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## III.4 SECA Solid Oxide Fuel Cell Power Plant System Cost Reduction

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### Subcontractors:

- Versa Power Systems, Inc., Littleton, CO
- Pacific Northwest National Laboratory, Richland, WA

### Objectives

FuelCell Energy Corporation (FCE) has been engaged in a Department of Energy (DOE) managed, Solid State Energy Conversion Alliance (SECA) project to develop a 3-10 kW solid oxide fuel cell (SOFC) power plant system since April, 2003. The FCE team recently successfully completed Phase I of the project, surpassing all DOE specified metrics for performance and cost. FCE utilizes the planar cell and stack technology of its SOFC provider, Versa Power Systems, Inc. (VPS), for all its SOFC development programs. Two major objectives of the Phase I Cost Reduction project development effort were to demonstrate the performance of a 3 to 10 kW prototype SOFC system and to develop factory cost estimates showing such systems could be manufactured on a cost-effective basis. FCE has recently been selected through a competitive process by DOE to participate in a multi-phase project for development of very efficient, large-scale (multi-MW) coal-to-electricity power plants with near zero-emissions. The new project's technical objectives will be merged with the existing SECA Phase I SOFC Cost Reduction project technical objectives based on the similarities for cell and stack development in both projects. One of the key project objectives is the development of fuel cell technologies, fabrication processes, manufacturing infrastructure and capabilities for scale-up of SOFC stacks that are cost competitive with existing commercial competing power generation technologies. Specific Cost Reduction related objectives for these projects are:

- Scale-up existing SOFC cell area and stack size (number of cells) within a building block unit and stack tower to minimize cost.
- Scale-up existing manufacturing infrastructure and capabilities for SOFC cell and stacks production on a cost effective basis.

- Increase SOFC cell and stack performance to maximize power and efficiency for reduced cost on a per kilowatt basis.
- Power block unit system cost goal is to be <\$400/kW.

### Accomplishments

Two major objectives of the Phase I Cost Reduction project development efforts were to demonstrate the performance of a 3 to 10 kW prototype SOFC system and to develop factory cost estimates showing such systems could be manufactured on a cost-effective basis. Following are milestone accomplishments related to these objectives:

- A 3 kW prototype SOFC system (3-1) was tested as a project requirement at VPS Ltd. (Calgary) for over a 2,100-hour operational period. Test results successfully surpassed all DOE-specified Phase I SECA program performance metric targets that included power output, system efficiency, system availability and overall system endurance.
- Following the metric test mentioned above, the prototype 3 kW SOFC system was shipped to the DOE's National Energy Technology Laboratory (NETL) in Morgantown, West Virginia, and re-tested for another 1,600 hours validating the performance of the metric test conducted at VPS.
- A detail factory cost estimate analysis was conducted indicating the total 3-10 kW system cost to be \$776/kW based upon an annual production rate of 50,000 units and a peak power rating of 5.1 kW. This surpasses (less than) the SECA Phase I metric of \$800/kW using the same assumptions.
- Both the metric system performance tests and the factory cost estimate were audited and confirmed by independent third party consultants approved by the DOE.

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### Introduction

FCE has been engaged in a DOE managed, SECA project to develop a 3-10 kW SOFC power plant system since April, 2003. FCE has recently been selected by DOE to participate in a multi-phase project for development of very efficient coal to electricity, large scale (multi-MW) power plants with near zero-emissions. The new project's technical objectives will be merged with the existing 3-10 kW program

Phase I technical objectives based on similarities for cell and stack development. The primary objectives of these projects are to develop affordable, SOFC-based power plant systems with high efficiency that are cost competitive with other power generating technologies of similar capacity without incentive funding support. In order to be cost competitive with other power generating technologies of similar capacity without the need for incentive funding programs, significant SOFC stack and system cost reduction must occur from the current low volume development level to high volume, mass production prices. The achievement of the project cost targets is a key facet of the SECA projects. FCE is ideally suited for these projects based on experience with cost reduction successes for their commercial fuel cell power plants now being installed worldwide. FCE will use the cell and stack design of their SOFC technology partner, VPS, as the basis for these projects. VPS has been actively engaged in cost-effective SOFC manufacturing process research and development since 1998 and has well established processes, quality procedures and equipment for the manufacture of small to intermediate size cells and stacks. The DOE specified metric for the final project (Phase III) system cost that is determined to be competitive with other power generating technologies of similar capacity without incentive funding is <\$400/kW for a multi-MW power plant, exclusive of coal gasification and CO<sub>2</sub> separation subsystem costs.

