

## GE Energy

### Quarterly Updates for Solid State Energy Conversion Alliance (SECA) Solid Oxide Fuel Cell (SOFC) Program (DE-FC26-01NT41245)

**Fourth Quarter 2001:** A novel recuperator design has been developed. The recuperator is simple in design and low in cost, and will eliminate the need for high-temperature conventionally designed heat exchangers in the SECA system.

**First Quarter 2002:** An assessment of available fuel reforming technologies has been conducted. Initial catalyst performance studies have been completed. Autothermal reforming has been down-selected as the main approach for the pre-reformer in the system, with a CPOX-based reformer as the risk-mitigation strategy.

**Second Quarter 2002:** A new half-sealed stack design has been developed. Stable stack performance on unreformed methane has been demonstrated. A module was run with a fuel composition of 0% H<sub>2</sub>, 11% CH<sub>4</sub>, 19% H<sub>2</sub>O, balance N<sub>2</sub>. This module produced 0.163 W/cm<sup>2</sup> power at a voltage of 0.60V. This was an important feasibility demonstration for high efficiency system concepts that require significant levels of internal reforming.

**Third Quarter 2002:** A baseline conceptual system design has been completed. The key results of this design effort include a system model for performance estimation/prediction, process flow diagram, equipment list, and control strategy. A preliminary cost assessment of the SECA system was performed and reported. As part of this assessment, a comprehensive stack cost model was developed. The model is flexible and modular, and was used to perform probabilistic estimates of cost. Successful scale-up of fuel cells, demonstrating performance on 8" radial cells that is equivalent to that of our baseline 4 3/8" cells.

**Fourth Quarter 2002:** Competing configurations have been identified and modeled, and trade studies have been conducted. Flowfields have been designed to optimize fuel utilization, cell-to-cell flow uniformity and pressure drops in the stack. Fabrication of test vehicles to validate the new designs is underway. Stack performance has been improved. Modules (comprising cell and interconnect) have been run stably at 80% fuel utilization in 64% hydrogen/36% nitrogen fuel, at 0.6V and 0.400 A/cm<sup>2</sup> (for a power of 0.240 W/cm<sup>2</sup>). This is a significant step toward achieving SECA stack performance targets. Multi-cell stacks have been built and successfully tested with 8" cells.

**First Quarter 2003:** System performance and cost models were linked into a simulation tool, enabling cost and performance trade studies. Concepts for the SOFC stack, fuel pre-processor, tail-gas burner and recuperator were down-selected and designs were started. Improved interconnect materials for the SOFC stack were down-selected. A modified anode process was developed which increased cell performance by ~7%. Cells were tested in simulated reformat fuel (of the composition planned for the SECA prototype system), achieving a peak power of 0.290 W/cm<sup>2</sup> at 800°C and 80% fuel utilization.

**Second Quarter 2003:** Single-cell module tests were performed to validate key features of the down-selected SOFC stack design, with impressive results. Stable performance was achieved at 93% fuel utilization (in fuel of 64% hydrogen, balance nitrogen). At this condition, a power density of 0.234 W/cm<sup>2</sup> was obtained at 0.66 V. At 80% fuel utilization and the targeted SECA operating condition, the module achieved a power density of 0.290 W/cm<sup>2</sup>. The GE-developed sealant material was shown to have the capability to meet SECA sealing and thermal cycling requirements. Design of the fuel pre-processor was completed and the design review passed. Control strategies for startup, shutdown and normal operation of the SECA system were completed.

**Third Quarter 2003:** The conceptual system design was completed. Design of the stack was completed and fabrication of sub-scale stacks (up to 1kW) begun. Stable performance was achieved at 95% fuel utilization in single-cell module tests. Interconnect metals were identified which show the potential to meet SECA degradation requirements. A fuel cell module was taken through 10 thermal cycles and continued to run stably at 88% fuel utilization. Methane internal reforming capability to (and beyond) the target methane concentration was demonstrated.

**Fourth Quarter 2003:** The prototype system design effort was kicked off. The first iteration of the design, including system diagram, bill of materials, and heat & material balance, was completed. Several fuel cell modules and stacks were tested, including a 5-cell stack which performed stably at 70% fuel utilization through 5 thermal cycles and 200+ hours of steady-state operation. Improved cathode materials were developed which demonstrated no loss in performance at 60% cathode thickness, representing a significant cost savings. The use of low-cost YSZ in the anode was tested in large cells: performance was excellent, but some performance degradation over time was observed. Analysis of these cells is underway to determine the source of the degradation. The first fuel processor prototype unit was completed and tested successfully with both natural gas and propane fuels. Performance tests on the fuel processor have validated the models used for design. The first prototype power electronics unit was completed and demonstrated 94.5% efficiency vs. a prototype target of 95%. Further testing and optimization of the power electronics are underway.

