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

Jody Doyon
Vice President, Government Programs Administration
Fuel Cell Energy, Inc.
3 Great Pasture Road
Danbury, CT 06813
Phone: (203) 825-6125
E-mail: jdoyon@fce.com; Website: www.fce.com

DOE Project Manager: Travis Shultz
Phone: (304) 285-1370
E-mail: Travis.Shultz@netl.doe.gov

Subcontractors:
- Versa Power Systems, Inc., Littleton, CO
- Gas Technology Institute, Des Plaines, IL
- Worley Parsons, Inc., Reading, PA
- Nexant, Inc., San Francisco, CA
- SatCon Power Systems Inc., Burlington, ON, Canada
- Pacific Northwest National Laboratory, Richland, WA

Objectives

The overall objective of this three-phase coal-based solid oxide fuel cell (SOFC) power plant development project is to develop a cost-competitive, highly efficient, multi-MW solid oxide fuel cell power system using coal-derived synthesis gas with near zero emissions. Specific project 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 (higher heating value [HHV]) from coal.
- Design, build and test a proof-of-concept, multi-MW SOFC power plant system (>1 MW) for high efficiency with 90% CO_2 separation for carbon sequestration. This testing will be conducted at FutureGen or another suitable DOE Solid State Energy Conversion Alliance (SECA) selected site.
- System cost to be <$400/kW for a multi-MW power plant, exclusive of coal gasification and CO_2 separation subsystem costs.

Accomplishments

- Planar SOFC cell area manufacturing scale-up from the baseline 121 cm^2 to over 1,000 cm^2 has been successfully demonstrated using the Versa Power Systems, Inc. (VPS) TSC II process.
- Cell performance repeatability of cell active area scaled-up to 350 cm^2 has been validated with several single cell repeat unit tests. These results indicate that there is no major electrochemical performance loss due to cell scale-up from an active area of 81 cm^2 to 350 cm^2.
- Pilot production manufacturing scale-up analysis is in progress. 500 kW to 1 MW production capacity by the end of the year is planned.
- Review of commercially-available gasification technologies for integration with SOFC power block has been conducted. One prime candidate has been selected for further study.
- Review of acid gas removal processes for dual purpose of sulfur and carbon dioxide removal from coal syngas has been conducted. Selexol process has been identified as a prime candidate for acid gas removal.
- Three system design options are being developed for consideration with various integration schemes for reliability and cost. Further engineering analysis and down select planned.

Introduction

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. 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. Some of the key project objectives are the development of SOFC technologies, cell and stack size scale-up, SOFC performance optimization, increased stack manufacturing capacity development and MW-class module engineering design. FCE will use the VPS planar SOFC cell and stack technology for this project. VPS has well established processes, quality control procedures and equipment for the manufacture of small to intermediate size cells and stacks. This serves as a solid basis for cell area and stack size scale-up. The other key objective is implementation of an innovative system concept in design of a multi-MW power plant with anticipated efficiencies approaching 50% of the HHV of coal. Combined with existing carbon dioxide separation technologies, the power plant is expected to achieve 50% overall efficiency while emitting near-zero levels of emissions of SOx, NOx, and greenhouse gases to the environment. Power block and balance of plant

cost reduction, performance enhancement and efficiency improvements will be required to achieve the project cost objectives. A ~10 MW proof-of-concept power plant demonstration will be conducted at FutureGen or another suitable SECA selected site. Successful development will provide low-cost, highly efficient multi-MW SOFC power plants that operate on coal syngas with near-zero emissions to help reduce the nation's dependence on foreign fuel sources. 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 cell and stack development with their SOFC technology partner, VPS.

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. This will include the scale-up of existing SOFC cell area and stack size (number of cells) and performance improvements. Preliminary engineering design and analysis for multi-MW power plant systems will also be conducted. The Phase I deliverable will be test demonstration of a SOFC stack building block unit that is representative of a MW class module on simulated coal syngas.
- Upon successful completion of Phase I and selection by DOE to continue, Phase II of the project will focus on modularization of the Phase I stack building block units into a MW-size module. Detailed design engineering and analysis for multi-MW power plant systems will also be conducted. The Phase II deliverable will be the test demonstration of a MW-size representative SOFC stack module on simulated coal syngas.
- Upon successful completion of Phase II and selection by DOE to continue, Phase III of the project will focus on the design and fabrication of a proof-of-concept multi-MW power plant. The Phase III deliverable will be tested for at least three years at FutureGen or another suitable SECA selected site.

