Small-Scale Low Cost Solid Oxide Fuel Cell Power Systems

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Objectives

- Develop a commercially viable solid oxide fuel cell (SOFC) power generation system with a factory cost of $400/kWe through a 10 year, three-phase program.
- Demonstrate a prototype 5-7 kWe SOFC combined heat and power system for a variety of remote applications at the end of phase 1 (4 years).

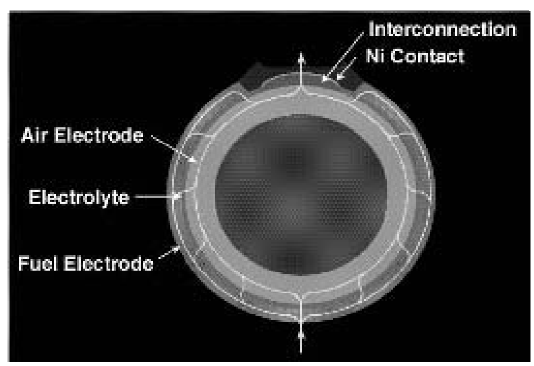
Key Milestones (Phase 1)

- Complete design of Proof-of-Concept system.
- Test Proof-of-Concept system.
- Achieve power density of 0.35 W/cm^2 with cathode supported seal-less planar cells.
- Complete design of alpha system.
- Test alpha system.

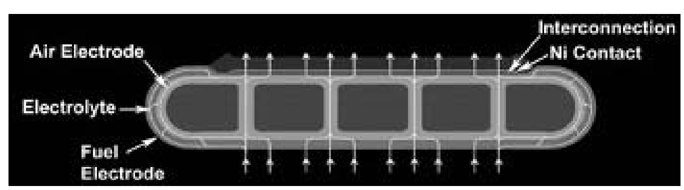
Approach

To achieve the cost goals of this program, a number of technical issues shall be addressed and resolved. These are: improvement of cell power density through new cell design and new cell materials, lowering operating temperature to 800 °C, allowing use of lower cost module materials, development of on-cell reformation to eliminate internal reformers, development of high volume manufacturing processes, and simplification of balance of plant. All of the above technical issues focus on increasing the power density and/or reducing cost.

Prior to the start of the program, it was recognized that Siemens Westinghouse's cathode-supported seal-less tubular cell design would not be able to meet the cost and performance targets of this program, and identified a need to develop a cell with higher power density and compact design. We chose a new design that combines the seal-less feature and a flattened cathode with integral ribs. This new design, referred to as high power density (HPD) SOFC, has a closed end, similar to the tubular design. The ribs reduce the current path length by acting as bridges for current flow. The ribs also form air channels that eliminate the need for air feed tubes. Due to shorter current path, this cell design has lower cell resistance and hence higher power output than tubular cells. A comparison of the current paths between tubular and HPD cells is shown in Figure 1.



Tubular



Seal-less Planar

Figure 1. *Current Paths in Cathode Supported Seal-less Tubular and Planar Cells*

Another approach to reduce cell resistance is by lowering activation polarization at the cathode-electrolyte interface. This can be achieved by applying a porous and relatively thin layer of a mixture of electrolyte and cathode material at the cathode-electrolyte interface, which provides increased three-phase boundary length for the reduction of oxygen.

State-of-the art Siemens Westinghouse tubular SOFCs nominally operate at 1000 °C utilizing yttria stabilized zirconia (YSZ) as the electrolyte. The focus in this program is to lower the operating temperature to nominally 800 °C. Lowering the operating temperature allows use of lower purity materials (and hence lower cost). Sr and Mg doped lanthanum gallate (LSGM) was selected as the electrolyte for low temperature operation. The oxygen ion conductivity of LSGM at 800 °C is comparable to that of YSZ at 1000 °C. Additionally, LSGM has excellent chemical and structural compatibility with perovskite cathode materials.

Current Siemens Westinghouse SOFC systems employ internal reformers to reform fuel. Significant cost savings can be realized if fuel reformation can be accomplished on the cell, thereby eliminating internal reformers. Elimination of internal reformers would also make the module more compact.

Module and balance of plant design will involve simplification, reduction in size, elimination of parts and suitability for mass production. Siemens Westinghouse, and its partner Fuel Cell Technologies (FCT), are testing 5-kWe SOFC systems that employ Siemens Westinghouse's tubular cells. The lessons learned from the operation of these systems will be incorporated in the present program.

Results

Analytical modeling was initiated to optimize the number of ribs (channels) for maximum power and mechanical stability from thermal stresses during operation. Based on initial results, HPD cell design with five channels (HPD5) was selected for cell preparation in the initial stage.

Over 50 HPD5 tubes were extruded and sintered. Analytical modeling to further improve the cell design continued. An improved design with 10 channels, referred to as HPD10, is being considered. Tubes of HPD10 geometry were also extruded and sintered. Figure 2 shows cells with HPD5 and HPD10 geometries alongside a tubular cell.

Figure 2. *Tubular and HPD Cells*

Compositions were investigated for cathode and interconnection compatible with LSGM. The investigation involved determination of thermal expansion, thermal cyclic shrinkage, electrical conductivity and chemical compositions of candidate materials. Based on the results, a cathode composition was selected for powder preparation.

Parallel with the development of LSGM and compatible materials, we investigated ways to improve low temperature performance of YSZ electrolyte cells. This involved development of new cathode composition and cathode interlayers, and developed composite interlayers consisting of mixed ionic and electronic conducting phases. A slurry-based process was used to deposit the interlayers. Several tubular cells with composite interlayers (YSZ electrolyte) were electrically tested. These cells showed increased power at lower temperatures, as shown in Figure 3.

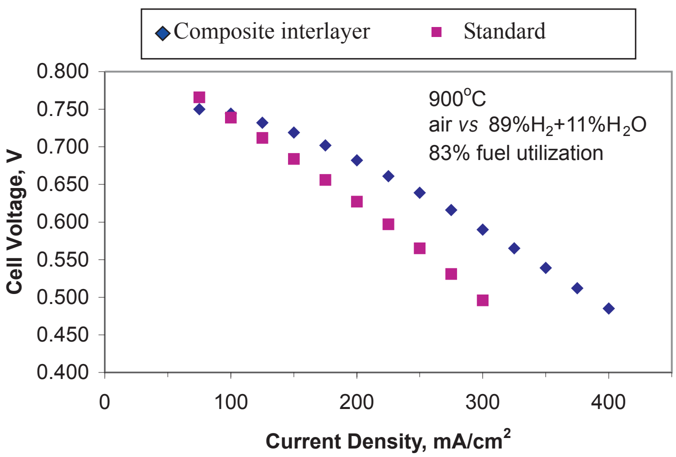


Figure 3. *Performance Comparison–Standard Interlayer Versus Composite Interlayer (Tubular Cells).*

Siemens Westinghouse's partner, Blasch Precision Ceramics, is developing a low-cost, impermeable ceramic housing for the stack. Blasch has considered and investigated eight external coating/surface treatment technologies to impart gas impermeability of their mullite bonded alumina refractory ceramic. Four of these were terminated for various reasons, and four are under further investigation. A gas permeability test apparatus for ceramic disk specimens was designed and assembled, and has been used. Adhesion of metal foil to the ceramic has been tried, but without success to date. Blasch has also internally devised a coating method (to impart gas impermeability), and has set-up and just begun working with this equipment. Additionally, application of chemicals and powders has been tried by different methods with some success. Some of the chemicals applied effectively reduced gas permeability by 30 percent.

A conceptual design for the residential system was started. The overall thrust of the task is to start from the existing residential prototype system design and develop concepts to simplify the system.

FCT initiated the design of balance of plant systems. Design of a hot gas recirculator was completed and a prototype was assembled for testing. The design of gas fired start-up heater was completed, and a prototype was tested. Inverter development was carried out for both grid-connected and stand-alone operation. Considerable work was carried out on load-sharing between the battery and stack to enable a degree of load following capability. A simple desulfurizing cartridge was tested and several deodorants were characterized.

Conclusion

Since the ten-year program started in September 2002, some preliminary conclusions can be made. It was demonstrated that cathode supported seal-less planar cells can be fabricated. Increased power density was achieved with the use of a cathode-electrolyte interlayer.