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U.S. SOLID OXIDE FUEL CELL POWERPLANT DEVELOPMENT AND COMMERCIALIZATION

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ABSTRACT

Solid Oxide Fuel Cell (SOFC) powerplants have many potential attributes which make them suitable for distributed generation applications. Power densities for SOFC's are very promising. Power densities possibilities of 2.0 watts per square centimeter have been reported to be possible. Westinghouse Electric is the leader in tubular SOFC technology. Several completely packaged and self-contained generators, up to nominal 25-kilowatt (kW) size, have been manufactured and tested by Westinghouse Electric. A manufacturing facility currently produces these generators. In the U.S., several planar designs are also under development. Organizations developing planar designs include the Institute of Gas Technology (IGT), Ceramatec, Ztek, Technology Management Incorporated (TMI), and Allied Signal Aerospace Corporation. One of the most promising developments in SOFC powerplants is the conceptual development of very high efficiency fuel cell gas turbine powerplants. The combination of the SOFC and turbine has the potential for enormous synergies.

INTRODUCTION

SOFC powerplants offer the potential for ultra-high energy conversion efficiency levels and ultra-low emissions levels--a combination attractive in energy markets world-wide. Because of this, organizations in the U.S., such as the Department of Energy's (DOE's) FETC, user groups, the Environmental Protection Agency, the Department of Commerce, National Institute of Standards and Technology, the Department of Defense, the Gas Research Institute, and the Electric Power Research Institute are funding this promising technology.

Because of the DOE and industrial investment in the 1980's and 1990's, fuel cells such as the phosphoric acid fuel cell, are now crossing the commercial threshold. DOE and predecessor agencies have funded the development of fuel cell systems since the 1970's.

In the last few years, focus has shifted in the U.S. to the advanced fuel cell types, including 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.

<u>Solid Oxide Fuel Cells Status</u>

In the U.S., several SOFC technology configurations are being developed. Since the SOFC may be operated over a wide range of temperatures, several lower-temperature configurations with alternative materials are being considered. While alternative electrolytes and electrodes are being investigated, most developers are using the 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.

Power densities for SOFC's are promising. Power density possibilities of 2.0 watts per square centimeter on hydrogen at 1,000 °C have been reported for SOFC's by the Lawrence Berkeley Laboratory. The high-power density with thin-layered components could make the SOFC the highest power density fuel cell.

Westinghouse Electric is the leader in tubular SOFC technology. The Westinghouse Electric tubular configuration is shown in Figure 1. Several completely packaged and self-contained generators, up to nominal 25-kW size, have been manufactured and tested by Westinghouse Electric. A 4-megawatt (MW)/year 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 almost 70,000 hours, with less than 1 percent per 1,000 hours degradation. Pressurized operation to 15 atmospheres of the tubular SOFC has recently been demonstrated at Ontario-Hydro. This pressurization testing is a key aspect of the eventual integration of the SOFC with the gas turbine. A 100-kW generator test, in the Netherlands, is also planned for the 1996-1997 timeframe (2-6). Westinghouse is marketing its products under the name of SureCELL®.

Several planar designs are also under development. Organizations developing planar designs include IGT, Ceramatec, Ztek, TMI, and Allied Signal Aerospace Corporation. These developers hold strong patent positions on cell designs, which is essential for low-cost manufacturing.

