Project ID #TVP5

Chattanooga Fuel Cell Demonstration Project

a partnership of

the enterprise center

THE UNIVERSITY of TENNESSEE at CHATTANOOGA

Ion America

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CHATTANOOGA FUEL CELL DEMONSTRATION PROJECT

introduction by

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Overview

Project Status

- Project start: Jul 2004
- 100% Complete

Barriers

- Barriers addressed
  - C. Hydrogen Refueling Infrastructure.
  - F. Centralized Hydrogen Production from Fossil Resources.
  - I. Hydrogen and Electricity Coproduction.

Budget

- Total project funding
  - DOE Share: $2,485,250
  - Contractor Share: $230,217
- $2,485,250 for FY05
- $0 received in FY06

Partners

- The Enterprise Center
- The University of Tennessee at Chattanooga
- Ion America

Objectives

- Develop and demonstrate a prototype 5 kW grid parallel, solid oxide fuel cell (SOFC) system that coproduces hydrogen

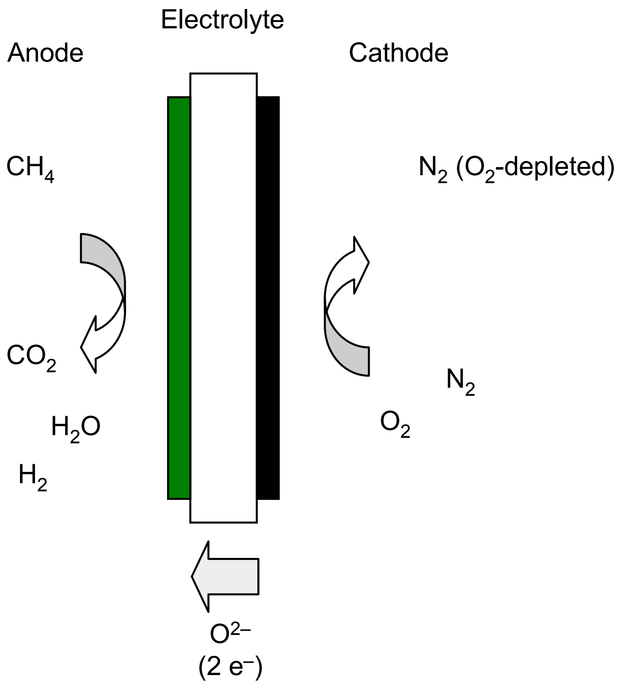
Relevance to the Hydrogen Program:

- Technology validation of a pathway to help build a hydrogen economy without new infrastructure
  - Equipment coproduces electricity and hydrogen
  - System operates with high capacity factor even when the demand for hydrogen is relatively low

Approach

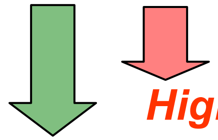
- The Enterprise Center (Chattanooga, TN) facilitated efforts between Ion America (Moffett Field, CA), the City of Chattanooga, and The University of Tennessee at Chattanooga (UT-Chattanooga) to work cooperatively to develop a 5 kW class, grid parallel, SOFC system
- UT-Chattanooga Alternative Energy Lab placed the prototype into a regimen as a part of field demonstration and to test the overall functionality and reliability of the system
- The installation was configured to simultaneously and efficiently produce hydrogen and electricity from commercially available natural gas feed stream
- This ability to produce both hydrogen and electricity at the point of use provides an early and safe pathway to hydrogen production without the need for transportation and distribution infrastructure

SOFC Concept



Overall reaction using methane fuel:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 8e^- +$ Heat



High Quality Heat → Cooling

Premium Power

- Cheapest alternative among fuel cells; competitive with grid power and other distributed solutions
  - Inexpensive materials
  - High volume low cost manufacturing processes
- Extremely high reliability
  - No moving parts
  - Solid state energy conversion
- High efficiency energy generation capability (45-60% net AC)
- High temperature (800-900°C) Operation affords
  - Fast chemical kinetics
  - Very high quality waste heat
  - High cogeneration efficiency (80-90%)
- Great fuel flexibility
- Environmentally very clean at no additional cost – 50-60% reduction in GHG emissions, near-zero SO_x and NO_x

