IV.1 Coal-Based Solid Oxide Fuel Cell Power Plant Development

Objectives

The objective of the Coal-Based Solid Oxide Fuel Cell (SOFC) Power Plant Development program is to develop a cost-competitive, highly efficient, multi-MW SOFC power plant system to operate using coal-derived syngas with near-zero emissions. This project is being merged into an existing FuelCell Energy (FCE) SECA Phase I project with similar SOFC cell and stack development objectives. Specific program technical objectives are as follows:

- Scale up existing SOFC cell area and stack size (number of cells) for large-scale, multi-MW power plant systems.
- Increase SOFC cell and stack performance to maximize power and efficiency operating on coal-derived fuels. Achieve a minimum 50% overall system efficiency (based on higher heating values) from coal-derived fuels.
- Design, build and test proof-of-concept multi-MW SOFC power plant system including gas turbine (>1 MW) for high efficiency with 90% CO_2 separation for carbon sequestration. The testing will be conducted at FutureGen.
- Achieve system cost of <$400/kW for a multi-MW power plant, exclusive of coal gasification and CO_2 separation subsystem costs.

Approach

The project is organized in three phases according to schedule and technical objectives:

- Phase I of the project will focus on cell and stack development activities. This will include scale-up of existing SOFC cell area and stack size (number of cells) and performance improvements. Preliminary design engineering and analysis for multi-MW power plant systems will also be conducted. The Phase I deliverable will be a test demonstration of a representative SOFC stack building block unit on simulated coal syngas.
- Phase II of the project will focus on modularization of the Phase I stack building block units into MW-size modules. Detailed design engineering and analysis for multi-MW power plant systems will also be conducted. The Phase II deliverable will be a test demonstration of a MW-size representative SOFC stack module on simulated coal syngas.
- Phase III of the project will focus on design and fabrication of a proof-of-concept multi-MW power plant including an indirectly heated turbine for high efficiency and CO_2 separation for low emissions. The Phase III deliverable will be long-term testing of a multi-MW size power plant at FutureGen.

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Accomplishments

- Increased SOFC cell area and number of cells per stack building block unit resulting in ~5-fold increase in stack volumetric power output (SECA Phase I accomplishment).
- Completed SECA Phase I 3 kW SOFC stack test demonstration. The 121-cm^2 area, 112-cell tall stack and system was operated for over 2,000 hours, including seven load transients, two thermal cycles and peak power demonstration.
- Developed preliminary factory cost bill-of-materials for stack and 3 kW system for DOE third party audit validation.

Introduction

FuelCell Energy has been selected by the Department of Energy (DOE) to participate in a multi-phase project for development of very efficient coal to electricity power plants with near-zero emissions. This project is being merged into an existing FCE SECA Phase I project with similar SOFC cell and stack development objectives. As illustrated in Figure 1, FCE is ideally suited for this project based on their experience in various DOE-managed projects to develop commercial large-scale, MW size fuel cell power plants; high-efficiency hybrid fuel cell–turbine systems; and SOFC cells and stacks with their SOFC technology partner, Versa Power Systems (VPS).

