VI.E.3 Chattanooga Fuel Cell Demonstration Project*

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Ion America

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*Congressionally directed project

Objectives

- Develop and demonstrate a prototype 5 kW grid parallel, solid oxide fuel cell (SOFC) system that coproduces hydrogen, based on Ion America's (IA's) technology.
- Transport, install, and commission the SOFC system in the Alternative Energy Lab located at the University of Tennessee at Chattanooga (UT-Chattanooga).
- Demonstrate efficiency and reliability of the unit in operation using natural gas (NG).
- Explore strategies to enhance efficiency and reliability of the unit.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.5.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(C) Hydrogen Refueling Infrastructure.

(F) Centralized Hydrogen Production from Fossil Resources.

(I) Hydrogen and Electricity Coproduction.

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 11: Validate cost of producing hydrogen in quantity of $3.00/gge untaxed.** Technology validation of the IA 5 kW class SOFC system that coproduces hydrogen and electricity is a critical step towards validating the cost of producing hydrogen in quantity at $3.00/gge untaxed using solid oxide systems produced in high volume [1,2].
- **Milestone 12: Five stations and two maintenance facilities constructed with advanced sensor systems and operating procedures.** Successful operation of the IA SOFC by faculty and graduate students in a reasonable facsimile of an operational environment will provide an invaluable learning experience upon which to base operating procedures and sensor systems for safety under practical usage. With a successful demonstration of the fuel cell, consideration will be given to construction of both prototype fueling stations and maintenance facilities.
- **Milestone 13: Total of eight stations and four maintenance facilities constructed with advanced sensor systems and operating procedures.** Continued successful operation of the University Operations Laboratory together with successful experience with the prior stations and maintenance facilities will lead to an expansion and improvements in the installed base of stations and maintenance facilities.
- **Milestone 14: Validate $2.50/gge hydrogen cost.** Cost reduction of critical components and development of larger SOFC systems at IA in high volume should enable future systems to achieve hydrogen costs below $2.50/gge [1,2].

Accomplishments

- 1st completely autonomous planar SOFC system monitored remotely from Sunnyvale, CA.
- 1st known completely autonomous "state machine" mode SOFC system operation.
- 1st known demonstration of planar SOFC fuel cell system for hydrogen and electricity coproduction.

- 1st planar SOFC system to successfully demonstrate hydrogen recycle.
- Demonstrated up to 5.1 kW of grid-tie power and hydrogen coproduction using pressure swing adsorption (PSA) purification of the anode exhaust stream.
- Achieved hydrogen purity with <10 ppm CO (lower detectability limit of online gas analyzer).
- Achieved hydrogen purification yields of up to 90%.
- Demonstrated control strategy for operating PSA with 5 kW SOFC system.
- System handled grid failure during operation in Sunnyvale.
- Achieved peak system efficiency of 60.2% and peak DC stack efficiency of 37.7%.
- Inaugurated the UT-Chattanooga Alternative Energy Lab.

Introduction

The hydrogen economy will be enabled by creating a dense network of systems that are able to generate, store, and dispense cost-effective hydrogen on demand. Such a network will enable the proliferation of equipment (such as fuel cell cars) requiring cost-effective hydrogen for their operation. Manufacturing and deploying these early systems carries significant economic risk, since they will generally be used with a low capacity factor, until an adequate supply of end-users demands hydrogen on a regular basis. Low capacity factors translate into higher capital cost per unit of delivered hydrogen and presents a barrier to companies manufacturing these early devices. Systems capable of providing other valuable benefits during times when demand for hydrogen is low enable high capacity factors for systems deployed early in the build-out of the hydrogen generation network, thereby nurturing the economic growth of the hydrogen economy.

IA has developed a prototype SOFC system that is capable of efficiently generating electricity while coproducing hydrogen. SOFCs generate electricity at elevated temperatures where reforming reactions occur rapidly. When fuel (such as NG) is fed into the cell, the fuel is reformed (to mostly carbon monoxide and hydrogen). Part of the reformate is oxidized (for electricity generation), and part of it is purified as a hydrogen product. The amounts of electricity and hydrogen produced can be controlled automatically or by an operator (manually dialed in) across a range of utilization space. SOFC technology has been identified by DOE as a potentially attractive solution and is mentioned in its Fuel Cell Report to Congress (pp 4) [3]. The Enterprise Center (Chattanooga, TN) facilitated a valuable and synergistic collaboration between a start-up business – IA (Sunnyvale, CA), the government (the City of Chattanooga and the DOE), and an academic institution – UT-Chattanooga to work cooperatively in order to expedite the field demonstration of IA's early SOFC prototype.