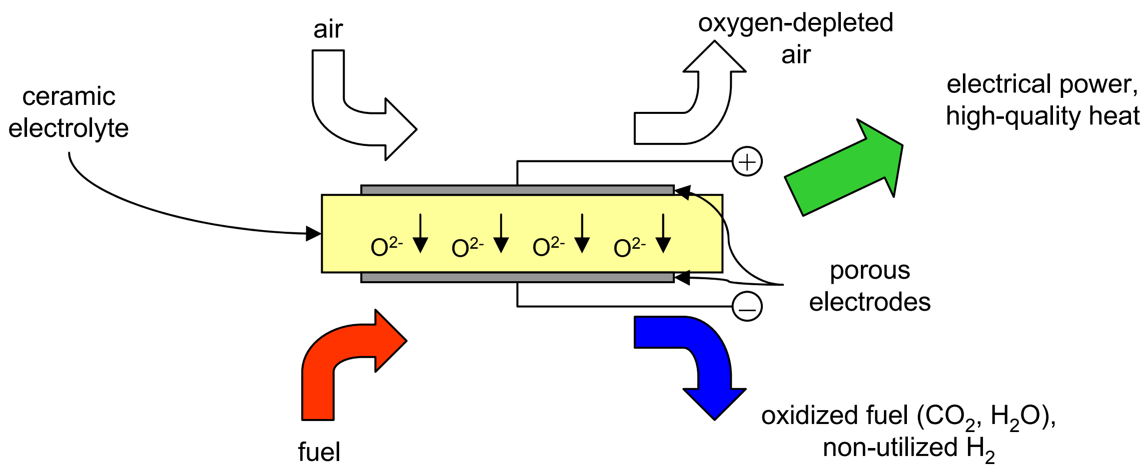
SOFC Coproduction of Hydrogen

- Solid oxide fuel cells (SOFC) coproduce hydrogen during electrical power generation
- Within an SOFC stack, we have

steam methane reforming:	$CH_4 + H_2O \rightarrow CO + 3H_2$
water-gas shift:	$CO + H_2O \rightarrow CO_2 + H_2$
CO oxidation:	$CO + {}^1/_2O_2 \rightarrow CO_2$ + electricity + heat
hydrogen oxidation:	$H_2 + {}^1/_2O_2 \rightarrow H_2O$ + electricity + heat
partial oxidation:	$CH_4 + {}^1/_2O_2 \rightarrow CO + 2H_2$ + electricity + heat

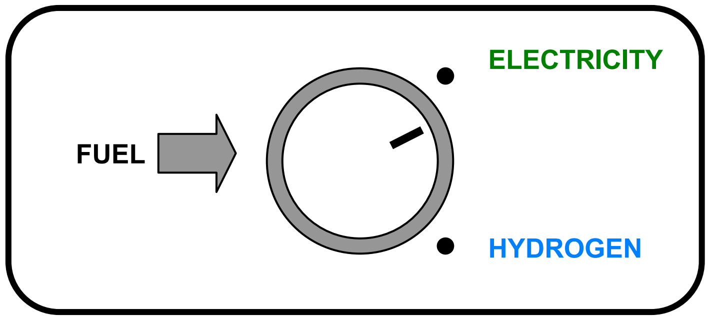
Not all hydrogen produced is utilized for power generation

Utilization can be varied from 50% – 80%



Electricity & Hydrogen Coproduction

Rate of electricity and hydrogen production as a function of fuel (methane) utilization, total fuel flow held constant



- Each SOFC can simultaneously produce hydrogen and electricity.
- Since H2 can be stored, more can be produced at night when electricity demand falls.
- A 5 kW SOFC could produce 5 kg H_2/ day, which corresponds to a GGE of 5 gallons / day (equal energy basis)--enough for daily complete refill of a fuel cell car.

