for each cylinder.

IGNITION: 0° to 4° in advance of TDC by conventional spark ignition system.

* Dr. Zweig is a lung surgeon whose research showed that by age 12, the average city dweller has impaired lung function and that many diseases of the lung are associated with automotive emissions from hydrocarbon fuels.

Another upcoming development regarding this technology is the LARSEN RADAX ENGINE. Invented and designed by Mr. Mel Larsen, This engine is designed to set a new world record in thermal efficiency. Figure 11.1 shows specifications of this new engine.

FIGURE 11.1

1. NAME; RADAX - from radial and axial.

2. 8 cylinders: 4 opposing cylinders on each end. 306 horsepower, engine weight, 200 pounds.

3. Unprecedented arrangement of the Larsen cycle that eliminates objections to conventional 2 stroke engines.

4. No Throttle; free breather like a diesel.

5. Power output controlled by amount of fuel injected for each power stroke like a diesel.

6. The central output cam has three lobes giving 3 power strokes per cylinder, per rev. Each rotation of the output shaft is torqued by 24 piston strokes.

7. The geometric relation of the mirror-imaged cylinder positions to the opposing 4 cylinders provides for 2 cylinders to fire at the same time to provide opposing balance of reciprocating components.

8. The 2 groups of opposing cylinders on opposite ends give inherent internal balance without counterweights.

9. Each pair of cylinders fire every 30^0 of shaft rotation.

10. Two pair (4 cylinders) are on the power stroke at any one time.

11. All 8 cylinders fire 3 times for each shaft revolution (24); 24 or 12 dual strokes - compare this to a 4 stroke V8 with 4 power strokes per revolution - 1 every 90^0.

Chapter 12

HOME, GARDEN, EDUCATION AND INDUSTRY

There are currently several uses of hydrogen technology under development for home and garden applications. One of the worlds leading educational centers for manufacturing engineers is the Arizona State University College of Technology and Applied Sciences. Located at the former Williams Air Force Base, the ASU College of Technology and Applied Sciences offers hands on opportunities along with classroom instruction of manufacturing engineering topics. Curently, Professor Donald Kelley is leading his Capstone Class of seniors in manufacturing studies of common things such as automobiles and lawnmowers which operate with little to no emissions and in some cases even clean the air as they operate (known as minus emissions).

With assistance from the American Hydrogen Association, Professor Kelley's classes have learned how to make, store and use hydrogen as a fuel in ordinary engine driven equipment. These studies focus on how to make cost effective equipment that is safer but as convenient to use as their fossil fueled counterparts.

The Society of Manufacturing Engineers (SME) has taken notice of this work and is sponsoring their work in a prestigious international contest by WESTEC. This entry will detail a business start-up including the manufacturing studies, a prototype lawnmower and a marketing study. The ASU Capstone Project student leaders have determined that they could overcome the common lawnmowers disproportionately high levels of pollutive emissions including unburned hydrocarbons, carbon monoxide and oxides of nitrogen.

Closely following the students progress is the Phoenix Rotary Club. Mr. Ray Smucker, who heads the publicity bureau of the club's "Pollution Free Planet" program said, "This is the type of business opportunity-analysis that our 1.2 million Rotary members around the world can understand and endorse. We are anxious to help bring city managers and other delegates from the worlds most polluted cities to AHA's out-reach programs so they can learn how to use renewable hydrogen to achieve sustainable prosperity along with environmental protection. Rotary International's 10 year program to "Protect Planet Earth" will be greatly advanced by students that enter the workplace with practical knowledge of how to engineer and manufacture profitable solutions to the pollution and unemployment problems that plague every city". [41]

In 1996, Energy Partners of West Palm Beach Florida in collaboration with equipment manufacturer, John Deere, developed a 6x4 utility vehicle that utilized PEM fuel cell technology. The prototype unit (shown in figure 12) consists of a John Deere 6x4 Gator chassis and was powered by an Energy Partners' 10kW PEM fuel cell. This vehicle carried two passengers and a payload of 750 pounds for approximately 6 hours at speeds of up to 23 MPH [42].