### Approach

The SOFC Cost Reduction project is organized in three phases according to schedule, technical and cost objectives. Following is a short description of the approach as it relates to the SOFC Cost Reduction project:

- Phase I will focus on cell and stack development activities. This will include scale-up of existing SOFC cell area, stack size (number of cells) and performance improvements. Phase I deliverable for the 3-10 kW SOFC Cost Reduction development project will be test demonstration of a 3 kW power block system that meets all DOE performance and cost metrics. This includes demonstration of system peak power performance that will be used as the basis for cost. The DOE specified metric for the Phase I 10 kW system factory cost must be less than \$800/kWe.
- Upon successful completion of Phase I and notice by DOE to continue, Phase II of the SOFC Cost Reduction project will verify the robustness of the 3-10 kW SOFC stack design (10,000 hours life, 50 thermal cycles) and validate the ability to meet the Phase II cost target of \$600/kWe.
- Upon successful completion of Phase II and notice by DOE to continue, during Phase III of the SOFC Cost Reduction project, the overall work plan shall be to continue manufacturing process development for the 3-10 kW module and to meet the \$400/kWe cost target and to conduct tests on opportunity fuels.

### Results

FCE has been engaged in a DOE managed SECA Phase I project to develop a 3-10 kW SOFC power plant system since April, 2003. Much progress has been made in the SECA Phase I project on cell and stack scale-up, increased performance and cost reduction. VPS has successfully scaled up its Tape casting, Screen-printing and Co-firing (TSC) manufacturing process from the baseline 81 cm<sup>2</sup> to 121 cm<sup>2</sup> in this project. This defined the cell area that was tested in the 3-1 SOFC prototype system as a program deliverable. The 3-1 system as shown in Figure 1 was tested at VPS Ltd. to demonstrate the DOE specified performance metrics for power output, system efficiency, system availability and overall system endurance. Figure 2 and Table 1 summarize the test performance and results. The 3-1 SOFC system test results surpassed all the DOE Phase I SECA program performance targets. The performance test set-up, measurement equipment and results for the metric test were audited and confirmed by an independent third party consultant approved by the DOE. Following the metric test mentioned above, the prototype 3 kW SOFC system was shipped to the DOE's NETL in Morgantown, West Virginia, and re-tested for another 1,600 hours validating the performance of the metric test conducted



FIGURE 1. Packaged 3 kW SOFC System

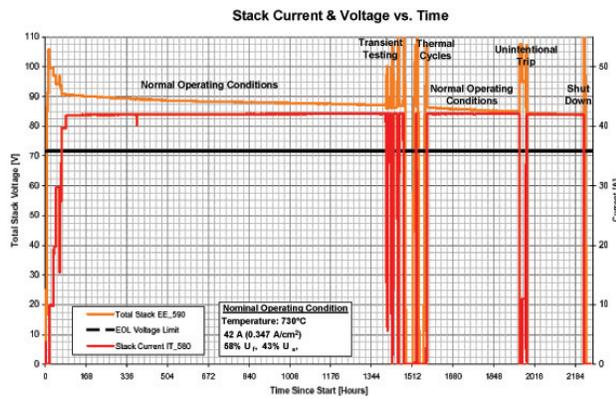


FIGURE 2. SECA 3 kW SOFC System Performance

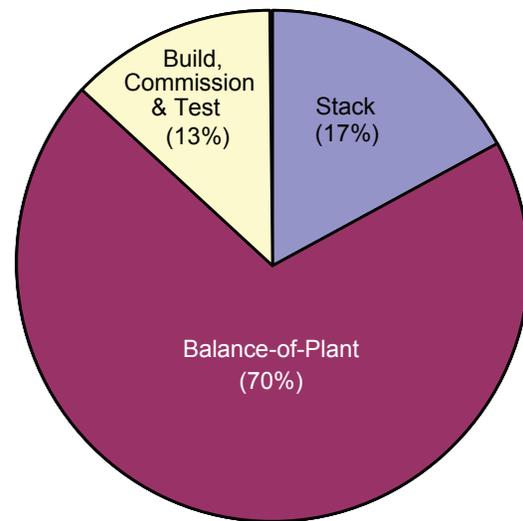


FIGURE 3. Packaged 3 kW SOFC System Costs

TABLE 1. SECA Cost Reduction Project Phase I Metric Test Results

	Steady State Operation (BOT)	Steady State Operation (EOT)	Peak Power Operation	SECA Metric	
Net DC Electrical Power	3.39 kW	3.13 kW	5.26 kW	3 to 10 kW	✓
Net DC Electrical Efficiency	38.7%	36.4%	33.3%	> 35% (Steady State)	✓
Stack Power Density	280 mW/cm <sup>2</sup>	260 mW/cm <sup>2</sup>	430 mW/cm <sup>2</sup>	N/A	
Steady State Degradation		1.2% / 500 hours	N/A	< 2% / 500 hours	✓
Transient Degradation (7 load interruptions, 3 thermal cycles)		0.7%	N/A	< 1.0%	✓
Availability		98.6%	N/A	< 80%	✓

✓ All SECA 3 kW Phase I Cost Reduction Program performance metrics have been successfully demonstrated!

at VPS. A detail factory cost estimate analysis was conducted indicating the total 3-10 kW system cost to be \$776/kW based upon an annual production rate of 50,000 units and a peak power rating of 5.1 kW. This surpasses (is less than) the SECA Phase I metric of \$800/kW using the same assumptions. As shown in Figure 3, the stack accounts for ~17% of the total system cost, while the balance of plant (BOP) components account for ~70% of the cost. The remainder of the system cost (~13%) is associated with building, commissioning and testing (BC&T) of the power block unit. The low cost associated with the stack reflects the many years of process development and cost reduction activities at VPS. Greater than 75% of the BOP costs are procured components. Once a design configuration

is stabilized to enable volume pricing, multiple vendor sourcing is established and value-engineering programs are in play, it is anticipated that significant cost savings (>50%) will be realized. As the power plant size becomes larger, the BOP and associated costs will also diminish proportionally on a cost-per-kilowatt basis. This provides the greatest cost reduction opportunity for the coal-based, large scale, multi-MW sized power plants to be developed in FCE’s new SECA project. The methodology and results from the factory cost estimate analysis were audited and confirmed by an independent third party consultant approved by the DOE.

### Conclusion and Future Directions

- FCE has been engaged in a DOE managed SECA Phase I SOFC Cost Reduction project to develop a 3-10 kW SOFC power plant system since April, 2003. The FCE team recently successfully completed Phase I of the project, surpassing all DOE specified metrics for performance and cost.
- A 3 kW prototype SOFC system (3-1) was tested as a project requirement at VPS for over a 2,100-hour operational period. Test results successfully surpassed all DOE specified Phase I SECA program performance metric targets that included power output, system efficiency, system availability and overall system endurance.
- Following the metric test mentioned above, the prototype 3 kW SOFC system was shipped to the DOE’s NETL in Morgantown, West Virginia, and re-tested for another 1,600 hours validating the performance of the metric test conducted at VPS.
- A detailed factory cost estimate based on a commercial production output of 50,000 units per year was conducted on the 3-1 SOFC system

tested in the above bullets. System factory cost calculations surpassed the DOE Phase I program cost metric target being less than \$800/kW.

- Both the metric system performance tests and the factory cost estimate were audited and confirmed by independent third party consultants approved by the DOE.
- The FCE SECA team has now been redirected to participate in a multi-phase SECA project for development of very efficient coal-to-electricity power plants with near-zero emissions. The primary objective of the project is to develop an affordable, multi-MW size SOFC-based power plant system for utilization of synthesis gas (syngas) from a coal gasifier with near-zero emissions to help reduce the nation's dependence on foreign fuel sources. The final Phase III project deliverable will be a ~10 MW proof-of-concept power plant demonstration at FutureGen or another suitable SECA selected site.

### **FY 2007 Publications/Presentations**

1. "Coal Based Large SOFC/T Systems", H. Ghezel-Ayagh, J. Doyon, Fuel Cell Energy Inc; Paper presented at the 2006 Fuel Cell Seminar on November 13–17, Honolulu, Hawaii.
2. "Development of Solid Oxide Fuel Cells at Versa Power Systems", B. Borglum, E. Tang, M. Pastula, R. Petri, Versa Power Systems; Paper and presentation at the 2006 Fuel Cell Seminar on November 13–17, Honolulu, Hawaii.
3. "SOFC Development Status at Versa Power Systems, Inc.," B. Borglum, Presentation at the 2006 Lucerne Fuel Cell Forum, July 4, 2006.