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Fuel Cell Market Applications

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Fuel Cell Market Applications

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INTRODUCTION

Fuel cell systems offer the potential for ultra-high efficiency energy conversion and the enhancement of the quality of our environment. Because of this, DOE is sponsoring the development of fuel cells for stationary power generation market applications.

Concerns for the global environment are driving future power generation systems toward technologies that produce extremely low environmental emissions. Because of their high efficiencies, fuel cell powerplants will help in reducing carbon dioxide emissions. Since combustion is not utilized in the process, fuel cells generate very low amounts of NO_x, and they emit very little sulfur oxides. Fuel cells have been exempt from air permitting requirements in southern California. Relying on electrochemistry instead of combustion, the fuel cell is attractive for both heavily polluted urban areas and remote applications. Not only will it emit none of the smog-causing pollutants associated with conventional powerplants, it is ideal as a distributed power source; that is, it can be sited close to the electricity user--for example, at electrical substations, at shopping centers or apartment complexes, or in remote villages--minimizing long-distance transmission lines.

The focus of the U.S. Fuel Cell Program is on commercialization from the outset. Most work is performed by industrial teams which will ultimately commercialize the technologies, and they are generally directly responsible for any work which supports initial demonstration and commercialization. Some generic R&D is performed by universities, national laboratories, and others. This work is generally targeted for a somewhat longer timeframe than initial demonstration and will provide the foundation for later system improvements.

The U.S. DOE Fuel Cell Program is a market-driven program which has over 40 percent cost-sharing from the private sector. The program is being implemented by the U.S. DOE Morgantown Energy Technology Center (METC). The fuel cell developers enjoy the support of user groups with over 75 utility and other end-user members. In addition, DOE cooperates with the Gas Research Institute (GRI) and the Electric Power Research Institute (EPRI) to fully and efficiently leverage funding for the U.S. Fuel Cell Program.

Because of the Federal investment in the 1980's and early 1990's, first-generation fuel cells are now crossing the commercial threshold. DOE and predecessor agencies have funded the development of fuel cell systems since the 1970's. Initially, phosphoric acid fuel cells (PAFC's) were the primary focus, and these units, operating on natural gas, are now in the initial stage of commercialization. In the last 5 years, focus has shifted to the advanced fuel cell types, including molten carbonate fuel cells (MCFC's) and solid oxide fuel cells (SOFC's). These systems offer higher efficiencies, the potential for lower capital cost, and because of higher operating temperatures, are more suitable for cogeneration than lower temperature fuel cells.

The Fuel Cell Program objectives are to develop and demonstrate cost-effective fuel cell power generation, which can initially be commercialized into various market applications using natural gas fuel by the year 2000. Figure 1 shows the major program activities.

FUEL CELL TECHNOLOGY

Fuel cells generate electricity and heat using an electrochemical process similar to a battery. A fuel cell will continuously produce power as long as a fuel, such as natural gas, and an oxidant, air, are supplied to the system. Present early market systems are achieving over 45 percent (LHV) cycle efficiency. The next generation systems are expected to achieve 55 percent and eventually 70 percent (LHV) cycle efficiencies.

As shown in Table 1, several different types of fuel cells are being developed for stationary power applications. The electrolyte controls the operating temperature of the cells, which in turn determines the materials of construction. PAFC's are now becoming commercially available, while MCFC's and SOFC's promise even higher efficiencies for the future [1].

Table 1. Types of Fuel Cells

Characteristic	PAFC	MCFC	SOFC
Electrolyte	Phosphoric Acid	Lithium Carbonate/ Potassium Carbonate	Stabilized Zirconia
Operating Temperature	400 °F	1,200 °F	1,800 °F
Electrical Conversion Efficiency (LHV)	45-50%	50-65%	50-60%
Materials	Carbon Platinum	Nickel Stainless Steel	Ceramic

A basic fuel cell (Figure 2) consists of two electrodes, with the anode and cathode separated by an electrolyte. Fuel cell types are characterized by their electrolyte. For example, PAFC's utilize a phosphoric acid electrolyte in a matrix between anode and cathode electrodes. To produce a useable quantity of electric power, individual cells are assembled into a vertical "stack" of repeating components which are electrically interconnected. A fuel cell powerplant (Figure 3) consists of the stack or power section integrated with a fuel processor and a power conditioner to convert the power from direct current to alternating current.

The fuel cell is inherently modular. Constructed as an assembly of individual cells, stacks ranging from 100- to 250-kilowatt (kW) form a modular building block. Depending on the generating capacity required, 10 to 20 stacks can be grouped with a fuel processor and a power conditioner to create a 1- to 2-megawatt (MW) powerplant. Larger plants will use a larger number of stacks. In high growth areas or remote sites, modular powerplants located near the demand can offset the cost of right-of-way access and transmission lines.

PAFC STATUS

DOE and GRI, beginning in the late 1970's, supported an on-site effort that included an R&D program and a manufacturing and field test program with International Fuel Cells (IFC). The program resulted in the production and testing of over fifty 40-kW on-site cogeneration powerplants distributed to sites throughout the U.S. and Japan. This program was successfully completed in 1986 and formed the technology base for the current 200-kW, on-site work. The PAFC is a proton-conducting fuel cell, which has routinely reached an operating performance level of 200 watts per square foot (2150 watts per square meter) at ambient pressure.

