V.K.1 Development of a Low-Cost 3-10 kW Tubular SOFC Power System

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Fiscal Year (FY) 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-combined heat and power (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 (Table 1). 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	2011 Status
Electrical Efficiency	%	40	40
Combined Heat and Power Efficiency	%	80	85
Durability @<10% rated power degradation	hours	40,000	12,000
Start-up Time	minutes	<30	<20
Transient Response (from 10-90%)	seconds	<3	<10
Cost	$/kWe	750	729 (estimate on volume)

FY 2011 Accomplishments

- Improved electrical efficiency of stationary units from 35% to 40%.
- Improved durability to over 7,000 hrs demonstrated to over 12,000 hrs demonstrated.
- Increased operating current density and power per cell by 67% while maintaining performance stability.
- Developed a cell manufacturing process capable of cutting high temperature firing times in half with improved yield and cell cost.

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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, (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 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 years review, substantial power per tube as well as the significant reduction in operating temperature were demonstrated. It was then stated that the focus of 2010 would then need to revolve around assuring that these increased power per tube figures did not result in any deleterious effects on life expectancy and that they did not interfere with the overall continual goal of cost reduction. Likewise, it was stated that the increased cell power would be further utilized with a number of new generator designs and reforming technology to result in increased overall efficiency meeting the DOE's multi-year goals. All of these goals were met in the research performed under this project in 2010.

Figure 1 shows through testing for nearly 4,000 hrs that an increase in cell current density and cell power did not result in an increased rate of performance decay. The figures shows that for approximately 500 hrs of the initial test the current density was held at 150 mA/cm^2 and was subsequently increased to 400 mA/cm^2 for an additional 3,000 hrs. Over this initial period at the pre-2010 operating conditions the voltage decay was limited to -18 mV/1,000 hrs. When the current density was increased, the two cells tested resulted in a decay of -14 and -19 mV/1,000 hrs which is statistically the same under both operating conditions.

Longer term data was also collected to demonstrate the ability to meet DOE's multi-year goal of 40,000 hr stack life. Figure 2 shows the data for one field unit operational for nearly 1.5 yrs. This unit is a full system located outside operating on residential line natural gas including any necessary clean-up and sulfur removal. In previous year reporting it was shown to have 4,500 hrs of operation and Figure 2 shows the stability for 10,000 hrs. This unit is presently at just over 12,000 hrs and continues to operate stably demonstrating over 25% achievement of the DOE goal. This unit will continue to operate and be monitored for stability.

In additions to gains in cell power enhancements were made into reforming technology and generator design to yield efficiency improvements. Figure 3 demonstrates both the power and efficiency gains resulting from these improvements. A fuel cell stack of the pre-2010 vintage was operated under its standard conditions resulting in ~500 W power output at 35-35% electrical efficiency (power/lower heating value of natural gas). The improved cell technology integrated with improved reforming technology resulted in slightly over 1,000 W power output at 42-43% efficiency.

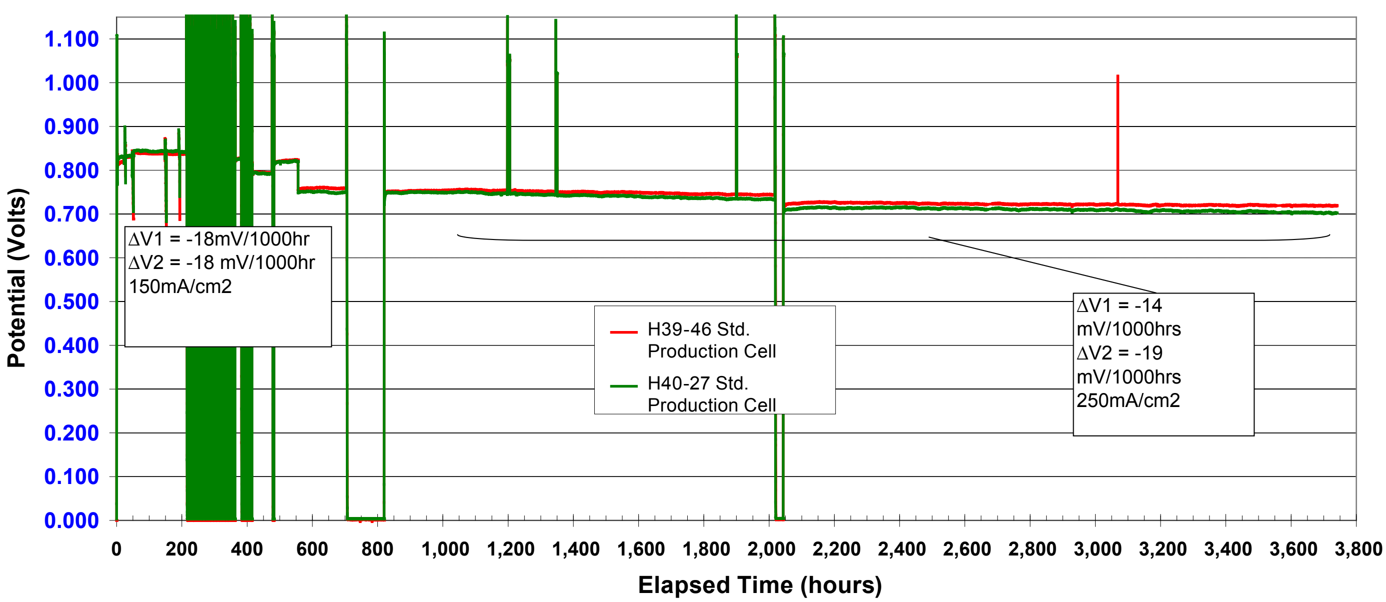
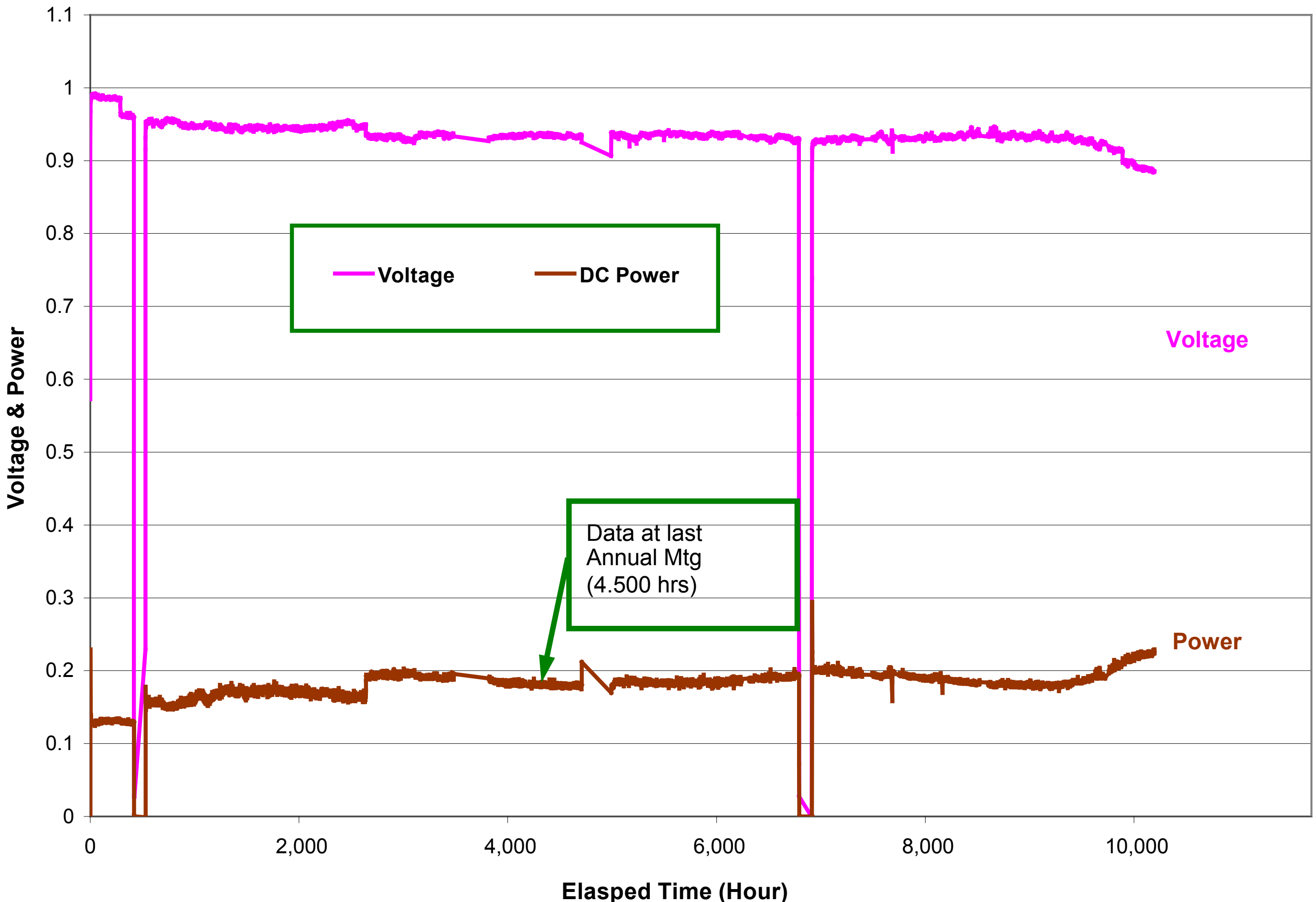