The technology is easily scalable from enterprise applications and filling stations to residential size, operates on most hydrocarbon fuels (e.g., NG, coal gas, ethanol), and produces low CO_2 emissions due to its high efficiency. The Chattanooga Fuel Cell Demonstration Project reported herein is an initial and independent evaluation of a practical fuel cell based on the unique SOFC technology developed by IA.

Approach

IA will construct and prepare a working prototype of a 5 kW class SOFC fuel cell based on their proprietary technology. The SOFC system will be capable of hydrogen coproduction by using PSA purification of the anode exhaust stream. The working prototype will be prepared to the point where it is ready for testing in a facility located in UT-Chattanooga. The unit requires scaling from the 1 kW class previously tested in their laboratory up to a 5 kW class unit with the necessary balance-of-plant (BOP) equipment to enable operation and coproduction of up to 5 kg H_2/day (5 gge/day), which is enough to completely refill a fuel cell car on a daily basis. This will allow the unit to function in a practical application typical of the environment in which it would be used to develop power or supply hydrogen. The unit will be packaged, shipped, and installed at the UT-Chattanooga's Alternative Energy Lab. In Chattanooga the prototype will be placed in a test facility and subjected to a regimen of testing to prove it has the potential to be utilized to power a strategic location or deliver hydrogen capable of being stored which could then be used as an automobile fuel. A subset of the evaluation will be to examine the design and measure in detail its performance to identify and recommend changes that can improve the production efficiency and cost metrics of electrical power or hydrogen.

Results

The UT-Chattanooga designated a building on campus for the purpose of creating a fuel cell testing laboratory. The building is located adjacent to the UT-Chattanooga SimCenter on the southeast corner of the campus. Under the present cooperative grant the laboratory was designed, constructed, and commissioned as the Alternative Energy Lab for testing the IA SOFC system with coproduction of hydrogen.

IA established detailed design requirements for the SOFC system based on the City of Chattanooga and DOE requirements. Design requirements include system safety requirements, electrical interface requirements to the utility grid, chemical feed stream and exhaust requirements, mechanical, installation, and interface requirements from the SOFC operating site, and operating and performance requirements. From the system requirements, the system architecture was established. The system architecture was validated using ASPEN Plus modeling. Chemical, thermal, and electrical designs were captured in a piping and instrumentation diagram, wiring diagram, and communication interface. A power budget was estimated, and system performance projections were prepared. The system design was frozen in order to begin subsystem design.

Chemical compositions and thermal parameters were calculated at critical locations in the system, and a control sequence was developed using a "state machine" (automated system operation following a predefined path of steps, whereby each step has a set of conditions for completion after which it moves to the next step, to ultimately end up in steady-state operation). Both stack and BOP designs were frozen in order to support parts procurement.

A detailed bill of materials (BOM) was specified. Special vendor requirements were being captured in the form of computer aided design (CAD) package of drawings. Component and subsystem test equipment were set up and system control software was written, tested, and debugged. All required component and subassembly tests for quality control (QC) and performance verification were completed and system assembly was completed. Subsystem requirements were defined. SOFC stack and BOP subsystem designs were completed. A failure modes effects analysis (FMEA) and safety analysis of the system was performed. Subsystem designs were frozen. Components and subsystem designs were qualified. An end-to-end system test of the hot box (including SOFC stacks), warm box, and LabView control system was performed using a 5 kW class SOFC system platform developed by IA. The test validated the hot box and warm box designs. Data from the test was collected, and was used to make several improvements to system components and to control algorithms that are used in the state machine. The revised state machine was updated and ported to a PC-based control platform.

Hydrogen purification subsystem testing was performed using a PSA with an online gas analyzer (OGA) to test purity of the product hydrogen. A gas chromatograph (GC) was used to cross check results of the OGA. Testing of the power conditioning system was performed, and an acceptance test was completed.