In the IFC program, the cell and stack technology development resulted in a private sector program to demonstrate an 11-MW fuel cell powerplant. The site of the plant is in Goi, Japan, near Tokyo. Tokyo Electric Power Company operates the site and has employed IFC to design the direct current (DC) power section and to build the eighteen 700-kW fuel cell stacks. Toshiba is responsible for the design and fabrication of the balance-of-plant (BOP) equipment. The powerplant began operation in 1991 and has generated full power.

The METC DOE-sponsored PAFC development work at IFC was completed in 1992. ONSI Corporation, located in South Windsor, Connecticut, has been actively involved in the development and marketing of on-site PAFC systems and has a 40-MW/year manufacturing facility. In their PAFC commercialization, the ONSI Corporation, a subsidiary of IFC, is offering a complete packaged phosphoric acid powerplant for $3,000/kW. Named PC25, over fifty 200-kW units are in operation in the U.S. and around the world. Operating experience has been excellent with availabilities of over 90 percent. The PAFC is so reliable, it is being considered for uninterruptable power supply applications.

Although PAFC technology is the most mature of the fuel cell types being developed under DOE sponsorship, and cell and stack performance exhibited by all designs is close to acceptable for early commercial operation, cost remains as an issue. Powerplant costs must be reduced to be competitive with other advanced technologies. A current goal is to reduce these costs to less than $1,500 to $2,000/kW. An operating life of 40,000 hours is desired and may not be an issue. In fact, 70,000 hours of life is now thought to be attainable. IFC is currently developing 1-MW class units based on a five-stack design and developing the PC25C, which is lower in size and cost.The major improvement represented by the PC25C was the smaller, lighter weight invertor whose smaller size helped lower the PC25's weight by 20,000 pounds.

ONSI claims several things about its large 1.2 MW PAFC plants it is offering: the PAFC is not a strandable asset since it is moveable; re-packaging of the PAFC into 1.2 MW plants will lower cost and footprint; availability is increased by using multiple, high-reliability units making it a natural for UPS applications; and that it can provide high power availability with low reserve margins.

In its premium power application, IFC's uses a static switch" to switch to grid only when the fuel cell which is baseloaded is be maintained. The grid is the uninterruptable power supply (UPS). This is quite unlike the applications where the reciprocating engine is used as an UPS. The engine is not baseload run and used only in an emergency being tested daily.

MCFC STATUS

Overall system efficiencies of 50 to 60 percent are forecast for natural gas and coal gasification MCFC powerplants. The MCFC, like other fuel cells and unlike turbines and diesels, offers high efficiency at small size and at part-load. Furthermore, an MCFC powerplant can operate on coal or natural, refinery, or process gas. MCFC stack designs incorporate either internal or external fuel and oxidant manifolding and either internal or external reforming. All MCFC designs include flat cell components in the cell package (i.e., anode, matrix to hold carbonate, cathode, current collector, and separator plate).

Figure 4 illustrates the structure of an MCFC stack. Conductive, bipolar separator plates connect the individual cells in a stack both structurally and electrically. The bipolar separator plate is made of stainless steel, and each plate physically separates the fuel gas stream of one cell from the oxidant gas stream of the adjacent cell. One side of each separator plate channels a fuel stream so that it flows over a porous anode, while the flip side channels an oxidant stream over a porous cathode. Each bipolar separator plate also collects current, thus, electrically connecting adjacent cells of a stack in series. Electrons are conducted from the anode through the bipolar separator plate and into the cathode of the adjacent cell. There they react with the oxidant gas stream and form carbonate ions. The carbonate ions diffuse through the electrolyte and into the anode, where they react with the fuel gas stream, releasing electrons into the anode. Electrons are conducted in this manner through all the cells, thus, establishing DC through the stack. An external circuit connects a load between the two end plates of the stack, completing the circuit.

At least two MCFC developers, Energy Research Corporation (ERC) and M-C Power (MCP), have conceptual designs of efficient integrated MCFC powerplants. Operating conditions for these MCFC's are projected to be in the range of 150 to 250 amperes per square foot (ft^2) (160 to 270 milliamperes per square meter [M^2]), at 0.60 to 0.80 volts, with 50 to 85 percent fuel utilization [2].

The goal of the MCFC program is to develop and commercialize low-cost, packaged, simple, and modular fuel cell systems. DOE is accelerating the drive for private sector commercialization of multifuel, MCFC powerplants. DOE, METC is concluding support of MCFC powerplant system development with ERC and MCP under the 1990 Program Research and Development Announcement (PRDA).

