VIII.D.3 Chattanooga Fuel Cell Demonstration Project*

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Subcontractors:
University of Tennessee at Chattanooga
Ion America

Start Date: July 2004
Projected End Date: September 2005

**Congressionally directed project*

Objectives

- Obtain a 5-kW class solid oxide fuel cell (SOFC) system based on Ion America's technology
- Transport and install operating unit at University of Tennessee in Chattanooga (UTC)
- Demonstrate efficiency and reliability of the unit in operation using natural gas
- Explore strategies to enhance efficiency and reliability of the unit

Technical Barriers

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

- C. Hydrogen Refueling Infrastructure
- D. Maintenance and Training Facilities
- E. Codes and Standards
- 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 Ion America 5-kW class SOFC system that coproduces hydrogen and

electricity is a critical step towards validating the cost of producing hydrogen in quantity of $3.00/gge untaxed using solid oxide systems produced in high volume [1,2].

- *Milestone 14: Validate $2.50/gge hydrogen cost.*
  Cost reduction of critical components and development of larger solid oxide systems at Ion America in high volume should enable future systems to achieve hydrogen costs below $2.50/gge [1,2].

Approach

- Design and assemble the 5-kW class SOFC fuel cell at Ion America
- Prepare and instrument the test facility at the University of Tennessee at Chattanooga
- Test 5-kW class unit at Ion America, ship to Tennessee, conduct acceptance trials
- Conduct test program to demonstrate both continuous and load cycling operation of the unit; measure performance and identify loss mechanisms
- Prepare final report documenting results

Accomplishments

- Completed system definition and froze system design
- Completed and froze subsystem design
- Validated the design of most subsystems with component and subsystem testing
- Performed an end-to-end system test of the hot box (including SOFC stacks), warm box, and control system
- Commenced testing of power conditioning system and hydrogen purification subsystem based on pressure swing adsorption (PSA)
- Tested stacks with various electrolytes and electrodes and downselected electrolytes and electrodes for the system
- Commenced balance of plant (BoP) assembly
- Identified site for UTC Fuel Cell Facility
- Specified and commenced modifications to the UTC Fuel Cell Facility

Future Directions

- Verify operation of the 5-kW class SOFC
- Install and operate unit in Chattanooga
- Complete initial phase of testing
- Measure performance under varying load conditions
- Determine efficiency as a hydrogen generator and as an electrical generator
- Determine loss mechanism in unit; evaluate scalability of unit; prepare report

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Introduction

Given the importance attached to fuel cells, much work has been initiated by both government and industry to overcome the technical barriers to widespread introduction of these devices. Notable among these barriers are the cost, durability and fuel infrastructure issues arising in both transportation and stationary power generation by fuel cells. As a result of the efforts to overcome these barriers, a number of fuel cell types have been identified as particularly promising, and some field evaluations of certain types of cells, e.g., the polymer electrolyte membrane fuel cell, are underway. In reviewing the technology, the University of Tennessee at Chattanooga and the City of Chattanooga, through its Enterprise Center, have identified a unique and potentially attractive solid oxide regenerative fuel cell (SORFC) under development by Ion America in Sunnyvale, California. SOFC technology has also been identified by the Department of Energy as a potentially attractive solution and is mentioned in its Fuel Cell Report to Congress (pp 4) [3]. The Department of Energy has included work on this technology in its R&D partnership program.

