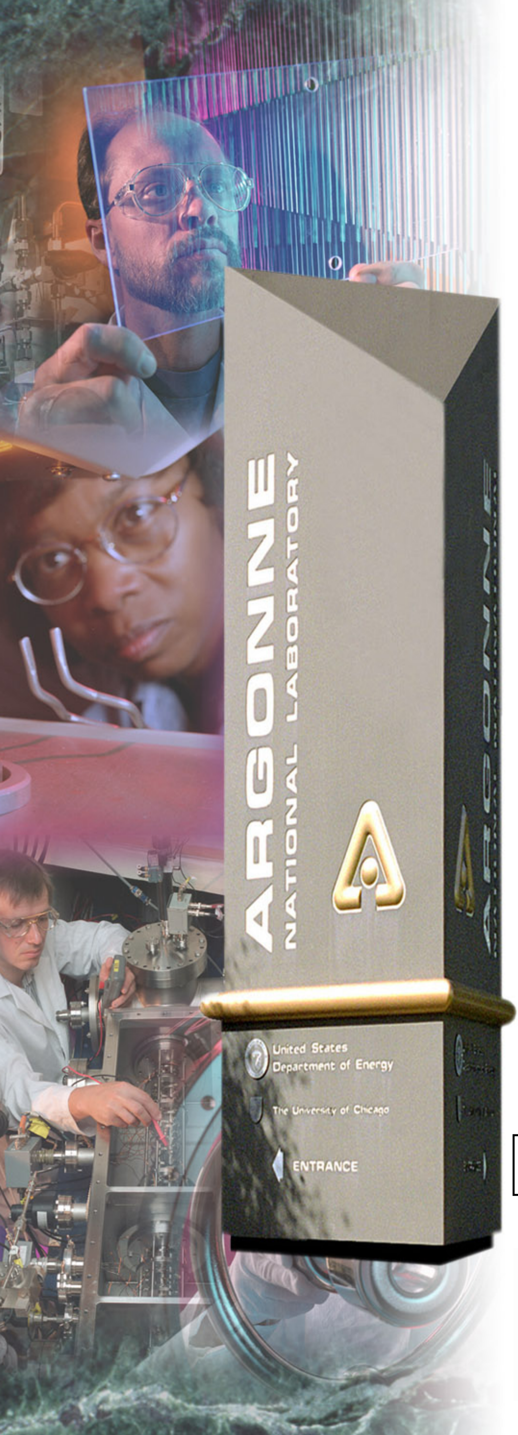

Bipolar Plate-Supported Solid Oxide Fuel Cell "TuffCell"

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Chemical Engineering Division

2005 DOE Hydrogen Program Review

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FC36

U.S. Department of Energy
Energy Efficiency
and Renewable Energy

Project Overview

Time line:

- Start date: October 2001
- End date: open
- Percent complete: 50%

Budget:

- Funding FY02-05: $800k
- FY04: $250k
- FY05: $250k

Barriers addressed:

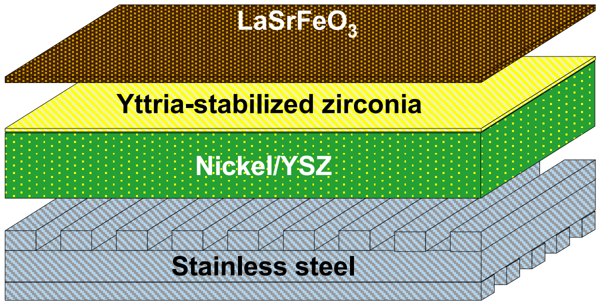
- Durability
- Cost
- Electrode performance
- Startup time/Transient operation

Collaborations:

- Korea Advanced Institute of Science and Technology: Professor Joong-Myeon Bae
- Motorola
- Idaho National Laboratory

Project Objectives

- **To develop a new solid oxide fuel cell (SOFC) concept for auxiliary power units and portable power applications**