The project timelines are summarized in Table 1. After successful completion of the System Test Task at IA (Sunnyvale, CA), the unit was packaged into multiple crates and delivered to UT-Chattanooga

TABLE 1. Timelines for the Project

Jul 2004	**Proposed** project start date
Feb 2005	**Actual** signed contract and release of funds
Feb 2005	Requirements established and system specification defined
Aug 2005	Subsystem Design and Test tasks completed
Oct 2005	Stack and Balance of Plant (BOP) assembly tasks completed
Dec 2005	System logged 707 hours of operation on 19 Dec 2005 System completed 779 hours of operation at IA's Sunnyvale location before shipping to UT-Chattanooga
Jan 2006	System shipped to UT-Chattanooga on 13 Jan 2006
Feb 2006	System started 4 Feb 2006 at UT-Chattanooga System officially inaugurated by Congressman Zach Wamp on 17 Feb 2006
Jun 2006	System logged 3744* hours of operation and 11.32 MWh of AC power to the grid * Includes 779 hours and 2.05 MWh from Sunnyvale operation

FIGURE 1. Shipping the SOFC System (top); Receiving at UT-Chattanooga (bottom)

Alternative Energy Laboratory (Figure 1) on January 17, 2006. When the crates were delivered at the Alternative Energy Laboratory, various facility upgrade projects were still underway. The system was uncrated and assembled by January 21, 2006, while the infrastructure work related to electrical grid tie, water plumbing, exhaust duct work, network connectivity and natural gas connection was allowed to finish.

Upon receiving necessary approvals from Tennessee Valley Authority and State Fire Marshall's office, the system was started on February 4, 2006, and by 4:00 PM on February 5, 2006 the system started delivering power to the grid (Figure 2). Congressman Zach Wamp, in the presence of various dignitaries, inaugurated the fuel cell

FIGURE 2. SOFC System Installed and Operational inside the Alternative Energy Lab

FIGURE 3. System Inaugurated by Congressman Zach Wamp (right) on 17 Feb. 2006

at the Alternative Energy Laboratory on February 17, 2006 (Figure 3).

Ion America has been remotely monitoring the system performance from the Sunnyvale facility in California, and since start-up the system has clocked total of 3,744 hours and generated 11.32 MWh of electricity. Key metrics including efficiency are shown in Figure 4.

Conclusions and Future Directions

- A 5 kW grid-parallel SOFC system for electricity and hydrogen coproduction was successfully demonstrated at IA in Sunnyvale, CA and in the newly inaugurated Alternative Energy Lab at UT-Chattanooga. Successful collaboration between The Enterprise Center, UT-Chattanooga and IA validates the synergy between governmental, academic and start-up business. A key pathway to help build a hydrogen economy without new infrastructure was successfully validated. By using equipment that coproduces electricity and hydrogen, the system operates with high capacity factor even the demand for hydrogen is relatively low.
- Enhanced efficiency will be demonstrated in the future by performing technology validation projects using larger SOFC systems (100 kW class) that are already being developed at IA.

DC efficiency:

$$\eta_{stack} = \frac{\text{DC power from stack}}{\text{LHV of fuel}}$$

Peak stack efficiency = 37.7%

System efficiency:

$$\eta_{system} = \frac{\text{total power (DC) + LHV of } H_2}{\text{LHV of fuel}}$$

Peak system efficiency = 60.2%

System parasitic losses:

→ BOP power at peak power as a % of total DC power = 10.7%

FIGURE 4. Key Metrics for Efficiency and Parasitic Losses

FY 2006 Publications/Presentations

1. Jim Henry and Joe Ferguson, "Chattanooga Fuel Cell Demonstration Project", U.S. Department of Energy Hydrogen Program, 2006 Annual Merit Review Meeting, Arlington, Virginia, May 16-19 (2006); http://www.hydrogen.energy.gov/pdfs/review06/tvp_5_henry.pdf

2. Darren Hickey, Mark Cassidy, Jim McElroy, Fred Mitlitsky, and Venkat Venkataraman, "Optimization and Demonstration of a Solid Oxide Regenerative Fuel Cell System ", 207th Meeting of The Electrochemical Society, Ninth International Symposium on Solid Oxide Fuel Cells (SOFC-IX), PV 2005-07, S.C. Singhal and J. Mizusaki, Editors, Quebec City, Canada, May 15-20 (2005).

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1. K.R. Sridhar, Jim McElroy, Fred Mitlitsky, Venkat Venkataraman, and Mark C. Williams, "Applications and Markets for Solid Oxide Regenerative Fuel Cells", 207th Meeting of The Electrochemical Society, Ninth International Symposium on Solid Oxide Fuel Cells (SOFC-IX), PV 2005-07, S.C. Singhal and J. Mizusaki, Editors, Quebec City, Canada, May 15-20 (2005).

3. The Department of Energy's Fuel Cell Report to Congress, February (2003); http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf