V.G.2 Development of a Low Cost 3-10 kW Tubular SOFC Power System

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Contract Number: DE-FC36-03NT41838

Project Start Date: April 1, 2008
Project End Date: September 30, 2011

Objectives

The goal of the 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 remote and micro-CHP (mCHP) platforms to allow short and longer term market penetrations.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell 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	2010 Status
Electrical Efficiency	%	40	35
Combined Heat and Power Efficiency	%	80	85
Durability @<10% Rated Power Degradation	hours	40,000	7,000
Cost Start-Up Time	minutes	<30	<25
Transient Response (from 10-90%)	seconds	<3	<10
Cost	$/kWe	$750	$729 (estimate on volume)

Accomplishments

- Passed "Go/No-Go" test by achieving 0.7%/1,000 hr degradation (goal <2%) over 1,500 hr testing.
- Have demonstrated a 24% increase in power density enabling 33% reduction in stack volume and 15% reduction in stack weight.
- Operated over 5,000 hrs at an ambient temperature of over 45°C.
- Have received $1.1M in Italian government funding to match DOE development funds for mCHP units.

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Introduction

Achieving combined heat and power goals of over 40% net electrical efficiency and over 85% total energy efficiency are goals of the DOE 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) cost reducing cell manufacture, (3) increasing stack and system efficiency,

(4) prototype system testing, and (5) integration into a mCHP platform. This phase of the project will make a major drive toward the DOE's goals set forth for 2012 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 heat removal and 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, significant progress was achieved in improving the power of each individual tube. Figure 1 shows that power progression since the 2009 yearly review. During 2009 the average of all cells tested operating at 800°C was a little over 200 mW/cm^2. In early 2010 that value was increased to approximately 550 mW/cm^2 or over 150% at the same operating temperature of 800°C. The operating temperature of the cell was then lowered by 50°C and the peak power was just below 500 mW/cm^2, again a greater than 100% improvement. Later in the fiscal year further enhancements were made in the cathode layer and the manufacturing process to apply that layer allowing a peak power of 615 mW/cm^2 at 750°C. Further testing is ongoing and the anticipation is that these same powers will be achievable at 700°C. The advantages of these power enhancements is straight forward as to less tubes resulting in less cost but the reduction in temperature further exacerbates the improvements by allowing for less insulation which is less cost and size of the overall unit.

Gains were not only realized in peak power per tube but also power per tube at normal operating points. Figure 2 shows the power density at 0.7 V operating voltage which is more near the average operating point of a generator. As can be seen, at the start of the DOE program each tube could only achieve 72 mW/cm^2 while prior to last years annual merit review the value had increased to 339 mW/cm^2. Since the 2009 review the power at 0.7 V operation has further been enhanced to 421 mW/cm^2 or an additional 24%. This achievement allows for a reduction in almost a quarter of the cell count which represents a sizable overall cost of the unit while maintaining an efficiency of a generator at or above 40% (net power/lower heating value). This also represents a sizable volume and weight reduction which can not be overlooked when considering shipping costs and installation difficulties for these smaller units by field personnel.

Power enhancements and size and weight reductions themselves are not enough to make for a commercially viable product. A sizable determination of the long-term acceptance of this product is its performance stability resulting in a lower overall cost of electricity and cost of ownership. Recognizing this to be the case Acumentrics worked with the DOE to develop a mid-project "Go/No-Go" milestone to demonstrate that the stability of the stack can achieve a goal of less than 2%/1,000 hr degradation. Figure 3 shows the results of that test over the first 1,500 hrs of its operation. The 1 kW unit was nominally operated near 600 W and achieved 0.7%/1,000 hr degradation passing the milestone with less than half the allowable limit. This unit was also tested for over 5,000 hr total operation showing comparable stability numbers which have proven its viability to be placed in a number of remote power applications. These applications will be further tested in the coming year and may prove to be viable test sites and a starting point for a market transformation project.