Results

FCE has recently successfully completed a DOE-managed SECA Phase I SOFC cost reduction project to develop a 3-10 kW SOFC power plant system using the VPS planar cell and stack technology. Two major objectives of the Phase I 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. Based on tests conducted over a 2,100-hour operational period, the prototype successfully met all DOE-specified targets. These areas included power output, system efficiency, system availability and overall system endurance. System cost calculations also surpassed the DOE metric target. Both the initial system performance tests and the factory cost estimate were audited and confirmed by independent third party consultants approved by the DOE. This VPS cell and stack technology serves as the basis for further development and scale-up in this multi-MW, coal-based system SECA Phase I project. To date, VPS has successfully scaled up its **T**ape casting, **S**creen-printing and **C**o-firing (TSC) manufacturing process from the baseline 121 cm^2 to over 1,000 cm^2 as shown in Figure 1. Cell testing performance repeatability of cell area scaled-up to 400 cm^2 (350 cm^2 active area) has been validated with several repeat single cell tests as shown in Figure 2. These results indicate that there is no major electrochemical performance loss due to cell scale-up from an active area of 81 cm^2 to 350 cm^2. New test facilities are being fabricated to enable cell testing of larger area cells. Figure 3 presents a simplified overview

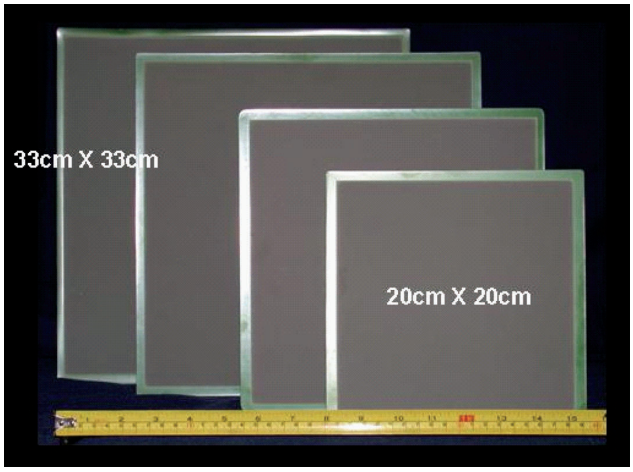

FIGURE 1. Planar SOFC Cell Area Scale-Up

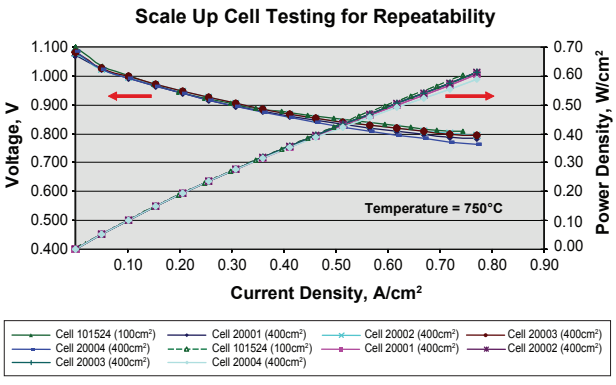

FIGURE 2. Test Performance of Scaled-Up Area SOFC Cells

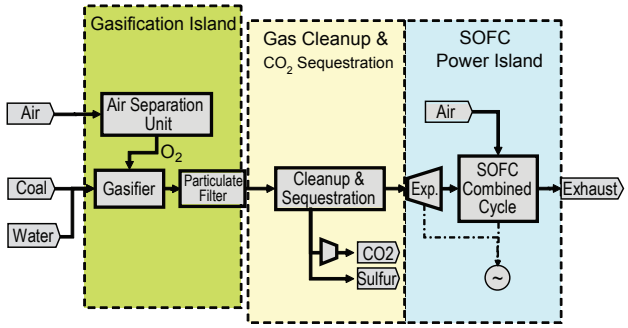

FIGURE 3. Coal-Based Integrated Gasification SOFC Fuel Cell (IGFC) Power Plant Overview

of the planned SOFC coal-based power plant system. Much progress has been made in detailed engineering design analysis with special attention to the coal-gas clean-up system and turbine combined cycle technology for maximum efficiency with minimum cost.

Conclusions and Future Directions

To date, significant progress has been made in the following areas:

- Planar SOFC cell area manufacturing scale-up from the baseline 121 cm^2 to over 1,000 cm^2 has been successfully demonstrated using the VPS TSC II process.
- Cell testing performance repeatability of cell active area scaled-up to 350 cm^2 has been validated with several repeat single cell tests.
- Pilot production manufacturing scale-up analysis is in progress. A production capacity of 0.5 MW to 1 MW is planned by the end of the year.
- Detailed engineering design analysis for the proof-of-concept (10 MW) and baseline (100+ MW) power plant systems are in progress with special attention to the coal-gas clean-up system and combined cycle technology for maximum efficiency with minimum cost.

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.