Project timelines

July 2004	**Proposed** project start date
February 2005	**Actual** signed contract and release of funds
February 2005	Requirements established and system specification defined
August 2005	Subsystem design and Test tasks completed
October 2005	Stack and Balance of Plant (BOP) assembly tasks completed
December 2005	System logged 707 hours of operation on December 19, 2005. Fuel Cell system completed 779 hours of operation at Ion America's Sunnyvale location before getting shipped to UT-Chattanooga.
January 2006	Fuel cell system shipped to UT-Chattanooga on January 13, 2006
February 2006	On February 4, 2006 the system was started at UT-Chattanooga. Fuel Cell was officially inaugurated by Congressman Zach Wamp on February 16, 2006
April 2006	System is still operational with 98% system availability with 2255* hours of operation. * Includes 779 hours from Sunnyvale operation

Accomplishments

- 1st completely autonomous planar SOFC system monitored remotely from Sunnyvale, CA
- 1st known completely autonomous “state machine” mode operation of SOFC system
- 1st known demonstration of planar SOFC fuel cell system for electricity and H2 cogeneration
- 1st planar SOFC system to successfully demonstrate hydrogen recycle
- System handled grid failure during operation in Sunnyvale
- The SOFC system gets its fuel from city natural gas supply

Accomplishments

System performance

System Delivery	17 Jan 2006
System Start-up	05 Feb 2006
Total operating time	1,476 hr / 2,255* hr *including 779 hours Sunnyvale operation, as of April 13, 2006
Range of Power output	3.0 – 5.1kW
Electrical Energy Produced	4,476 kW-hr / 6,522* kW-hr *including 2,046 kW-hr Sunnyvale operation, as of April 13, 2006
Power Generation Availability	98%

Accomplishments

Hydrogen production using Pressure Swing Adsorption (PSA)

- Demonstrated controls strategy for operating PSA with 5kW SOFC system
- PSA purified anode exhaust to produce hydrogen from exhaust carrying CO, CO_2, nitrogen, hydrogen and moisture.
- Achieved hydrogen purity with <10 ppm CO (lower detectability limit of online gas analyzer)
- Achieved hydrogen purification yields of up to 90%

Key Metrics

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%*

Shipping/Receiving/Installing Fuel Cell

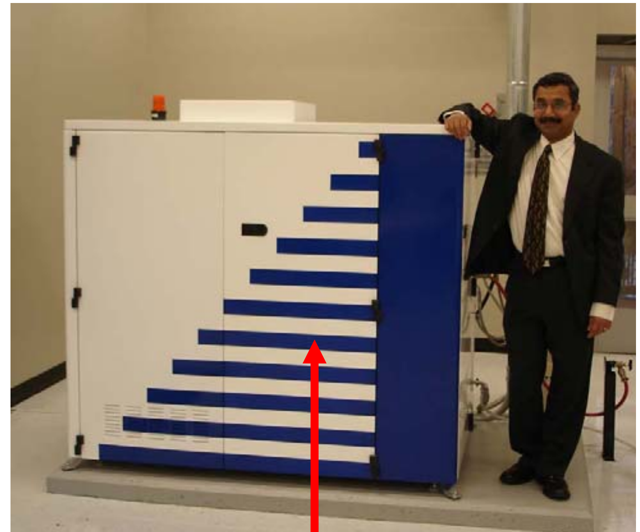
Hotbox getting ready for crating

Trailer arriving at Fuel Cell lab UT-Chattanooga

Unloading Fuel Cell system components into the Alternative Energy Lab

Loading fuel cell for its journey to UT-Chattanooga

Fuel cell inauguration



5kW system installed and operational on 05 Feb 2006

Hydrogen purifier

Alternative Energy Lab at UT-Chattanooga

System inaugurated by Congressman Zach Wamp on 17 Feb 2006

Summary

- Successfully demonstrated a grid-parallel 5kW prototype SOFC system for electricity and hydrogen cogeneration
- Demonstrated a technology pathway for hydrogen fueling without the need for transportation and distribution infrastructure
- Successful collaboration between The Enterprise Center, UT-Chattanooga and IonAmerica validates the synergy between governmental, academic and start-up business

Responses to Previous Year Reviewers' comments

- Does not seem likely that the large amount of work proposed (and needed) can be completed in next 4 months unless rate of progress on project is accelerated.
  - Project completed without any additional funds for DOE
- While project is well funded for FY05, progress to date seems slow. Seems questionable whether system can be built, tested, and validated within remaining 4 months of project.
  - Project successfully completed. Delays in early stages attributed to contractual and funding hurdles to initiate work
- This approach is very high risk and is not likely to achieve a 5 kW system as planned.
  - Objective successfully demonstrated
- There is no evidence of research to advance the technology, but rather a very expensive and risky build and test activity.
  - First known demonstration of SOFC for electricity and H_2 cogeneration
  - First known completely autonomous "state machine" mode operation of SOFC system