**First Quarter 2004:** Several stack tests were conducted, ranging from 5-cell to 10-cell stacks, with performance of 0.260 W/cm<sup>2</sup> at 0.71V and 75% fuel utilization (dilute hydrogen) achieved. A single-cell module completed a 1000-hour steady-state test, during which operating conditions were maintained at 0.366 A/cm<sup>2</sup> and 80% fuel utilization (dilute hydrogen). Performance degradation was very low: it was measured at 0.5% over the 1000 hours, and no increase in leakage rate was observed over that period. A 5-cell stack was tested under simulated reformat of varying composition. The methane content of the reformat was progressively increased up to 30%. Performance remained stable through this entire composition range. The stack design was modified to improve the manifold seal design. A new fuel processor design, which dramatically reduces volume and cost of the unit, has been tested. The unit performs well and requires lower inlet temperatures than originally expected. Testing of the fuel pre-processor continued with improved insulation methods developed. Testing of the power electronics indicates performance in excess of 94% efficiency over a wide range of operation (~3-6kW). Two combustor design options were explored to allow successful operation over a wide range of fuel and air flows.

**Second Quarter 2004:** A draft prototype system test plan was developed. Testing of the fuel pre-processor showed stable operation at 250°C inlet temperature, dramatically decreasing the required fuel line preheating in the system. Stable performance was also observed in a short-term test for the fuel pre-processor operating on propane. Tests were conducted to validate and optimize the cell and manifold seal approaches of the new stack design. The part-load model for the prototype system was updated with current component information. A 2-cell stack test was performed to evaluate performance and to validate the manifold seal approach of the updated stack design. The stack performed well, achieving a peak power of 334 mW/cm<sup>2</sup> at 45% fuel utilization. A single cell test was conducted to map the performance of the cell on reformat compositions expected in the prototype system. A design update for the stack enclosure was kicked off to minimize thermal and power losses as well as improve flow uniformity within the stack assembly. Significant progress was made in this effort with heat loss from the enclosure being reduced by over 50%. Efficiency and fault testing were completed with the inverter for the prototype system. Peak efficiency of 94.5% was demonstrated with the efficiency being greater than 93% for much of the operating envelope for the prototype system.

**Third Quarter 2004:** A 21-cell stack test was successfully tested and achieved 305 mW/cm<sup>2</sup> at 0.71V at 70% fuel utilization in dilute hydrogen. The next revision of the system cost projections was kicked off. An interconnect has been successfully fabricated with a new alloy that shows promise in reducing the degradation rate of the SOFC. An extraordinarily high power density

(404 mW/cm<sup>2</sup> at 0.7V and 88% fuel utilization with 64% hydrogen) was achieved with modified cells. This power density exceeds the target of 300 mW/cm<sup>2</sup> under similar operating conditions. . The part-load performance projections for the prototype system were updated based on the latest component flow-up information and packaging of the prototype system. The system efficiency entitlement remains above 40%. A 3-cell stack was built and tested with the prototype system's fuel processor. Prior to this testing, stand-alone testing of the fuel processor was conducted to debug the test stand and improve the steam delivery to the fuel processor. The blower for prototype system successfully completed the first 250-hour segment of its endurance testing at the nominal design point with no issues reported. A new peak power for the prototype inverter was established through testing. This testing demonstrated sustained operation with an increase in AC power output of approximately 20% subject to DC voltage constraints. Communication tests between the system controller and the inverter have been successfully completed. The system controller communication algorithm has also been updated for the modified current command of the inverter.

**Fourth Quarter 2004:** Assembly of the prototype system is underway. The system controller, signal conditioning, and auxiliary power have been assembled and installed on the prototype system. Final wiring will take place in 1Q2005. A 40-cell stack test was concluded. The test verified the mechanical and seal integrity of the large stack and provided the temperature profile of the stack. Even with the use of some recycled parts, the 40-cell stack achieved 1.59 kW at 427 mA/cm<sup>2</sup> with a 60% fuel utilization and average cell voltage of 0.65 V in dilute hydrogen. A single cell stack module was tested with the prototype system's fuel processor to gather degradation data for the SOFC operating on real reformat fuel. Testing to-date shows very little difference between the degradation of this module's performance on reformat versus previous experience with cells operating on dilute hydrogen. New high performance cells (404 mW cm<sup>2</sup> at 0.7V for 88% fuel utilization) developed meet the requirements on strength, degradation, and manufacturing yield for inclusion in the prototype system and therefore will be used to help maximize performance of the prototype unit.