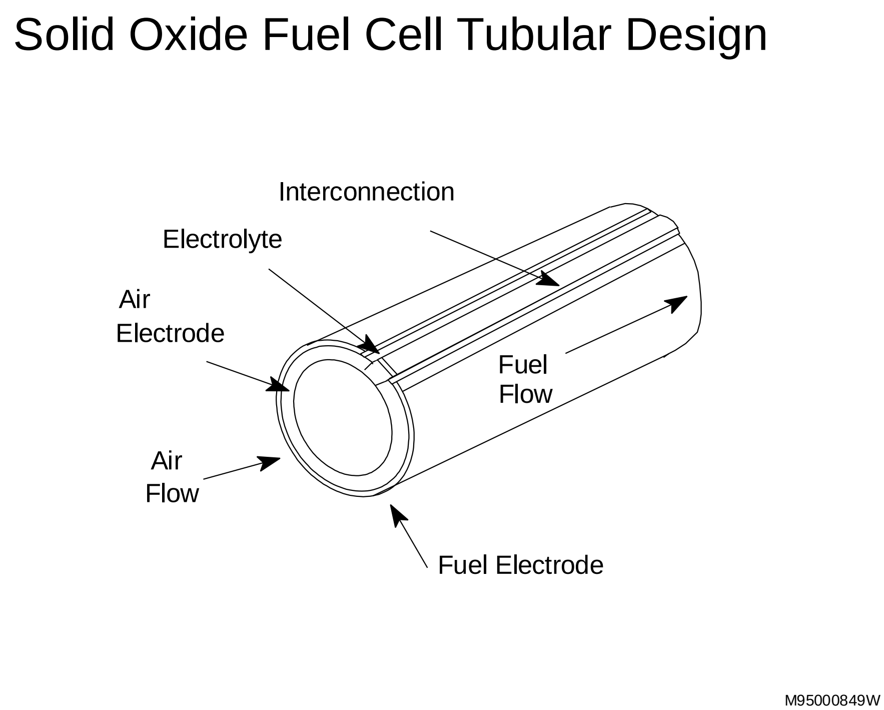

Figure 1. Westinghouse Tubular Configuration

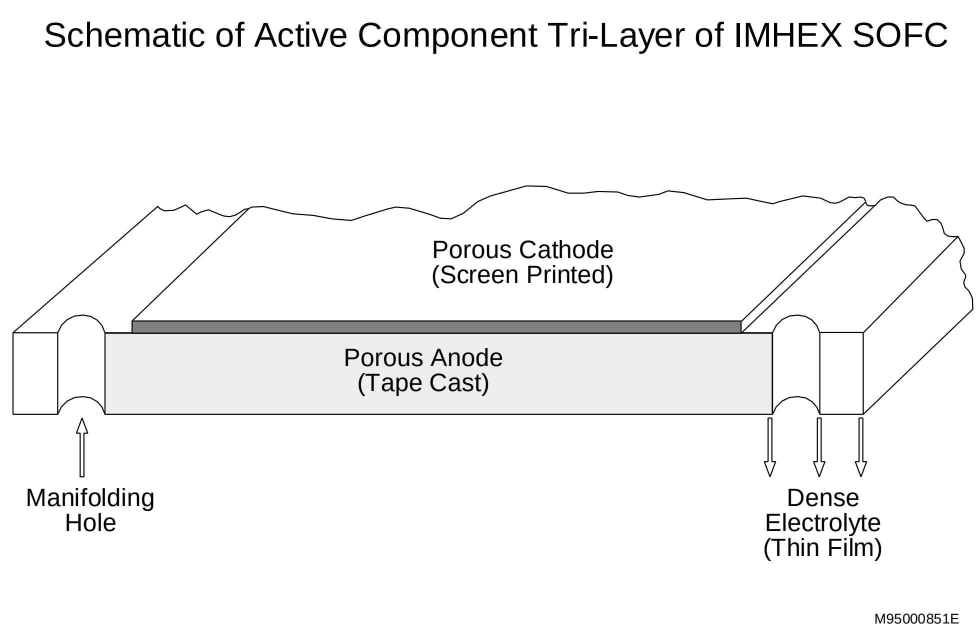

Figure 2. IGT IMHEX Configuration

IGT is developing an 800 °C, intermediate-temperature, internally manifolded planar design. This trilayer IGT design, shown in Figure 2, has, according to IGT, the advantages of more effective gas flow patterns, more compact design and cell stacking, more efficient current and voltage transfer from cell to cell, and more cost-effective manufacture (7). The IGT design is an internally manifolded fuel cell design using pressed metallic plates called IMHEX^R. Because the IMHEX^R design has no external gaskets and seals, only compression seals are necessary to obtain good sealing. The ceramic bipolar separator plates in the SOFC's currently under development are the single most expensive component. These make up more than 80 percent of the total materials and fabrication costs of the cell components (8). IGT replaces the ceramic separator plates with nickel-based metallic separator plates, thus lowering cost significantly. Since at 800 °C the zirconia electrolyte will have high-internal resistance losses, IGT is using the provskite gadolinium-doped barium cerium oxide, and glass/ceramic composite seals, which could sidestep most of the problems associated with glass-only or cement-only manifold seals.