The two MCFC developers have collected impressive stack test performance data under the 1990 PRDA. ERC is developing an externally manifolded, externally reforming MCFC and has constructed a 2- to 5-MW per year MCFC manufacturing plant. ERC has constructed a 100-kW test facility in Danbury, Connecticut, and has scaled up to a 6-ft^2 (0.56 M^2) area stack. They have tested a 4-ft^2 (0.37 M^2), 75-kW, 234-cell stack for 500 hours at their facility in Danbury and also at the Pacific Gas and Electric, San Ramon, California, facility. ERC has also tested three 6-ft^2 (0.56 M^2), 123-kW, 244-cell stacks in Danbury.

MCP is developing an internally manifolded, externally reforming MCFC and has constructed a 3-MW per year MCFC manufacturing plant. MCP has constructed a 250-kW acceptance test facility in Burr Ridge, Illinois, and has scaled up to an 11.4-ft^2 (1.06 M^2) full-area stack. They have tested several subscale-area stacks, including a 1-ft^2 (0.09 M^2), 7-kW, 70-cell stack. MCP has also tested three, 20-kW full-area stacks for over 1,000 hours.

The 1990 PRDA DOE contracts with these MCFC contractors have culminated with tests of 100- to 250-kW, full-area, full-height MCFC powerplant systems on natural gas in 1994-95. Testing of three 100-kW class MCFC at ERC in Danbury, Connecticut, has been accomplished. Testing of a 250-kW, full-area stack by MCP at the UNOCAL Science and Technology Center in Brea, California, began in early 1995.

DOE, in conjunction with EPRI, GRI, and the Department of Defense (DOD), is also funding Product Development Tests (PDT's) concurrently with system development at ERC and MCP. A successful demonstration track record will enhance support for MCFC technology from utilities and other end users in the distributed, repowering American Public Power Association industrial and commercial markets.

The initial MCFC PDTs will be in California in 1995. ERC will conduct a 2-MW PDT in Santa Clara, California, funded by the Santa Clara Demonstration Group, EPRI, and DOE. MCP will conduct a 250-kW PDT in San Diego, California, funded by DOE, GRI, and San Diego Gas and Electric at the Miramar Naval Air Station. ERC is also participating in a 2-MW Clean Coal Technology V Demonstration project with DOE and Duke Energy at a site to be determined.

DOE, METC recently competed a Product Design and Improvement (PDI) PRDA to resolve technology, system, and network issues. The major long-term issue in MCFC operation is cathode corrosion [3,4,5]. Major network and system issues are cost, heat loss management, footprint, packaging and integration, parasitic power losses, pressurization, and reforming. The objective of this work is to aim current MCFC stack development toward the development of a packaged, commercializable MCFC product. The PRDA will bring a multifueled, integrated, simple, low-cost, modular, market-responsive MCFC powerplant to the marketplace. The development program will be based on a commercialization plan to manufacture and package, demonstrate, and aggressively market MCFC powerplants. The PDI PRDA will culminate in the manufacture and construction of high-performance, low-cost, 500- to 2,000-kW MCFC powerplant module(s).

SOFC STATUS

Some general characteristics appear to be shared by many of the SOFC technologies being developed. While there is variability in materials being used for various components, the SOFC is an oxygen ion-conducting, solid-state device composed of a nickel-zirconia cermet anode, yttria-stabilized zirconia electrolyte, a strontium-doped lanthanum manganite cathode, and a doped lanthanum chromite interconnect [1]. The solid-state electrolyte of yttria-stabilized zirconia oxide is characterized by ionic conduction. The solid-state character of the SOFC electrolyte means there are few constraints on design. There is no problem of electrolyte containment, hence, the flexibility and the wide variety of designs or forms being pursued.

The flexible SOFC may be operated over a wide range of temperatures. The theoretical thermodynamic efficiency (73 percent based on the hydrogen oxidation reaction at 927 °C) is slightly lower for the SOFC than for the MCFC and the PAFC. However, the overall efficiencies of SOFC systems are more than the PAFC and certainly rival those of MCFC system configurations.

Power densities for SOFC's are promising. Power densities of 0.91 watts per square centimeter (more than 800 watts/ft^2) on hydrogen at 1,000 °C have been reported for SOFC's. Higher densities appear possible. The high-power density with thin-layered components could make the SOFC an attractive powerplant alternative. However, packaging and cost reduction will be required to make the SOFC promise a reality.

The high-temperature (1,000 °C) SOFC can provide greater fuel flexibility than lower temperature fuel cells, since the reforming reaction is favored at higher temperatures. Reforming heat requirements with low-temperature fuel cells can actually lower overall system efficiency for some fuel cells. Reforming is an important system consideration which will remain important in the absence of a low-cost hydrogen supply. In addition, a higher quality heat produced by the high-temperature SOFC's results in better bottoming cycle performance in some system configurations.

The funding for the SOFC development and commercialization effort is provided by a variety of sources, including DOE, the Department of Transportation, the Advanced Research Projects Agency of the DOD, EPRI, GRI, and private industry. DOE, METC cooperates closely with both EPRI and GRI in coordinating the U.S. SOFC Program. Currently, METC supports one SOFC developer, Westinghouse Electric.