FIGURE 1. Cell Stability at Increased Power per Cell



DC - direct current

FIGURE 2. Long-Term Durability Testing

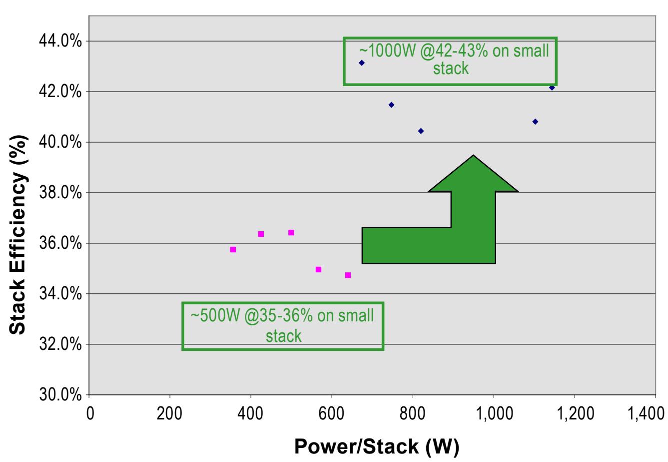


FIGURE 3. Power and Efficiency Enhancements

This doubling of power and seven efficiency point gains result in a lower cost unit since less cells are required for a given power output and allows Acumentrics' units to achieve over 40% efficiency meeting DOE's long-term goals.

In addition to cell power and stability enhancements, there have been a number of improvements in cost reduction. The fuel cell tube remains the major component to cost and the focus of significant cost reduction activities. Present technology has required that the anode be pre-sintered or "bisque" fired followed by an electrolyte application and subsequent high temperature firing. During the past year research focused on combining these two steps to allow for a co-sintering of the layers. This advancement results in significant cost reduction and productivity enhancements through reduction in capital required. Figure 4 shows the firing sequence of the two step process in addition to the single-step process. The original two-step process required over 85 hours of kiln firing while the single step reduces that to less than 50 hrs. This not only saves on capital equipment but saves on labor cost considering the removal of an unload and re-load step. Reducing handling also reduces loss from breakage further increasing yield and reducing cost. This process is presently being implemented into production.

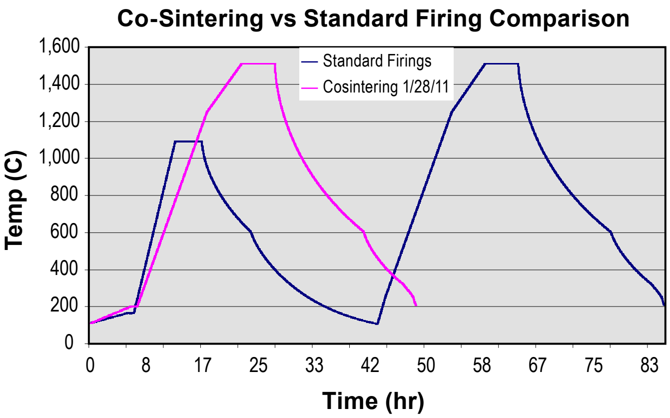


FIGURE 4. Electrolyte Co-Sintering Kiln Firing Cycles

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:

- Improved electrical efficiency of stationary units from 35% to 40%.
- Improved durability to over 12,000 hrs demonstrated.
- Increased operating current density and power per cell by 67% while maintaining performance stability.
- Developed a cell manufacturing process capable of cutting high temperature firing times in half with improved yield and cell cost.

Moving forward, further testing to achieve all of the DOE multi-year goals will be performed as well as cost reduction of the cell and all major sub-systems. Work will continue on market introduction of the technology into remote markets for short term introduction as well as mCHP for longer term market penetration.

FY 2011 Publications/Presentations

1. 2010 Fuel Cell Seminar, "Progress in Acumentrics' Fuel Cell Program", San Antonio, TX, October, 2010.

2. 2011 DOE Hydrogen Program Review. Washington, D.C., May 12, 2011.