The Ceramatec design, CPn^R, consists of stacks and a fuel processor and places some cells in a series, rather than in parallel, to obtain greater efficiency. Ceramatec has attained a power density of 0.18 watts per centimeter square (167 watts per square foot) and a current density of 250 milliamperes per square centimeter (230 amperes per square foot). Ceramatec has tested a 1.4-kW module and has a limited partnership with Babcock and Wilcox (9-10) for the commercialization of the technology. This partnership is SOFCo.

Ztek uses a radial design stacked into two-stack modules, which are then combined into arrays. Ztek, along with Tennessee Valley Authority, has completed testing a 1-kW stack (11-12).

TMI uses an Interscience Radial Flow design in which each cell is made up of four layers, with sealing being achieved through the use of rings, which also form the internal fuel and air manifolds (see Figure 3). Small stack testing from 1- to 10-cell stacks has been performed. Power densities around 0.08 watts per square centimeter (75 watts per square foot) have been attained (13). One of the promising features of TMI's SOFC development approach is use of sulfur-tolerant anodes.

Allied Signal Aerospace Corporation is developing the monolithic and flat planar designs and is now using tape calendaring to produce a thin-electrolyte, reduced-temperature fuel cell with a potentially low manufacturing cost (14-15).

It is often difficult to determine if the SOFC materials and their electrochemical and physical properties, per se, or if the individual SOFC designs contribute more to performance, as measured by power density, efficiency, longevity (or durability), cost, packagability, and system integrability.