In addition to cell power and stability enhancements, there have been

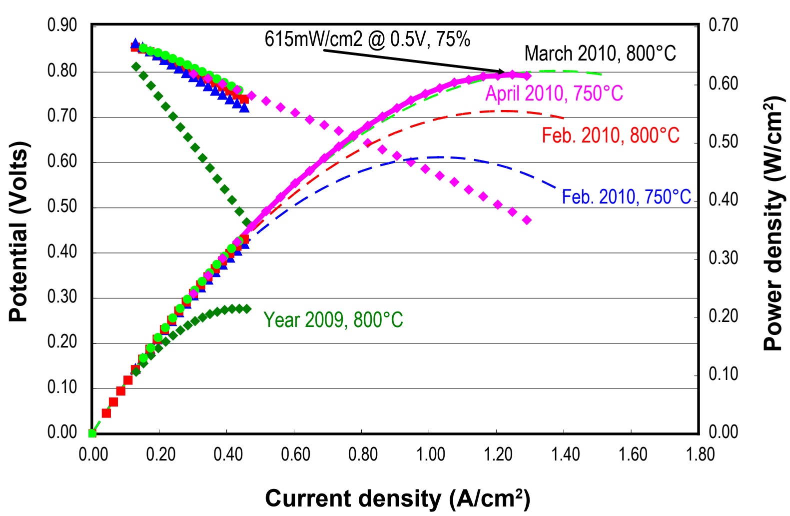

FIGURE 1. Single Cell Power Enhancements

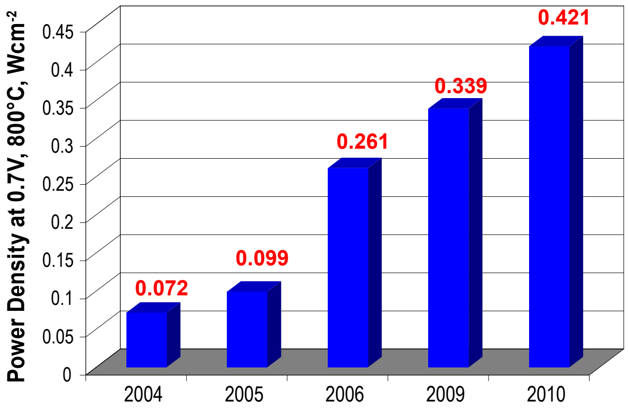

FIGURE 2. Power Enhancements at 0.7 V

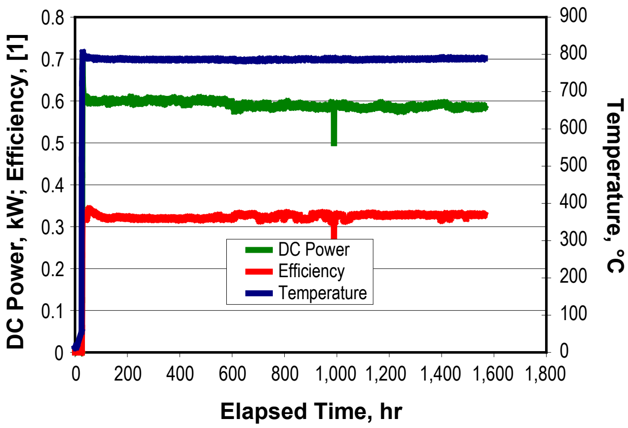

FIGURE 3. Passage of "Go/No-Go" Stack Stability Milestone

a number of improvements in the generator performance and cost reduction. One of the most significant generator cost reductions has come with improvements in the high-temperature recuperator used to pre-heat the incoming air utilizing the exhaust gas from the fuel cell stack. The goal of this device is to be as small, least expensive, and as efficient as possible while having a low pressure drop and lifetime that matches or exceeds that of the stack. Figure 4 shows the advancement in that device over the last year of development. The initial device was 300 in^3 in volume and nearly 18 lbs in weight. The latest generation has been reduced to a third of the volume or 100 in^3 and less than 4 lbs in total weight. Long term this results in less cost since the weight reduction has primarily come from the utilization of less metal and thereby reducing the material cost component of the overall device. Novell brazing techniques allowing for manufacture of the device with these thinner materials while maintaining the quality needed for the product.

FIGURE 4. Recuperator Advancements

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.

- Passed "Go/No-Go" test by achieving 0.7%/1,000 hr degradation (goal <2%) over 1,500 hr testing.
- Have demonstrated a 24% increase in power density enabling 33% reduction in stack volume and 15% reduction in stack weight.
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Moving forward, the advances made in cell power will be tested for longer durations to assure the achievability of lifetime goals. Further testing will demonstrate not only stability at steady-state operation but also consider thermal cycling for product platforms with less stringent operating hour requirements but more stringent cyclic duty. Work will also continue into resolving thermal management issues now that significantly higher power is being achieved in a smaller volume. Further work into the reduction of weight and cost of the metallic recuperator will be performed to meet the long-term product goals.

FY 2010 Publications/Presentations

1. 2009 Fuel Cell Seminar, "Progress in Acumentrics' Fuel Cell Program", Palm Springs, CA, October, 2009.

2. 2010 DOE Hydrogen Program Review. Washington, D.C., June 10, 2010.