Westinghouse Electric is the acknowledged world leader in SOFC technology. The Westinghouse Electric tubular configuration is shown in Figure 5. Several completely packaged and self-contained generators, up to nominal 25-kW size, have been manufactured and tested by Westinghouse Electric. A pre-pilot manufacturing facility currently produces the cells (tubes), bundles, and generators. The length of the tubes has been scaled-up to a nominal 2 meters in length. The porous air support tube has recently been eliminated. The cell is now supported by the air electrode. The Westinghouse Electric technology has been validated to a far greater extent than any other SOFC technology. Multiple tube tests have been successfully conducted for more than 50,000 hours, with less than 1 percent per 1,000 hours degradation. Pressurized operation of the tubular SOFC has recently been demonstrated at Ontario-Hydro. Testing of 25-kW systems at Southern California Edison and in Japan is expected to continue through 1996. A 100-kW generator test, at a to-be-determined location, is also planned for the 1995-1996 timeframe. Westinghouse Electric, a large integrated corporation, has a definitive development, demonstration, and commercialization program [6,7,8].

DOE, METC is not currently funding a planar SOFC developer. Several planar designs are also under development. Organizations developing planar designs include IGT, Ceramatec, Ztek, Technology Management Incorporated, and Allied Signal Aerospace Corporation. These developers hold strong patent positions on cell designs, which is essential for low-cost manufacturing.

THE WORLD POWER MARKET

Fuel cell technology is expected to play a role in the world power market. By the year 2010, it is estimated that approximately 130 gigawatts of new generating capacity will be installed in the United States while, in world markets and within a much closer time frame, nearly 550 gigawatts of generating capacity will be added. Fuel cell commercialization opportunities in the U.S. market are focused in several areas: repowering, central power plants, industrial generators, and commercial/residential generators.

The worldwide market for additional electric generation capacity dwarfs the domestic market. Nearly 550,000 megawatts of new capacity will be added by 2002. Estimates of plant repowering installations between 1999 and 2010 range from 15 percent to approximately 65 percent of the installed generating capacity. Most repowering will occur in central power plants: fuel cell installations of 100 megawatts or more are targeted to this market, powered initially by natural gas and later by coal gas.

New generating capacity of approximately 100 gigawatts will be required in the central powering market by 2010. Coal gas-powered fuel cell power plants are targeted to this market, with plants sized at 100 megawatts or more.

The market for additional industrial capacity by 2010 is estimated at 3 gigawatts, and the market for additional commercial/residential capacity at 6 gigawatts. These markets are targeted for early entry and will be a proving ground for natural-gas fuel cell power plants sized from 500 kilowatts to 20 megawatts.

THE CHANGING FACE OF ELECTRICITY GENERATION

Fuel cell power plants will provide a significant share of our electrical power in this decade and well into the next century. They are set to play a major role in a deregulated power industry. Large-scale plants will compete in the baseload power generation market while smaller plants will penetrate the distributed power and cogeneration markets.

Baseload generation currently relies on coal-fired, nuclear, or natural-gas-fired technologies. The natural-gas-fired fuel cell is more efficient, more environmentally friendly, and potentially more cost-effective than the current technologies in the baseload market segment.

Some utilities consider that the success of fuel cells, and some other technology, hinges on the emergence of dispersed power generation. Dispersed power generation is one of the phenomena accompanying the deregulation or disruption of the electric power industry. Hence, fuel cells is viewed by some as a disruptive technology since it is helping "introduce customer choice" and offers a set of attributes suitable for dispersed power generation.

De-regulation of the electric industry is about capturing system economies and efficiencies down to a point where the payout/return is not worth the investment/trouble. Self-dispatching of fuel cells in the de-regulated industry would be done to minimize cost or maximize profit - make the most money or save the most money. However, economics cannot control decisions such as frequency control, voltage control and spinning reserve since decision-making takes too long. These control decisions will probably not be economic ones.

Fuel cells should be able to capture economies in a de-regulated industry. The more aggressive, non-passive decision making which will accompany de-regulation will lead to opportunities for fuel cells. However, utilities need help in determining where fuel cells would benefit them; passive decision making by utilities, not looking at other economic alternatives, just going ahead and doing the standard substation upgrade - trashing power quality and raising costs for all customers - hurts fuel cells and other new technologies.

Technologies for the distributed power and cogeneration market segment include gas turbines, diesel engines, hydroelectric plants, solar and wind generation, already commercialized PAFC. In this market, MCFC and SOFC plants also held distinct advantages – the smaller applications favor fuel cells for their high-efficiency, low-emission, and load-following capabilities. In addition, the attractiveness of economical and reliable on-site power generation may significantly expand the market for small-scale commercial and industrial power plants. The Clean Air Act mandates significantly reduced emissions of sulfur and nitrogen compounds from existing power plants, and sets strict limits on emissions from new sources. In the short term, these restrictions may encourage the use of under-utilized fuels, particularly natural gas, by electric power producers.

SPECIFIC FUEL CELL ATTRIBUTES AND MARKET APPLICATIONS

Fuel cells have many attributes which make them suitable for specific market applications. These include low emissions, high efficiency, production of high grade waste heat, modularity, reliability, unmanned operation, and fuel flexible to name a few.