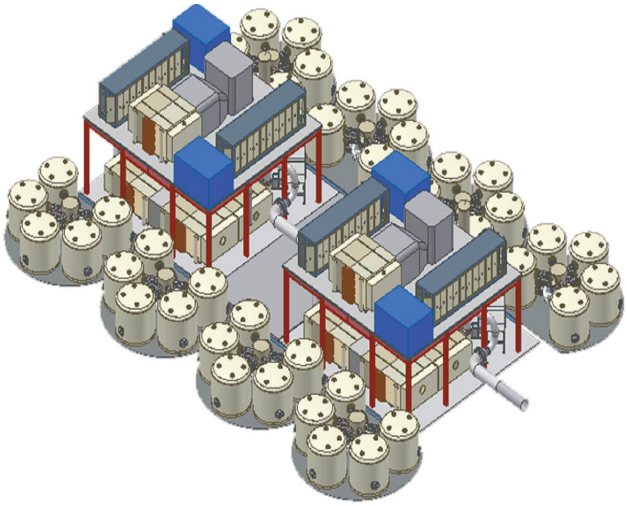

FIGURE 1. Coal-Based, Multi-MW SOFC Power Plant Development

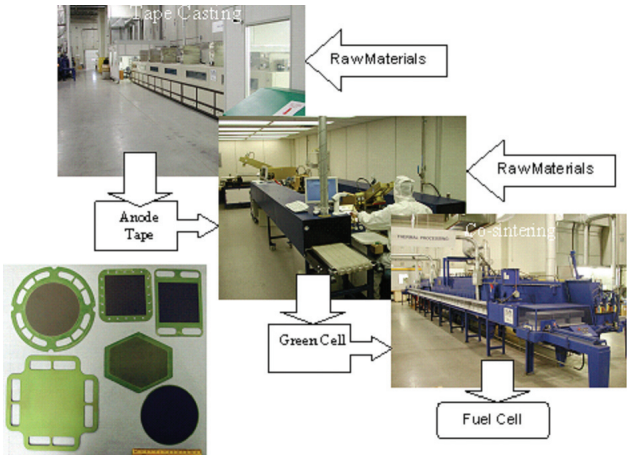

FIGURE 2. Versa Power Systems SOFC Manufacturing

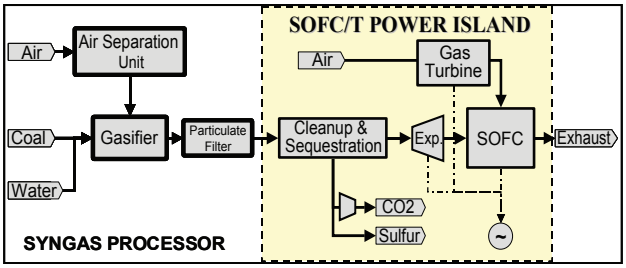

FIGURE 3. Coal-Based, Hybrid SOFC-Turbine Simplified System PFD

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. One of the key objectives is the development of fuel cell technologies, fabrication processes, manufacturing infrastructure and capabilities for scale-up of SOFC stacks for large multi-megawatt, base-load power generation plants. FCE will use the VPS SOFC cell and stack design currently being developed in an FCE SECA Phase I project as the basis for this project. VPS has well-established processes, quality procedures and equipment for the manufacture of small to intermediate size cells and stacks as depicted in Figure 2. This serves as a solid basis for cell area and stack size scale-up to be conducted in this project. The other key objective is implementation of an innovative system concept in design of a multi-MW power plant with anticipated efficiency approaching 60% of the higher heating value of coal. Figure 3 shows a simplified process flow diagram (PFD) for the proposed power plant system. Combined with existing carbon dioxide separation technologies, the power plant is expected to achieve greater than 50% overall efficiency while emitting near-zero levels of emissions of SOx, NOx, and greenhouse gases to the environment.

Approach

The path forward for development of coal-based multi-MW power plants includes a multi-faceted approach for both SOFC stack module design as well as development of a hybrid fuel cell/gas turbine system. The technical approach consists of an innovative fuel cell stack configuration, fabrication of scaled-up cells, newly developed fuel cell seals, novel implementation of a fuel cell clustering concept and integration of SOFC clusters with a gas turbine. The future development plans include investigation of both fabrication and operational issues related to scale-up of the fuel cell active area. An innovative and patented power cycle will be utilized to achieve very high efficiencies by integration of the fuel cell with an indirectly heated gas turbine. The power plant design is projected to have a factory cost of $400/kW, based on a production capacity of about 1.4 GW/year or twelve 120 MW power plants per year. This cost is very competitive with today's cost of combined cycle technologies.

The project is organized in three phases according to schedule and technical objectives. Details for the three phases are as follows:

Phase I (2-3 years)

- Scale up SOFC cell area and stack height (number of cells) and improve performance for a multi-kW stack building block unit.
- Design a baseline system that meets the program technical objectives.
- Ensure power plant design is consistent with a projected cost of $600/kW for a multi-MW system (exclusive of coal gasification and CO_2 separation subsystem costs).