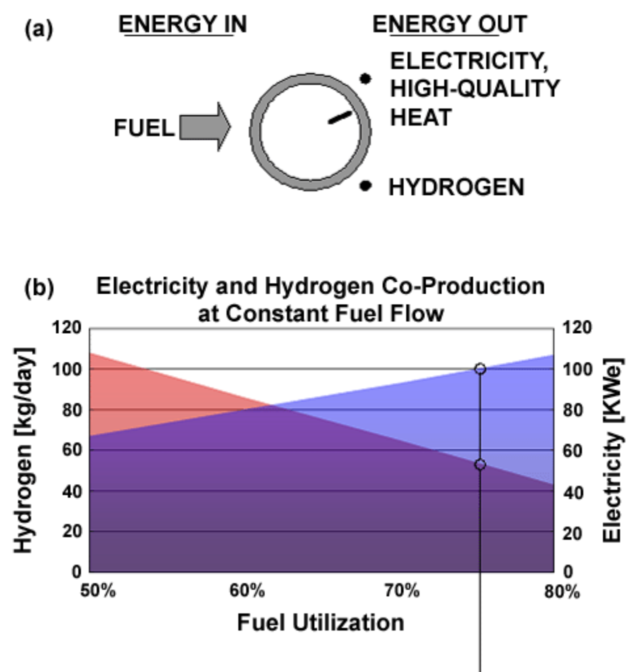
Ion America has developed an SOFC stack and system technology that has successfully demonstrated a continuous 1-kW electrical output capability using a hydrocarbon fuel. SOFCs generate electricity at elevated temperatures, where reforming reactions occur rapidly. When fuel (such as natural gas) is fed 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, as shown in Figure 1 for a fixed fuel flow rate for a 100-kW class SOFC system. The technology is easily scalable from enterprise applications and filling stations to residential size, operates on most hydrocarbon fuels (e.g., natural gas, 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 Ion America.

Approach

Ion America's scientists are constructing and preparing a working prototype of a 5-kW class SOFC based on their proprietary technology. The prototype requires scaling from the 1-kW class unit previously tested in their laboratory up to a 5-kW class unit with the necessary balance of power equipment to enable operation. This will allow the unit to function in a practical application typical of the environment in which it would be used to generate power or supply hydrogen. The second major task is to install the unit at the University of Tennessee at Chattanooga's Applied Technology Center. 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 provide electrical power or deliver hydrogen capable of being stored which could then be used as transportation 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 University of Tennessee at Chattanooga (UTC) has designated a building on campus for the purpose of creating a fuel cell testing laboratory. The building is located adjacent to the UTC SimCenter on the southeast corner of the campus. Under the present cooperative grant, the laboratory has been designed and will be constructed during the months of July and August of 2005. Photographs of the lab



Example: 100 kWe SOFC generator at 75% fuel utilization
A hydrogen production rate of 50 kg/day corresponds to
- a gasoline energy equivalent of 47 gallons/day (equal energy basis)
- support for a fleet of 25 fuel cell vehicles

Figure 1. Electricity and Hydrogen Coproduction as a Function of Fuel Utilization

Figure 2. Photographs of UTC Fuel Cell Testing Laboratory

are shown in Figure 2. A diagram of the lab is shown as Figure 3. The lab will be available to install the Ion America SOFC system when it is delivered to UTC after verification testing at Ion America in September 2005.

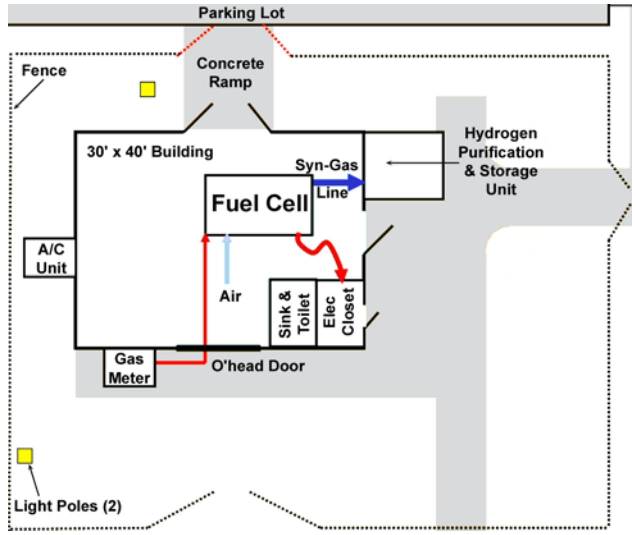


Figure 3. Diagram of UTC Fuel Cell Testing Laboratory

Ion America established detailed design requirements for the SOFC system based on City of Chattanooga and Department of Energy contract requirements. Design requirements include system safety requirements; electrical interface requirements for connecting 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, and is shown in Figure 4. 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 balance of plant (BoP) designs were frozen in order to support parts procurement.