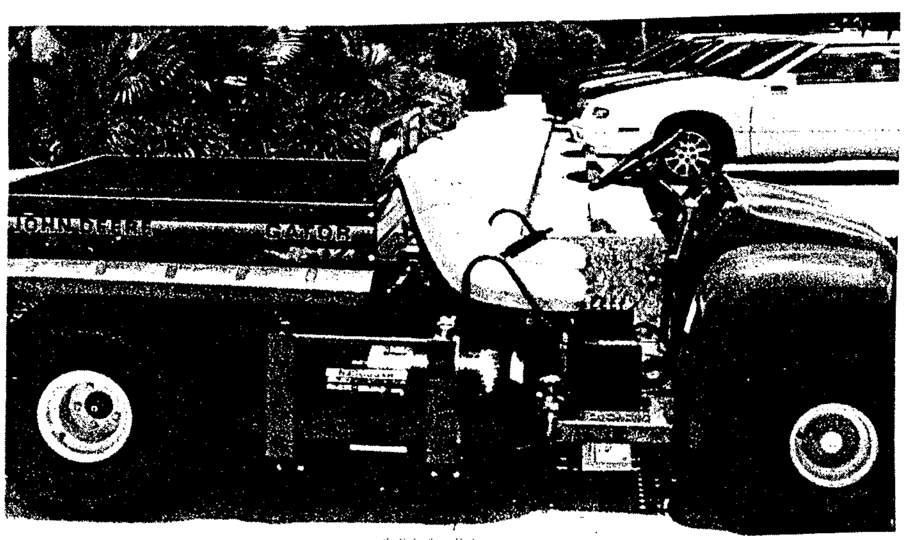
The Oregon chapter of the American Hydrogen Association has converted a 1978 Cadillac to demonstrate hydrogen awareness. This automobile consists of two systems [42]. The main system is used to demonstrate cooking/barbecuing with hydrogen while the second system uses hydrogen in the fuel system which increases gasoline mileage. This vehicle is typically shown on a beautiful beach or party at sunset conditions where shrimp, rice, vegetables and fruits are prepared. The rice and some vegetables are cooked and

the shrimp barbecued.

Since barbecues are a major source of air pollution during summer months, bans are sometimes issued on barbecuing due to air quality problems they create. Hydrogen only produces water when it is burned. When used as fuel in a barbecue grill designed for hydrogen use, this favorite All-American pastime can be enjoyed by all without the associated air quality problems of charcoal and gas grills.

Hydrogen also could reduce indoor air quality problems in industrial settings. Simple conversion of propane fueled equipment such as forklifts to hydrogen operation would reduce emissions to zero. With electrolyzer technology commercially available, hydrogen can be safely produced and used on site.

FIGURE 12 [42]



Finally, for those interested in purchasing fuel cell or other related technologies for home use, Two announcements were made while this document was being written regarding home sized systems. The expected cost will be around $3,000 to $5,000 and will be available soon.

FOR MORE INFORMATION

The author, Frederick J. Munster Jr. is a member of the American Hydrogen Association.

The American Hydrogen Association is a non-profit organization and conducts the following classes: Fuel Cells, Hydrogen Production, Automotive Conversion, and Investment Opportunity. Books available include childrens book "Hannah & Sara's Hydr O Bile". Another outstanding book available from AHA regarding all forms of renewable energy and written by leading experts and representatives of the industry is entitled "Renewable Energy Experts and Advocates."

For information on the above or if you are interested in joining AHA please contact:

The American Hydrogen Association

1739 W. 7th Ave.

Mesa, AZ 85202-1906

Phone: (602) 827-7915 Fax: (602) 967-6601

AHA's newsletter "Hydrogen Today" contains up to date information on technological advancements, new products and product availability.

GLOSSARY

Absolute Zero: A hypothetical temperature characterized by complete absence of heat and equivalent to -459.69^0F. The temperature at which gas would disappear is given the value of zero on the absolute temperature scale. Temperatures on this scale are degrees Absolute (^0A). The absolute scale in centigrade units are called degrees Kelvin (^0K). On the Fahrenheit scale, absolute temperatures are often called degrees Rankine (^0R). To approximately convert absolute temperature readings, add 273 to the centigrade reading or 460 to the fahrenheit reading.

Atomic Mass (A): The mass of any species of atom expressed in atomic mass units.

Atomic Mass Unit (u): A unit of mass for expressing masses of atoms, molecules and nuclear particles equal to 1/12 the mass of the neutral carbon atom having a mass number A = 12.