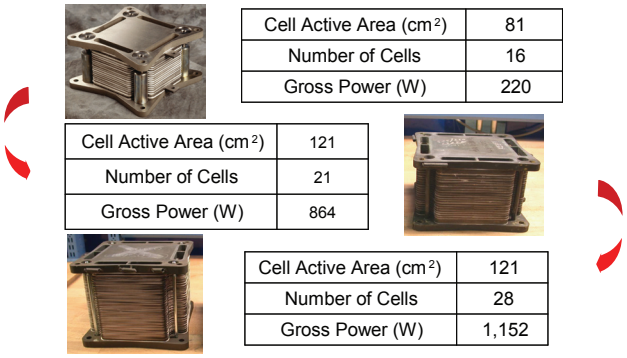

FIGURE 4. SOFC Scale-up in SECA Phase I Project

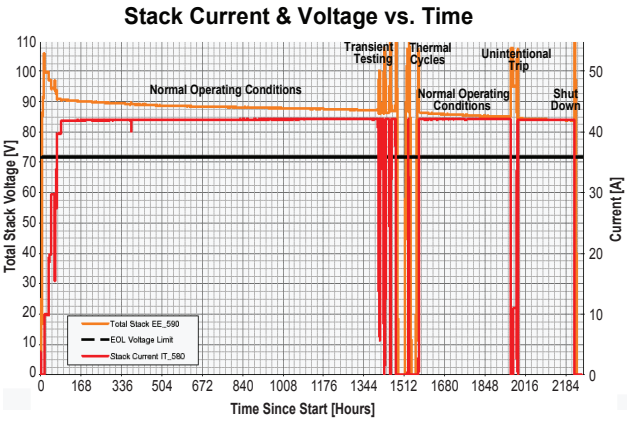

FIGURE 5. SECA 3 kW SOFC System Performance

- Fabricate and validation test a representative stack building block unit on simulated coal syngas.

Phase II (2 years)

- Develop a detailed design and cost analysis for the proposed power plant system that meets program objectives.
- Ensure power plant design is consistent with a projected cost of $400/kW for a multi-MW system (exclusive of coal gasification and CO_2 separation subsystem costs).
- Fabricate and validation test a representative fuel cell module building block unit for the multi-MW power plant on simulated coal syngas.

Phase II (5 years)

- Complete detailed design for multi-MW power plant system that meets program objectives.
- Procure and fabricate SOFC stack and system components and assemble proof-of-concept multi-MW power plant system including gas turbine (>1 MW).
- Locate coal gasifier site and integrate multi-MW power plant.
- Conduct long-term (~25,000 hours) test demonstration of multi-MW power plant system on coal-based syngas meeting program technical objectives for performance (power, efficiency), durability (load transients and thermal cycles), degradation and cost.

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. FCE has been asked to re-scope this project's technical objectives to merge with the Coal-Based SOFC Power Plant Development program objectives. This request is based on similarities of the technical objectives for cell and stack development in both programs, as well as FCE's experience with commercial MW size fuel cell power plant development, high-efficiency hybrid fuel cell–turbine systems and SOFC cell and stack development with VPS (see Figure 1). Much progress has been made in the SECA Phase I project on cell and stack scale-up and increased performance. As shown in Figure 4, increased SOFC cell area and number of cells per stack building block unit has provided an approximate 5-fold increase in stack volumetric power output. The FCE team recently completed a 3 kW test demonstration as part of the SECA program requirement with a stack tower configuration containing five of these scaled-up SOFC stack building block units. Figure 5 shows results of this milestone performance test that included seven load transients, two full thermal cycles and peak power demonstration. Initial data analysis indicates the test exceeded all SECA program performance requirements. Results are being compiled for DOE review and audit by a third party expert. A stack factory cost estimate has been developed for DOE auditors to review. The stack cost estimate is better than that required by the SECA program metric.

Summary

- FuelCell Energy (FCE) has been selected by the Department of Energy (DOE) to participate in a multi-phase project for development of very efficient coal to electricity power plants with near-zero emissions. This project is being merged into an existing FCE SECA Phase I project with similar SOFC cell and stack development objectives.
- The primary objective of the project is to develop an affordable, highly efficient, multi-MW size SOFC based power plant system for utilization of syngas from a coal gasifier.
- FCE is ideally suited for this project based on their experience with commercial MW size fuel cell power plant development, high-efficiency hybrid

fuel cell–turbine systems and SOFC cell and stack development with their technology partner, Versa Power Systems.

- Accomplishments in FCE's SECA Phase I project synergistic with this project include expanded manufacturing process capabilities and scale-up of SOFC cell area and stack height, resulting in ~5-fold increase in volumetric power density.
- A SECA Phase I 3 kW SOFC stack test demonstration of a system containing scaled-up stack units was completed as final validation of the scale-up process and components.
- The FCE team developed a preliminary factory cost bill-of-materials for the stack and 3 kW system to be audited by a DOE third party expert. Initial assessment indicates stack and 3 kW system costs meet or exceed SECA Phase I program requirements.

FY 2006 Publications/Presentations

1. "Coal Based Large SOFC/T Systems", H. Ghezel-Ayagh, J. Doyon, Fuel Cell Energy Inc; Paper presentation 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.