Increasing power generation without increasing emissions is the challenge facing power producers today, and fuel cells are a key approach to balancing our energy needs with our desire for a cleaner, healthier environment. Fuel cell power plants produce dramatically fewer emissions, and their by-products, primarily water and carbon dioxide, are so environmentally friendly that natural-gas fuel cell power plants have a blanket exemption from regulations in California's South Coast Air Quality Management District, possibly the strictest in the Nation.

Fuel cells convert a remarkably high proportion of the chemical energy in fuel to electricity. With efficiencies approaching 60 percent, even without cogeneration, fuel cell power plants are nearly twice as efficient as conventional power plants. And efficiency is not a function of plant size or load, either: small-scale fuel cell plants are just as efficient as large ones, and operation at partial load is as efficient as at full load. Higher efficiencies mean fuel savings for the producer and cost savings for the consumer.

High-grade waste heat from fuel cell systems is perfect for use in commercial, industrial, and residential applications, including cogeneration, heating, and air-conditioning. When by-product heat is used, the total energy efficiency of fuel cell systems roaches 85 percent.

The fuel cell stack is the basic component of a fuel cell power plant. Stacks are combined into modules, and plant capacity determined by the number of modules. Individual modules can go from idle to full load in minutes. Modular plants can help planners overcome many difficult expansion problems. Mass-assembly construction techniques and shorter lead times for installation reduce the capital risk in adding generating capacity. Capacity can be better matched to load, and the high costs of large new plants with under-utilized capacity can be avoided.

Modularity also produces a flat economy of scale: the cost per kilowatt is about the same in small plants as in large ones. And because electrical efficiency is determined by individual cell performance, the number of modules in the power plant has little or no effect on overall efficiency. As a result, fuel cell power plants offer the same advantages at 25 kilowatts as they do at 50 megawatts.

The modular nature of fuel cells allows power capacity to be added wherever it is needed. In the typical central power configuration, additional capacity is sited at the central plant or at substations. In a distributed power configuration, capacity is placed close to the demand. In high-growth or remote areas, distributed placement offsets the high costs of acquiring rights-of-way and installing transmission and distribution lines. A distributed configuration also eases public concerns about exposure to electromagnetic fields from high-voltage lines.

Smaller scale distributed configuration power plants are perfect for commercial buildings, prisons, factories, hospitals, telephone switching facilities, hotels, schools, and other facilities. In these applications, consumers get the best of all worlds — high-quality power that is economical and reliable. On-site power conditioning eliminates the voltage spikes and harmonic distortion typical of utility grid power, making fuel cell power plants suitable even for sensitive electronic loads like computers and hospital equipment. And in many cases, utility grid backup reduces the need for expensive uninterruptible power supply systems.

Fuel cells promise to be one of the most reliable, if not the most reliable, power generation technology. They are now being used by hospitals, hotels, and telephone companies as part of critical uninterruptible power systems.

Unmanned fuel cell operation may mean big savings in some applications. This is especially true for dangerous and metropolitan areas. Fuel cell designs with small footprints and easy installation are a must in cities. The footprint of the fuel cell is higher than that of turbines. However, gas turbines are derated in the summer and their maintenance cost is high.

Fuel cells need hydrogen, which can be generated internally from natural gas, coal gas, methanol landfill gas, or other fuels containing hydrocarbons. Although most market-entry fuel cell plants are fueled by natural gas, fuel flexibility means that power generation can be assured even when the primary fuel source is unavailable.

Potential customers have also identified premium power, grid support, voltage control, reliability improvement, VAR control, frequency control (fuel cell is a smart transformer), spinning reserve, incremental (modular) load growth (small incremental cost), emission offset, transmission and distribution (T&D) deferral, and customer retention as uses for the fuel cell. Fuel cell's value is dependent on "what it does, where it does it, and when it is does it"

The **ideal fuel cell application** would be for a new prison, hospital, orphanage, that is something with beds, requiring heat, electricity and a UPS; in an area with no T&D infrastructure so credit could be given for deferment of a substation upgrade; the fuel cell would be owned and operated by a "utility entity" having a distributorship taking credits for environmental benefits. The point is the right application needs to be high value application which can take credit for many quantifiable benefits.

The building application is potentially important for fuel cells. It is obvious that fuel cells can compete only on a life-cycle cost basis. The longer the life the better. Building operators do not want to get into the power business. One opportunity is to own and lease power plants for the operators. New ownership modes need to be explored. The retrofit market is important for buildings. Developers must be patient. It will take many years for fuel cells to penetrate any market.

DEVELOPMENT AND MARKET APPLICATIONS IN JAPAN

The Japanese are firmly committed to fuel cell development, as is evidenced by their funding commitment from both Government and private industry, extensive research facilities, and commitment of personnel.

Large companies, such as Fuji, Mitsubishi Electric Company, Mitsubishi Heavy Industries, Toshiba, and Hitachi are involved in fuel cell development in Japan. This contrasts with the situation in the U.S., where several of the fuel cell developers are smaller, entrepreneurial companies. The capital investment required for establishing manufacturing and distribution infrastructure should be easier to obtain for these large Japanese corporations than it will be for the small U.S. corporations.