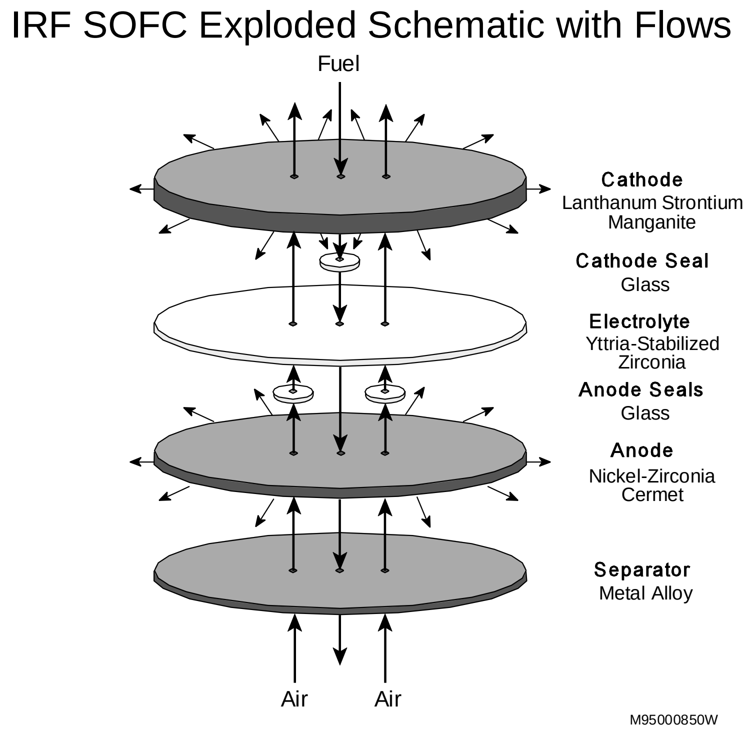

Figure 3. TMI Radial Configuration

High-Efficiency SOFC Gas Turbine Powerplants

One of the most promising developments in SOFC powerplants is the conceptual development of very high efficiency fuel cell gas turbine powerplants (16-23). The combination of the SOFC and turbine has the potential for enormous synergies, in that it offers a solution to two important problems: the low efficiency and relatively high nitrogen oxide (NO_x) emissions of small gas turbines and the high cost of small SOFC powerplants.

Because of the synergistic effects leading to the higher efficiencies and lower emissions achieved by combining a fuel cell and a gas turbine into a power generation system, many potential system configurations have been developed. Studies have indicated that this combination has the potential to increase the overall efficiency for the conversion of natural gas into electricity to over 70 percent. These systems are the logical extension of SOFC and gas turbine development and represent the most promising fossil energy powerplants ever conceived. Figure 4 shows that the efficiency expected from high efficiency fuel cell gas turbine powerplants is higher than either system by itself.

One promising configuration is the SOFC topper shown in Figure 5. By allowing the fuel cell in this powerplant to serve as the combustor for the gas turbine and the gas turbine to serve as the balance of plant for the fuel cells, the combined efficiency is raised to the

