VII.K.2 Bipolar Plate-Supported Solid Oxide Fuel Cell "TuffCell"

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Start Date: 2001
Projected End Date: Project continuation and direction determined annually by DOE

Objectives

- Develop a new solid oxide fuel cell (SOFC) concept for auxiliary power units (APUs) and portable power applications
- Address the following SOFC issues:
  - Durability to temperature cycling
  - Stack materials and manufacturing cost
  - Start-up time
  - Stack sealing

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Durability
- B. Cost
- C. Electrode Performance
- J. Start-up Time/Transient Operation

Technical Targets

Characteristic	Units	2006 Target	TuffCell Status
Cost[a]	$/kW$_e$	<800	200 (stack)
Cycle Capability (from cold-start) over operating lifetime	number of cycles	40	4
Durability	hours	2,000	25
Start-up Time	min	3045	75

[a]Cost based on high-volume manufacturing quantities (100,000 units/year).

Approach

- Support cell on metallic bipolar plate to improve durability, cyclability, and shock-resistance
- Minimize thickness of expensive ceramic-containing layers (anode, electrolyte, and cathode)
- Fabricate cell components using tape-casting and powder metallurgy techniques
- Eliminate manufacturing steps to reduce cost
- Eliminate sealing issue by developing self-sealed design

Accomplishments

- Developed cost comparison for TuffCell vs. conventional stacks
- Designed, fabricated and tested two and three-cell stacks
- Cyclability tests: 4 cycles at 10°C/min. heating rates (80 min. start-up time)
- Developed and demonstrated self-sealed anode chamber design to alleviate SOFC stack sealing issue

Future Directions

- Improve single cell performance (goal: >350 mW/cm^2)
- Test start-up time (goal: <30 min.)
- Conduct further temperature cycling tests (goal: >10 cycles over stack lifetime)
- Investigate durability (goal: >500 operating hours)

Introduction

Solid oxide fuel cells are attractive power sources for auxiliary power applications because they exhibit high power densities and efficiencies, have simplified fuel reforming requirements, and are fuel flexible. However, durability, stacking issues, and cost have so precluded their use for portable and transportation applications. The current SOFC operating temperature has been lowered to 650–800°C by supporting the cell on a thick ceramic-metal (cermet) anode layer and decreasing the thickness of the electrolyte layer to ~10 μm, thus decreasing its resistance. These lower operating temperatures have made SOFCs viable for auxiliary power, allowing better thermal integration with the fuel reformer (operating at ~700°C), the use of metallic flow fields and interconnects, and shorter start-up times. Current barriers that remain are: (1) durable gas seals around the cell perimeters and manifolds that can withstand rapid and repeated thermal cycling; (2) high materials and manufacturing costs; (3) stack degradation during steady-state operation, and (4) durability to mechanical vibration or shock.

Approach

Argonne's approach is to improve mechanical properties by supporting the brittle ceramic components on robust metallic layers; reduce materials and manufacturing costs by minimizing expensive materials and eliminating high-temperature processes; and resolve the sealing issue by incorporating a self-sealing design into the stack repeat unit.

The TuffCell is an SOFC repeat unit that contains all of the essential elements to build a stack. A thin electrolyte-anode bilayer is supported on a flow-field and bipolar plate sub-structure, in which the fuel compartment is self-sealed during the initial sintering process. Component layers consist of a thin film stabilized zirconia electrolyte (~10-μm thick) supported on a porous nickel-zirconia anode (~ 250-μm thick) that is in turn sinter-bonded to a 434 stainless steel support structure. The support structure consists of stainless steel foam and distributed posts that constitute the fuel flow field, and the bipolar plate forming the bottom of the anode/fuel compartment. Each component layer of the repeat unit is formed using tape-casting or slurry coating techniques. After drying, the layers are laminated together and the perimeters of the electrolyte, anode and foam are sealed together with the stainless steel slurry that is used in the bipolar plate and foam. This seals the TuffCell anode compartment to prevent mixing of the fuel and air. Stainless steel foam with dimensions smaller than the box is attached to the bottom of the bipolar plate to serve as the air flow field and current connection to the cathode of the underlying cell. TuffCell laminates are co-sintered in a programmable controlled-atmosphere furnace. After cell fabrication and sintering, tubes are attached to the fuel feed and exit of each cell, and a cathode is applied to each electrolyte surface. Individual cells are stacked together and the cathode is sintered *in situ* during the initial heating of the stack for cell test and operation.

Results

Work performed during FY 2005 focused on developing the new self-sealed design, conducting a cost analysis for large-scale manufacturing of the TuffCell, building and testing two and three-cell stacks, and initiating temperature cycling tests.

A new self-sealed design for the TuffCell was developed this year, which incorporates the seal for the anode chamber into the design and fabrication of the stack repeat unit. Figure 1 shows a cross sectional drawing of the new design and a photograph of a three-cell stack. This self-sealed anode design required modification of the tape casting and dip-coating slurry formulations, and revision of the process parameters for sintering. The cell geometry was also changed from a square to a circular shape to eliminate corners, and to eliminate potential initiators of crack development.

A cost analysis for large-scale manufacturing of TuffCell was prepared in a spreadsheet format. This was compared to a similar study made for a

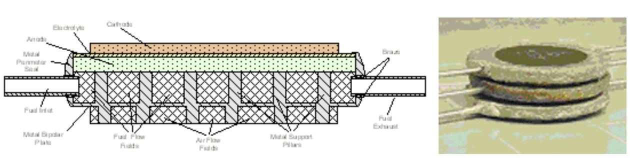

Figure 1. Cross-Sectional Sketch and Photograph of a Three-Cell Stack of the Newly Designed TuffCell

conventional anode-supported SOFC. Table 1 illustrates that the main differences are due to the materials and operating costs. The TuffCell has thinner layers of expensive zirconia and nickel. In addition, the single step sintering process for TuffCell lowers operating costs such as utility costs for powering the sintering furnaces.

Table 1. Cost Comparison of TuffCell with a Conventional Anode-Supported SOFC

	Matls.	Equip.	Pers.	Oper. Cost	Total
TuffCell	\$69 (34%)	\$50 (24%)	\$70 (35%)	\$14 (7%)	\$203
Anode-Supported SOFC	\$99 (36%)	\$52 (19%)	\$60 (22%)	\$63 (23%)	\$274

Single cell and multiple cell stack tests were performed using the new design. Single cell polarization measurements (Figure 2) showed that cell power density had dropped to about half of that reached in FY 2002. Efforts are being made to improve and exceed that performance. A single cell was also subjected to four thermal cycle tests. Figure 3 shows that the single cell performance was not degraded by three temperature cycles. The cell had been thermally cycled four times with no degradation to the open circuit potential. However, the test was terminated before the fourth

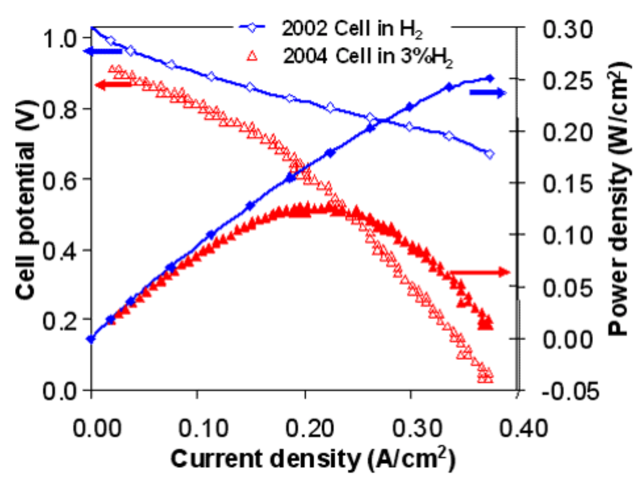

Figure 2. Polarization and Power Density of Single Cell TuffCells

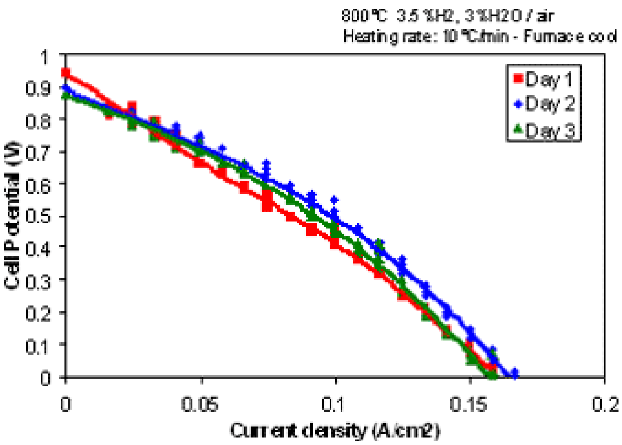

Figure 3. Thermal Cyclability of a Single Cell

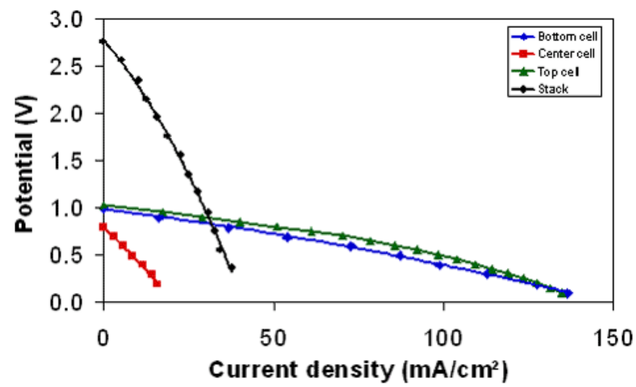

Figure 4. Polarization Results from the First Three-Cell Stack

polarization measurement due to inadvertent oxidation of the anode.

Two and three-cell stacks were built and tested. Figure 4 shows a polarization curve of the first three-cell stack. The stack reached an open circuit potential of 3 V, at which time the fuel was changed from 3% to 50% H_2. The center cell either had or developed cracks in the electrolyte, which caused a rapid degradation of the cell when the concentrated hydrogen mixture was applied. Figure 4 shows that the bottom and top cells performed reasonably well, whereas the center cell degraded the stack performance. This illustrates the need for replacing damaged or otherwise poor-performing cells. The new seal design in the TuffCell allows easy replacement of poor-performing cells.

Conclusions

- A cost analysis for large-scale manufacturing of TuffCell stacks was developed and compared to the manufacturing of conventional anode-supported SOFCs.
- Single cell tests were performed, achieving a maximum power density of 0.12 W/cm^2. Thermal cycling tests were initiated with single cells, achieving four cycles at 10°C/min. heat-up rates.
- Two and three-cell stacks were built and tested using the new self-sealed TuffCell design.

Special Recognitions & Awards/Patents

1. J. D. Carter, J.-M. Bae, T. A. Cruse, J. M. Ralph, and D. Myers, U.S. Patent Application, Docket No. ANL-IN-04-095, May 3, 2005.

FY 2005 Publications/Presentations

1. J. D. Carter, R. Kumar, D. Myers, and J. Ralph, "Metallic Bipolar Plate-Supported Solid Oxide Fuel Cell: TuffCell," 2004 Fuel Cell Seminar Abstracts, November 1-5, 2004, San Antonio, Texas, (Courtesy Associates, Washington D.C., 2004).