Japan's electric industry has very high capital and operating costs and might be an excellent place to introduce new, higher-cost technologies like the PAFC. This high cost may be attributable, in part, to both high fuel costs and inefficiencies in the Japanese goods and services distribution system. Some Japanese companies favor the deregulation of the electric industry, which is occurring in the U.S. and promises to lower electricity costs.

Japan is positioning itself to compete in the marketplace through support of multiple Japanese developers, additional field testing, and demonstration plants. Fuji, Hitachi, and Mitsubishi were asked to manufacture fuel cells after the success of the International Fuel Cell 40-kW units in the 1980's. The Japanese Government's PAFC program includes the 1000-kW at Tokyo Gas and a planned 5-megawatt (MW) demonstration unit. Fuji has delivered some 80 PAFC units in the 50-100-kW size. Fuji is preparing to mass produce PAFC.

There is a PAFC unit in Japan at a Nippon Telegraph and Telephone switchboard in Yokohama, Japan. The waste heat is also used to cool the equipment, using absorption chillers. This is a large market in Japan, where 0.5 percent of electricity is consumed by telephone switchboards. Also, Tokyo Gas will be selling heat recovery type adsorption chillers as a future product.

Due to low capital costs, Tokyo Gas considers the gas engine to be the primary competition of the PAFC, especially in peak shaving and uninterruptable power supply applications.

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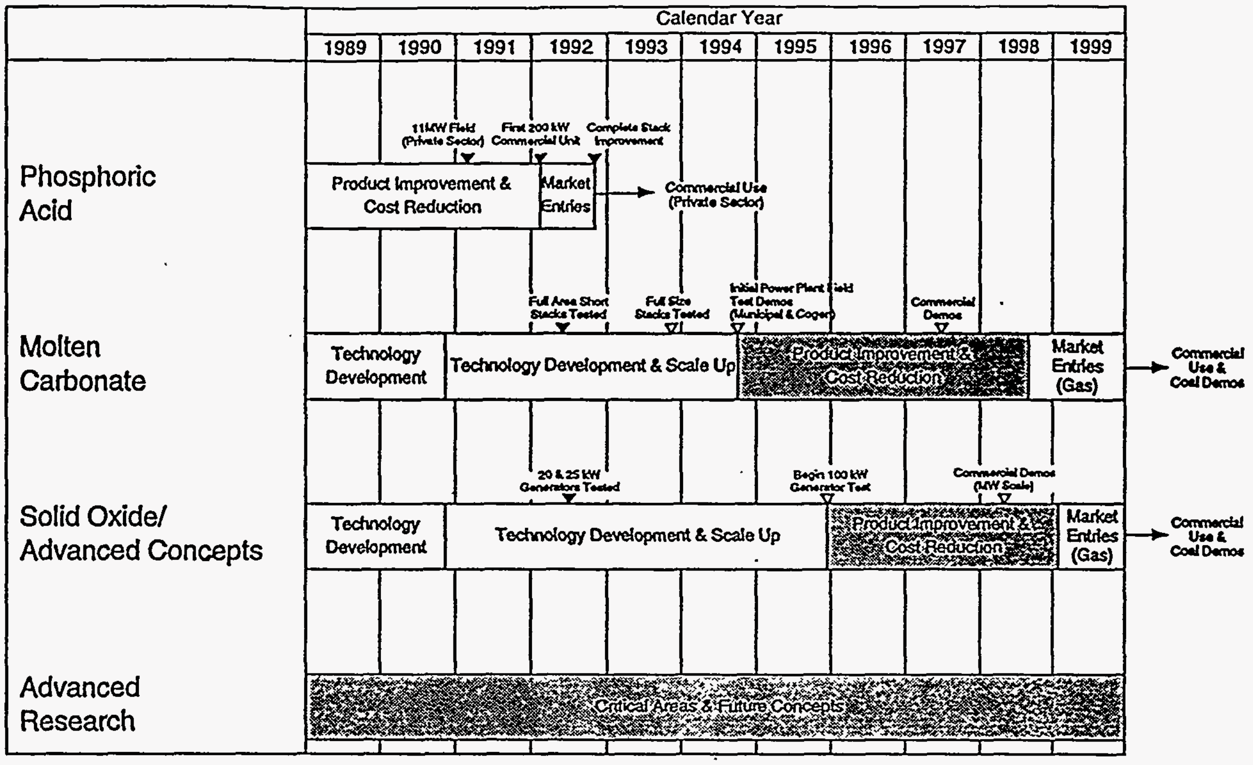

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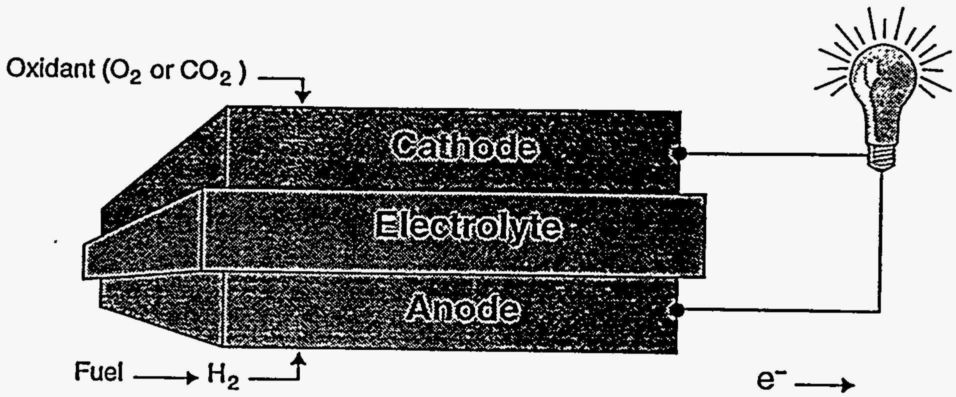
Figure 1. Fuel Cell Program Activities



- Electrochemical Process
- Direct Conversion to Electricity
  $H_2 + 1/2\,O_2 \longrightarrow H_2O$ + Electricity