A detailed Bill of Materials was specified and is ~90% complete. Special vendor requirements are

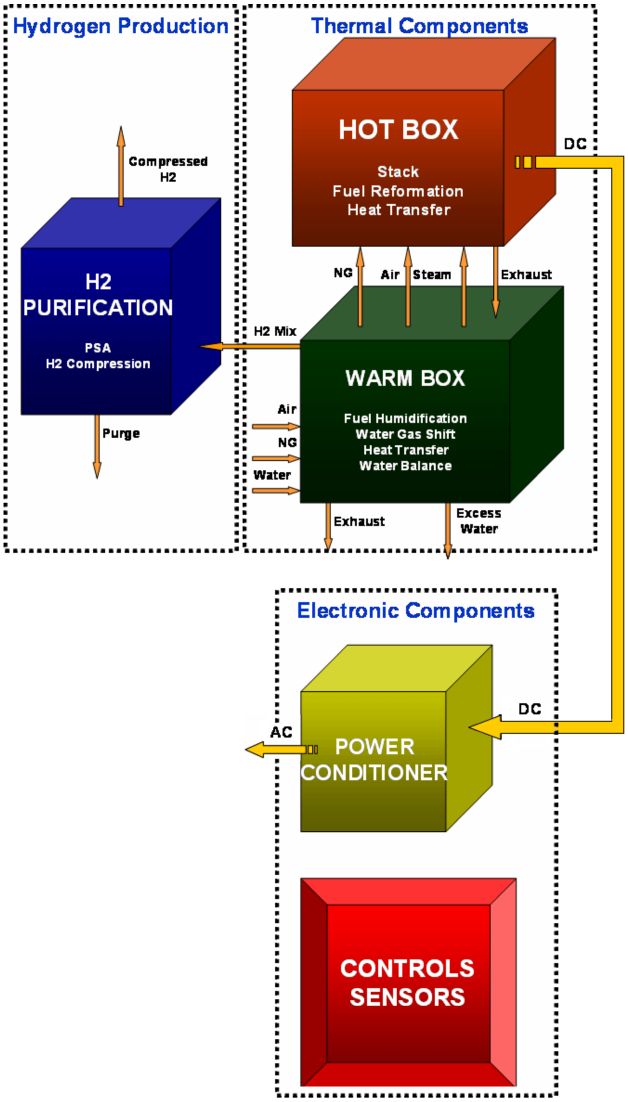


Figure 4. System Architecture

being captured in the form of a Computer-Aided Design package of drawings. Component and subsystem test equipment were set up, and system control software upgrades are occurring while parts procurement proceeds. All required component and subassembly tests for quality control and performance verification are being completed, and system assembly has begun. Subsystem requirements have been defined. SOFC stack and BoP subsystem designs were completed. The initial phase of control software was completed. An initial failure modes effects analysis and a safety analysis of the system were performed. Most subsystem designs were frozen. Most components and subsystem designs have been 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 Ion America. The test validated the hot box and warm box designs. Data from the test was collected and is being used to make several improvements to system components and to control algorithms that are used in the state machine. The revised state machine is being updated and ported to a PC-based control platform.

Hydrogen purification subsystem testing has commenced using a PSA with an online gas analyzer (OGA) to test purity of the product hydrogen. A gas chromatograph is being used to cross check results of the OGA. Testing of the power conditioning system (PCS) has commenced, and an acceptance test has been completed. Future SOFC system tests will include the PCS system.

Conclusions

- Initial operation and testing of a 5-kW class SOFC system has commenced at Ion America.
- The system will be installed and operated at UTC after verification testing is completed at Ion America in September.
- The UTC facility will be ready to accept the Ion America SOFC system when it is shipped.

FY 2005 Publications/Presentations

1. Joe Ferguson, Jim Henry, and Pashu Gopalan, “Chattanooga Fuel Cell Demonstration Project”, U.S. Department of Energy Hydrogen Program, 2005 Annual Merit Review Meeting, Arlington, Virginia, May 23-26 (2005); http://www.hydrogen.energy.gov/pdfs/review05/tvp_2_ferguson.pdf

References

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).

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).

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