V.I.5 Development of a Low Cost 3-10 kW Tubular SOFC Power System

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Objectives

The goal of this project is to develop a low-cost 3-10 kW solid oxide fuel cell (SOFC) power generator capable of meeting multiple market applications. This is accomplished by:

- Improving cell power and stability.
- Cost reduction of cell manufacturing.
- Increase stack and system efficiency.
- Prototype testing to meet system efficiency and stability goals.
- Integration to a micro-combined heat and power (mCHP) platform.

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) Performance

Technical Targets

This project is directed toward achieving the stationary generation goals of the DOE fuel cell power systems. This project will work on cost reduction of the desired product while also demonstrating required life and efficiency targets through multi-level testing.

TABLE 1. Progress Towards Meeting Technical Targets for Stationary Fuel Cell Power Generators

Characteristic	Units	2011 Goal	2009 Status
Electrical Efficiency	%	40	33
Combined Heat & Power Efficiency	%	80	84
Durability @<10% Rated Power Degradation	hours	40,000	7,000
Cold Start-Up Time	minutes	<30	<45
Transient Response (from 10-90%)	seconds	<3	<10
Cost	$/kWe	$750	$729 (estimate on volume)

Accomplishments

- Reduced cell thermal cycle degradation to <1%/100 thermal cycles from 20-30% to meet DOE stability and life objectives.
- Have reduced cell stack size by 82% and volume by over 75%.
- Have proven stack stability with purge less operation meeting needs of mCHP product requirement.
- Have achieved over 43% electrical efficiency (gross power/lower heating value natural gas) on latest stack technology.

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Introduction

Achieving combined heat and power goals of over 40% net electrical efficiency and over 80% total energy efficiency are goals of the Department of Energy and present administration to reduce our dependence on foreign energy and reduce the emission of greenhouse gases. SOFCs, with their ability to use the present U.S. fuel infrastructure and high grade waste heat are ideal candidates for this challenge. To date, the limitation on making this goal a reality has been the reliability and cost of such systems.

This project is designed to address these limitations and bring this promising technology to the market place. This is being achieved by working on all aspects of the SOFC power generator including: (1) improving cell power and stability, (2) reducing cost of cell manufacture, (3) increasing stack and system efficiency, (4) prototype system testing, (5) and integration into a mCHP platform. This phase of the project will make a major drive toward the DOE's goals set forth for 2011 stationary power generators.

Approach

To achieve the project objectives, the approach has been to perfect the individual system pieces followed by optimizing their integration through:

- Cell Technology: Improving power and stability of the cell building block.
- Cell Manufacturing: Improving processing yield and productivity while decreasing material consumption.
- Stack Technology: Refining stack assembly and improve integrity while cost reducing individual component costs.
- System Performance: Developing simplified controls and balance-of-plant components to allow for a reliable, highly efficient unit.

Results

In the past year, the focus has been on stabilizing the present cell technology and reducing the cost of this part while integrating it in the present generator design. Prior to this year, the performance and the stability of the individual cell tube were very good at steady-state operation but improvements in thermal cycle capabilities were needed. Work focused on identifying the root causes for degradation on thermal cycles which was ultimately reduced to the anode-cathode interconnection. Contact to the chromite interface was being weakened or broken on thermal cycles and was not able to reattach on subsequent heatups. Once the root cause was identified, a number of different techniques were trialed to determine what gave the best stability. Figure 1 shows the voltage of the cell under load for subsequent thermal cycles to over 450 cycles. The baseline design had a loss of greater than 10%/100 thermal cycles where the final method chosen and placed into production resulted in less than a 1%/100 thermal cycle loss.

Work also focused on cost reduction for manufacturing of the individual cells. A number of processes were automated as well as reductions made in material usage. The manufacture of the tube was converted from an extrusion process to an isopressing operation. Isopressing allows significant advantages including higher volume throughput, reduced scrap, and integration of a hemispherical closed end. Introduction of this process also allowed for the manufacture and testing of tubes with decreasing amounts of wall thickness. Since the tube represents over 90% of the total mass of the fuel cell, decreases in its wall thickness have a direct bearing on weight and cost. Figure 2 shows a picture of a 45% reduced wall thickness tube versus a standard tube. Cells were manufactured with wall thicknesses reduced by 35% and 45% with those of 35% performing equivalently to that of a standard cell. Cells with 45% reduced wall thickness have been manufactured and are going through testing at this point.

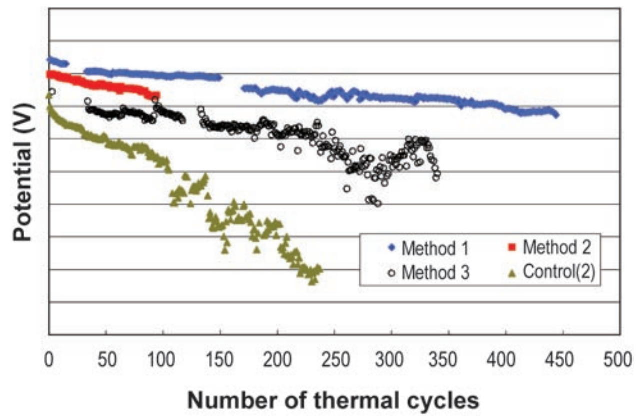

FIGURE 1. Single Cell Thermal Cycle Capability

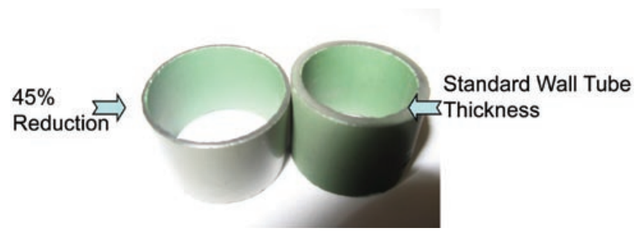

FIGURE 2. Comparison of Standard and 45% Thinner Walled Tube

Automation advances were also made into application of the lanthanum chromite interconnection and lanthanum manganite cathode. The plasma spray unit was increased in capacity from spraying one part at a time to eight parts per cycle. This has reduced loading/unloading labor time as well as wear on the plasma spray unit with a reduced number of starts and stops on the gun arc. For cathode coating, the process has been changed from a dipping process to a localized spray process with an automated part indexing feature giving more uniformity to the coating. Figure 3 shows the comparison of a dipped to a sprayed cathode demonstrating the more open structure to allow for mass transport and provide triple phase sites. This uniformity and improved structure has lead to less variability in performance with cells achieving power on the higher end of the normal distribution curve.

Significant advances have also been made in generator design and geometry. In earlier designs, there were 126 cells required to generate 1.25 kW

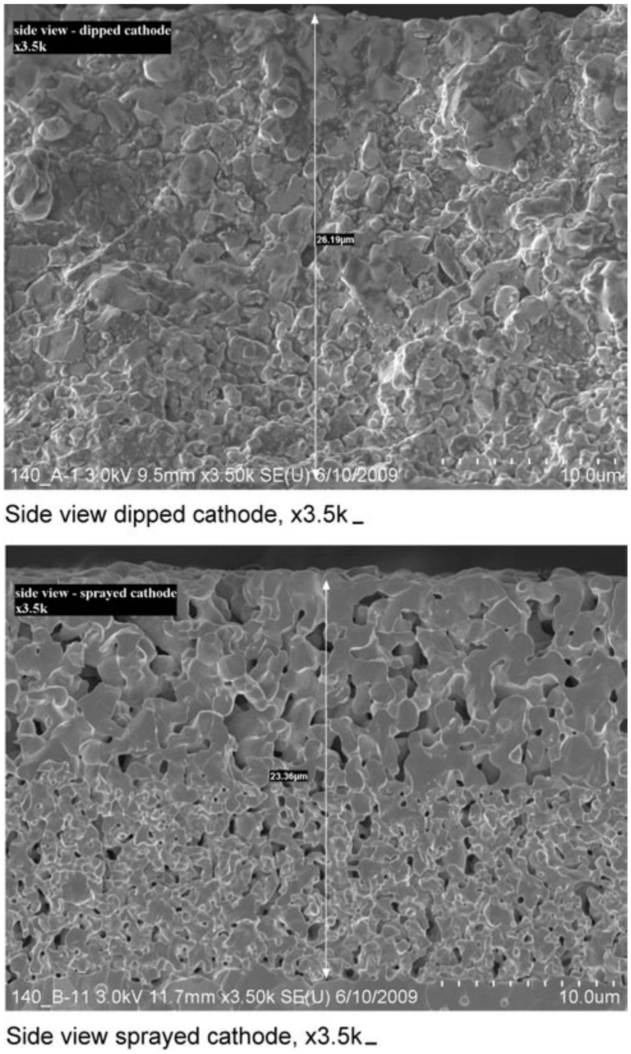

FIGURE 3. Morphology of a Dipped and Sprayed Cathode Tube

direct current. Under this project, that number has been reduced to 72, then 45, and presently 36 cells to achieve the same power level. This has also reduced stack weight by 75% from 92 to 23 lbs as well as volume by 82% from 44 L to <8 L. Gains have also been made in stack stability during thermal cycle as has been done on the individual cell. Figure 4 shows the stability of a standard cell stack under normal thermal cycle conditions. Cell stacks were reduced from the 800°C operating temperature to less than 200°C in less than one hour with subsequent heating back to 800°C in less than one hour. During twenty of these cycles, there was no noticeable decrease in performance from the stack. Also important from this test was the fact that the thermal cycles were done without the aid of a purge or cover gas on the anode side during cycle which would be required in any commercial product. During the last year, this same stack was subjected to testing with the fuel being steam reformed as opposed to the standard catalytic partial oxidation as used in the past. This

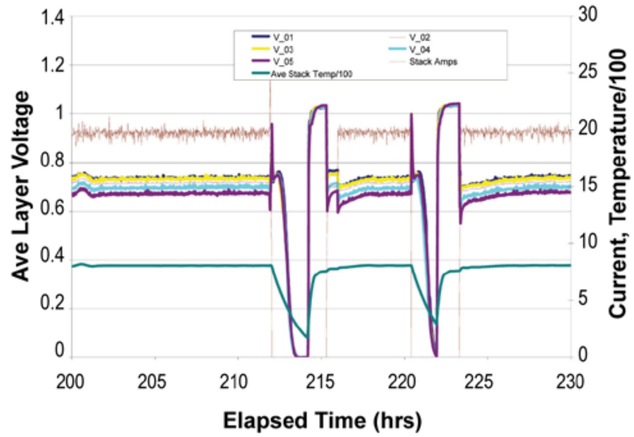

FIGURE 4. Stack Stability Testing

change in reformation technique as well as changes in the thermal distribution within the stack have resulted in efficiency gains from the mid 30's to the mid 40's for the same stack structure.

Conclusions and Future Directions

Significant strides have been made in achieving the goals set forth for stationary fuel cell generators under the DOE multi-year plan.

- Reduced cell thermal cycle degradation to <1%/100 thermal cycles from 20-30% to meet DOE stability and life objectives.
- Have reduced cell stack size by 82% and volume by over 75%.
- Have proven stack stability with purge less operation meeting needs of mCHP product requirement.
- Have achieved over 43% electrical efficiency (gross power/lower heating value natural gas) on latest stack technology.

Moving forward, the advances made in cell manufacturing will continue to achieve the desired DOE cost goals for stationary units through more automation and material reductions as well as yield improvements. Generator components will continue to be cost-reduced with further testing into life expectancy with the improved efficiencies demonstrated in the past year. The goal being to test a number of stacks with these conditions to generate sufficient data to determine repeatability and provide a platform to test cost reduction improvements.

FY 2009 Publications/Presentations

1. 2008 Fuel Cell Seminar, "Progress in Acumentrics' Fuel Cell Program", Phoenix, AZ, October 28, 2008.

2. 2009 DOE Hydrogen Program Review. Washington, D.C., May 20, 2009.