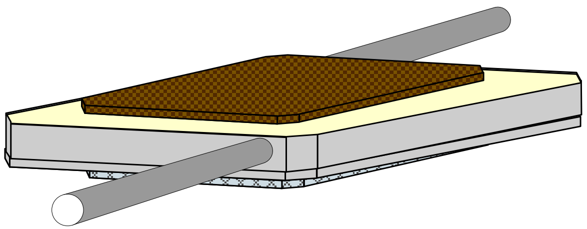


Anode-supported SOFC

- **Address the following SOFC issues:**
  - *Stack sealing*
  - *Startup time*
  - *Durability to temperature cycling*
  - *Materials and manufacturing cost*

Technical approach addresses SOFC issues

- Support cell on metallic bipolar plate to improve durability, cyclability, and shock-resistance
- Minimize content of expensive ceramics (anode, electrolyte, and cathode)
- Fabricate cell components using powder metallurgy techniques
- Eliminate manufacturing steps to reduce cost
- Eliminate sealing issue by developing self-sealed design



Self-Sealed Metallic Bipolar Plate Supported SOFC

Progress vs. FY05 Milestones

- **Complete Cost Analysis for TuffCell Stacks (2/05)**

  Estimated Costs:

  - Materials - $69/kW
  - Manufacturing (Equipment, Personnel, Operating) - $134/kW
  - Total: $203/kW

- **Fabricate and test a three-cell stack (6/05)**
  - 2-Cell stack was built on 12/04. Achieved 2 volts OCV in 3% H_2 bal. He.
  - Three single cell units were tested in 1/05.
  - 3-Cell stack built 3/05. Achieved 3 volts OCV in 50% H_2, 3%H_2O, bal. He

- **Complete start-up time and cyclability tests (9/05)**
  - Single cell stack units, cyclability tests have begun – Achieved 4 cycles at 10°/min heating rates.

Basis of TuffCell and Anode-supported SOFC cost comparison

- **Previous Excel spreadsheet was written to calculate the materials and manufacturing costs of conventional Anode-supported SOFC stacks.**
- **The spreadsheet was updated and modified to calculate materials and manufacturing costs of TuffCell stacks.**
- **12 worksheets of calculations for each SOFC type.**
- **Basis:**
  - Stack specifications: *5 kW, 42 V, 14x14 cm^2 active, 60 cells*
  - Manufacturing:
    - *500,000 stacks/year*
    - *Conventional ceramic processing methods and equipment*
    - *Plant operation: 24h/day,7day/wk, 49wk/yr*
  - Raw materials costs: *determined by direct contact with vendors, web-based and published prices*

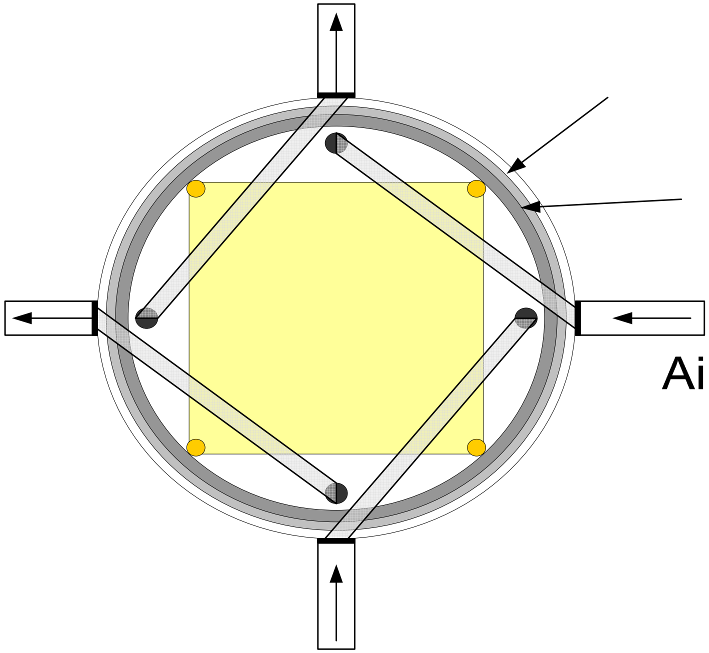
TuffCell provides significant cost savings over Anode-supported SOFC