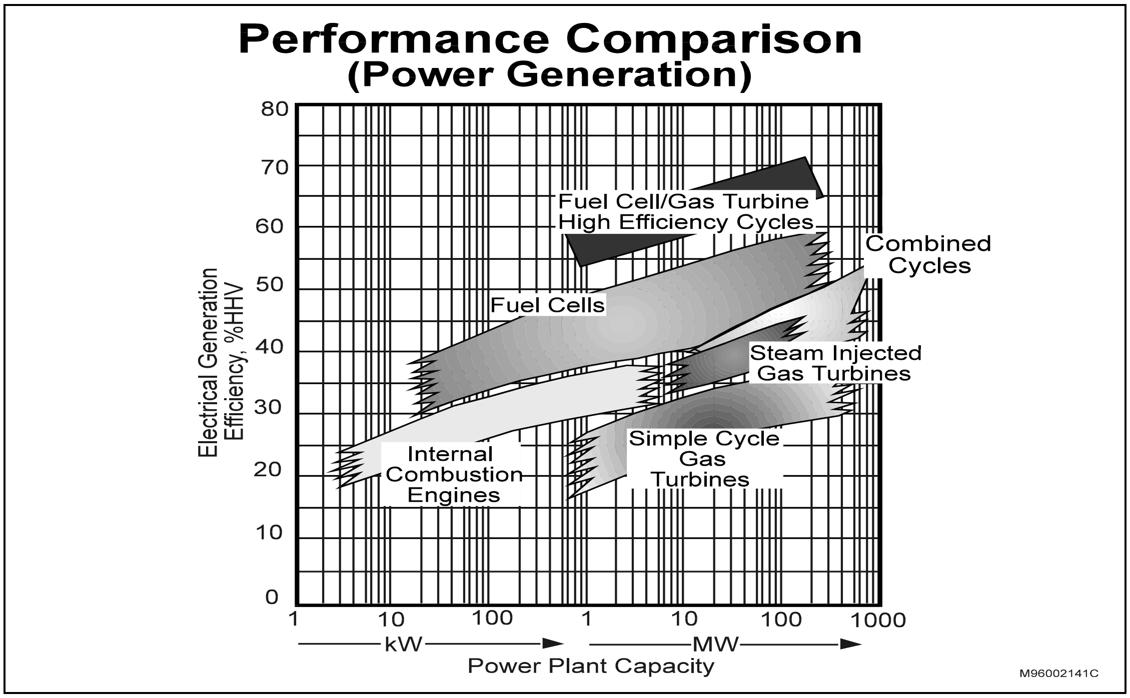

Figure 4. Powerplant Efficiencies

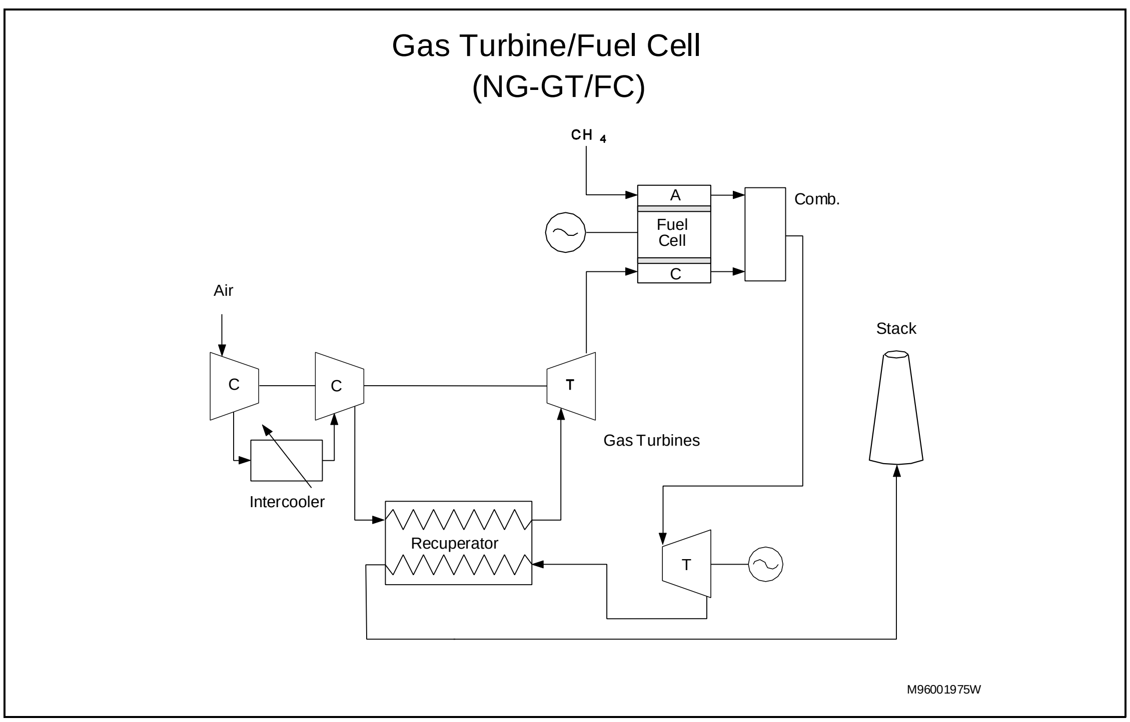

Figure 5. SOFC Topper

60 percent range, even at sizes of less than 3 to 10 MW, and NO_x emissions are essentially eliminated.

Potential Markets for the SOFC

The SOFC can expect to play a role in the world power market. By the year 2010, it is estimated that approximately 130 gigawatts (GW) of new generating capacity will be installed in the U.S., while in world markets and within a much closer timeframe, nearly 550 GW of generating capacity will be added (24). Fuel cell commercialization opportunities in the U.S. market are focused in several areas: repowering, central powerplants, industrial generators, and commercial/residential generators.

The worldwide market for additional electric generation capacity dwarfs the domestic market. Nearly 550,000 MW 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 powerplants: fuel cell installations of 100 MW or more are targeted to this market, powered initially by natural gas and later by coal gas.

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

In the U.S., SOFC's have many potential attributes which make them suitable for distributed generation applications (24). These include low emissions, high efficiency, production of high-grade waste heat, modularity, reliability, unmanned operation, and fuel flexibility, to name a few. These smaller applications favor SOFC's 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 powerplants. The Clean Air Act mandates significantly reduced emissions of sulfur and nitrogen compounds from existing powerplants 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.

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