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Figure 2.. Basic Fuel Cell

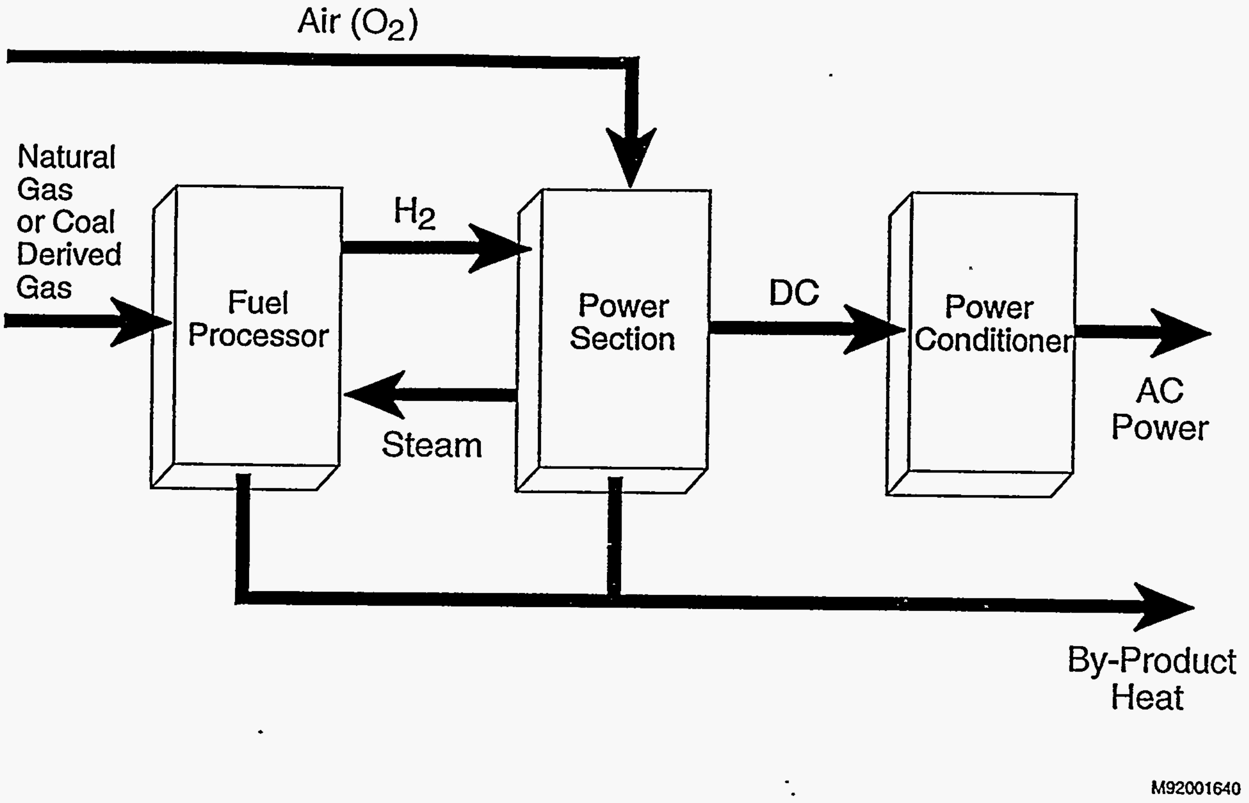

Figure 3. Fundamentals of a Power Plant

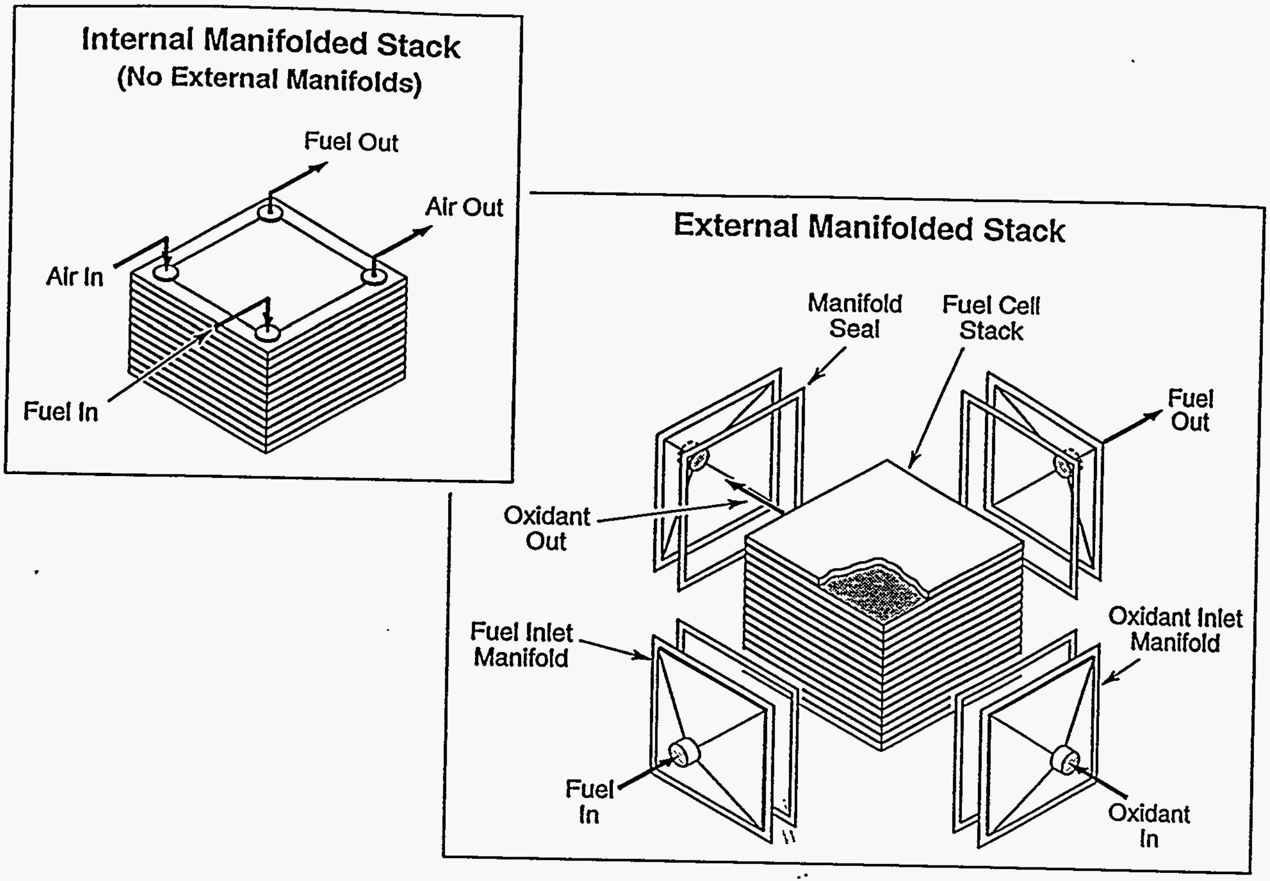

Figure 4. MCFC Stack Structural Designs

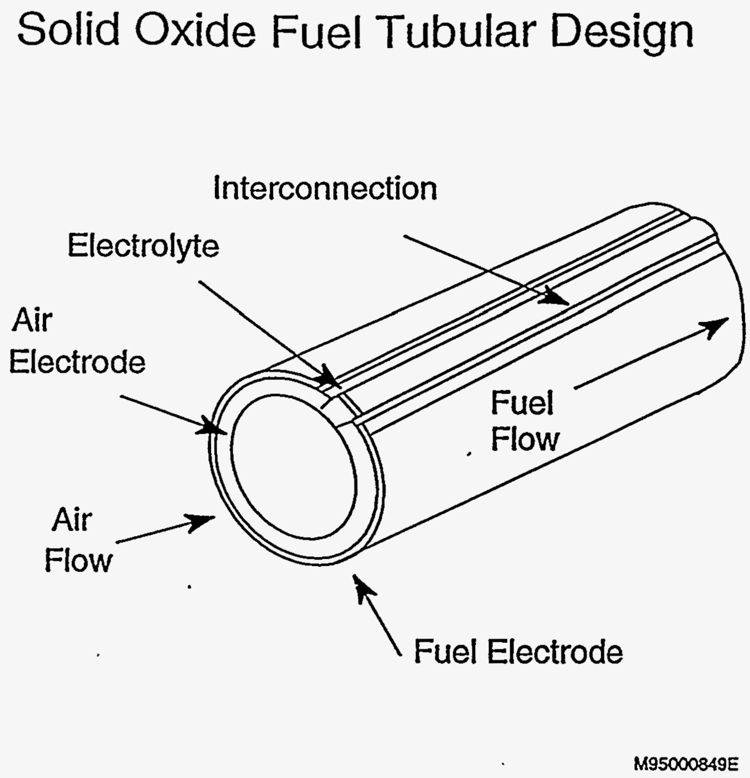

Figure 5. Westinghouse SOFC Design