Atomic Number (Z): number of protons.

Alternating Current (AC): An electric current with its direction reversed at regular intervals. Electric current in the U.S. alternates with a frequency of 60 hertz (Hz), or cycles per second. Some European countries use 50 Hertz.

Ampere (Amp): A unit of measure of electric current. One ampere equals 6.25×10^{18} electrons passing a point in one second.

Atmosphere (atm): A unit of pressure equal to the pressure of the air at sea level or approximately 14.7 pounds per square inch.

British Thermal Unit (BTU): A common measuring unit of energy. It is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit. One BTU equals 252 calories, 1055 joules and 0.293 watt-hours. A cubic foot of natural gas equals about 1000 BTUs.

Calorie (cal): A unit of heat energy equal to the amount of heat needed to raise one gram of water one degree Celsius in the presence of 1 atmosphere. The calorie is used when temperature is measured on the Celsius scale, while British Thermal Unit is used when measurement is on the Fahrenheit scale. One calorie equals 4.18 joules.

Catalyst: A modification or increase in the rate of chemical reaction precipitated by a separate agent and remains essentially unchanged or unaltered by the reaction.

Celsius (oC): A metric temperature scale on which the freezing point of water is 0 degrees and the boiling point of water is 100 degrees. The formula for converting a celsius temperature to Fahrenheit is $^0C=5/9\ (^0F-32)$.

Circuit: The complete path traveled by an electric current.

Covalent: Valence characterized by the sharing of electrons. the number of pairs of electrons an atom can share with neighboring atoms.

Cogeneration: Using industrial waste heat to generate electrical power, thus saving energy from other sources.

Cooperative: A group of persons who have organized a joint venture for the purpose of supplying electric energy in a specified area (Cooperatively Owned Electric Utility).

Conversion: The process of altering the physical or chemical nature of a substance. Also, conversion can refer to the use of one energy source to produce another.

Cryogenic: Relating to the production of very low temperatures.

Demand, Electric: The requirement for electric power to be delivered by a system at a given instant, or averaged over any designated period of time, expressed in kilowatts or other units.

Diatomic: Having two atoms in the molecule.

Direct Current: An electric current that flows only in one direction through a circuit, as from a battery.

Distribution: The act or process of distributing electric energy from convenient points on the power system to the consumer.

Electron: An elementary particle consisting of a charge of negative electricity equal to about 1.602 x 10^{-19} coulomb and having a mass when at rest of about 9.107 x 10^{-28} gram or 1/1837 that of a proton.

Electronegativity: Having the tendency to attract electrons.

Energy: In scientific terms, the capability or capacity of doing work.

Energy Conservation: The practice of extending the useful life of the earth's energy resources through wise and efficient management.

Environment: The sum of all external conditions and influences affecting the life, development and ultimately the survival of an living organism.

Ethanol: A class of substances known as alcohol, C_2H_5OH. Burning ethanol produces a pale blue flame with no soot and much heat making it a desirable fuel.

Equilibrium: A state of balance between opposing forces or actions that is either static or dynamic. A state of adjustment between opposing or divergent influences or elements.

Exothermic: Characterized by or formed with evolution of heat.

Fahrenheit: The temperature scale in which the freezing point of water is 32 degrees and the boiling point is 212 degrees. The formula for converting a Fahrenheit temperature to Celsius is $^0F=9/5(^0C=32)$.

Fossil Fuels: Coal, oil, natural gas and other fuels originating from geologic deposits of ancient plant and animal life. These fuels depend on oxidation for release of energy.

Fuel Cell: A device in which fuel and oxygen are combined to produce chemical energy which is converted directly to electrical energy.

Generation: (1) The act or process of producing electric energy from other forms of energy. (2) The amount of electric energy so produced.

Gigajoule (GJ): A metric unit of work or energy (equal to 1 billion joules).

Heat: Molecular kinetic energy transferred from one object to another or obtained by conversion from another form of energy.

Heat Energy: Energy that causes an increase i the temperature of an object, or changes the object from a solid to liquid or from liquid to gas.

Ion: (1) An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons. (2) A free electron or other charged subatomic particle.

Isomeric: The relation of two or more compounds, ions or radicals that contain the same number of atoms of the same element but differ in structural arrangement or properties.

Joule: A metric unit of work or energy; the energy produced by a force of one newton operation through a distance of one meter. Equivalent to one watt second. A joule is equal to 10^{18} watts; estimated conventional gas resources are said to equal 10,500 joules.

Kelvin: A unit of temperature equal to 1/273.16 of the kelvin scale temperature of the triple point of water.

Kelvin Scale: A thermometric scale on which the unit of measurement equals the centigrade degree and according to which absolute zero is 0^0, the equivalent of -273.16^0 C. or -459.69^0F.

Kilowatt (kW): A unit of power, usually used for electric power (equal to 1000 watts), or to energy consumption (at a rate of 1000 joules per second). Roughly, a power of 1 Kw is capable of raising the temperature of a pound (one pint) of water 1^0F in one second.

Kilowatt-Hour (kWh): The amount of work or energy delivered during the steady consumption of 1 kilowatt of power for a period of one hour. Equivalent to about 853 calories of heat energy.

Kinetic Energy: The energy possessed by objects in motion.

Load: The power and energy requirements of users on the electric power system in a designated area or the amount of power delivered at a given point.

Mass Number (A): total number of neutrons and protons.

Mechanical Energy: The energy of motion used to perform work.

Megawatt (MW): A unit of electrical energy equal to 1000 kilowatts or 1 million watts.

Methanol: A light volatile flammable poisonous liquid alcohol (CH_3OH)formed in the destructive distillation of wood or made synthetically with petroleum.

Nafion: A special polymer which is a registered trademerk of E.I. Dupont DeNemours.

Natural Gas: An odorless, colorless, tasteless, non-toxic, clean burning fossil fuel, natural gas is largely CH_4 (methane), a natural occurring hydrocarbon that can also be produced synthetically as by coal gasification. At times it contains ethane, propane, butane, helium and hexane.

Neutron: An uncharged elementary particle that has a mass nearly equal to that of a proton and is present in all known atomic nuclei except the hydrogen nucleus.

Neutron Number (N): Is the mass number minus atomic number, $N = A-Z$

Ohm: The unit of measure of electrical resistance. One volt will force a current of one ampere through the resistance of one ohm.

Petroleum (Crude Oil): A naturally occurring material (Gaseous, liquid or solid) composed mainly of chemical compounds of carbon and hydrogen. Fractional distillation yields gasoline, diesel, lubricating oil and other products.

Proton: An elementary particle that is identical with the nucleus of the hydrogen atom, that along with its neutrons is a constituent of all other atomic nuclei. that carries a positive charge numerically equal to that of an electron and has a mass of 1.67×10^{-24} gram.

Radical: (1) A single replaceable atom of the reactive atomic form of an element. (2) a group of atoms that is replaceable by a single atom, that is capable of remaining unchanged during a series of reactions, or that might show a definite transitory existence in the course of a reaction.

Recycle: To process what is often waste materials in order to regain the material for beneficial human use.

Resource: The estimated total quantity of a natural resource such as petroleum, natural gas, coal, wood, minerals, wind, solar etc.

Thermal Energy: The total potential and kinetic energy associated with the random motion of the particles of a material.

Transmission: The act or process of transporting electrical energy in bulk from a source or sources of supply to other utility systems. It is done by high voltage to reduce loss.

Turbine: A rotary engine powered by a jet or stream of fluid. it can be used to power a generator for electricity production. Large wind energy conversion systems are commonly referred to as wind turbines

Volt: A unit of electrical pressure which forces electrical charges to move through conductors. One volt will force one amp of current to move through a resistance of one ohm.

Watt: A metric unit of power, usually used in electric measurements, which gives the rate at which work is done or energy expended. One watt equals one joule of work per second. Stated in another manner, one watt is the work done when an electrical force of one volt pushes 6×10^{18} electrons through a resistance of one ohm in one second.

Work: (1) Work is performed by a force moving an object. (2) Something the author needs to do after writing this document.

Valence: The degree of combining power of an element or radical as shown by the number of atomic weights of a univalent element (such as hydrogen) with which the atomic weight of the element or the partial molecular weight of the radical will combine or for which it can be substituted or compared.

Z: The symbol representative of Atomic Number.

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