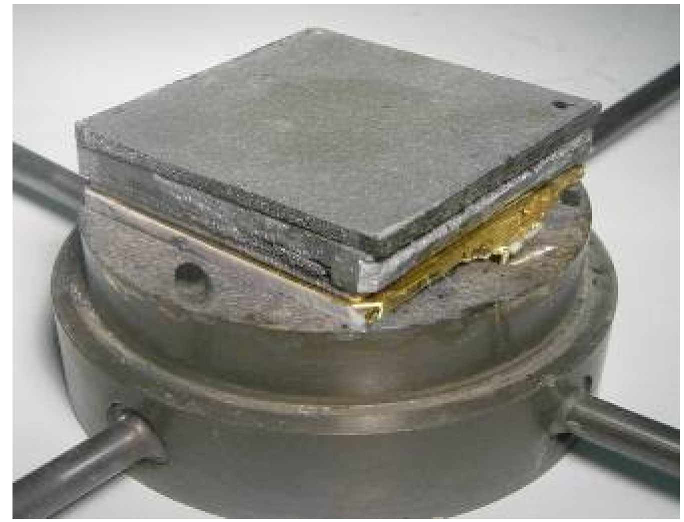
- **Cost of building SOFC Stacks - $/kWe (% total cost)**

	Materials	Equipment	Personnel	Operating Cost	Total
TuffCell	$69 (34%)	$50 (24%)	$70 (35%)	$14 (7%)	$203
Anode-Supported SOFC	$99 (36%)	$52 (19%)	$60 (22%)	$63 (23%)	$274

26% cost savings due to reduction of materials and operating costs

Last year's stack depended on conventional sealing methods

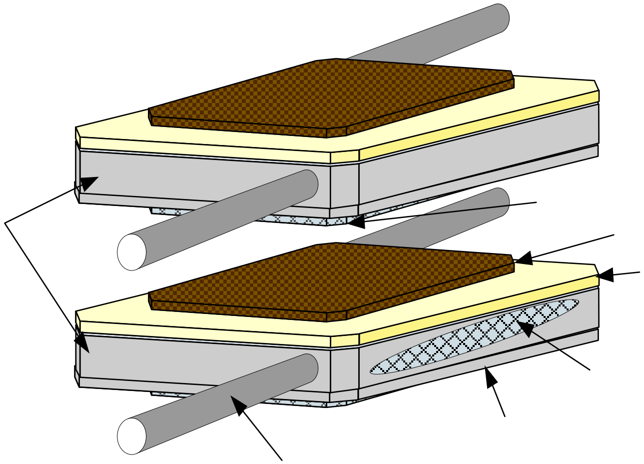




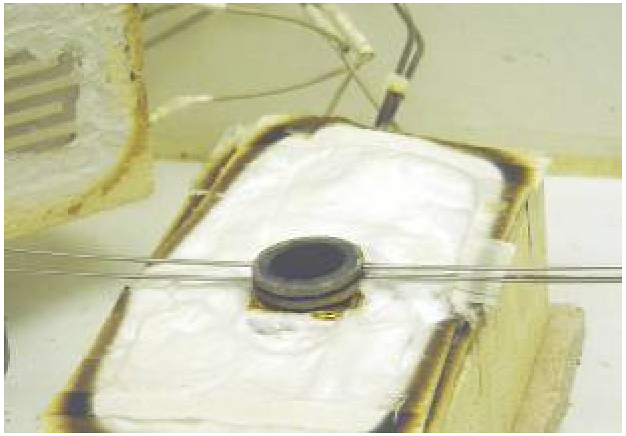
- **Gasket seals depended on flat cells**
- **Corner seals difficult to achieve**

New seal concept simplifies stack building

- **Edges of anode chamber sealed with metal**
- **Feed and exit tubes brazed into edge of stack unit**
- **Cells stack together as easily as batteries in a flashlight**

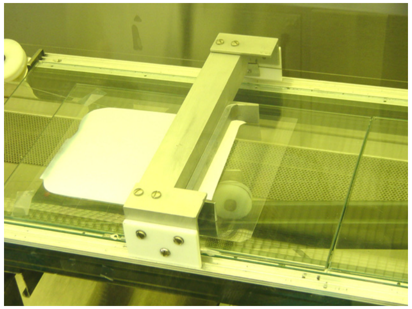


Circular geometry

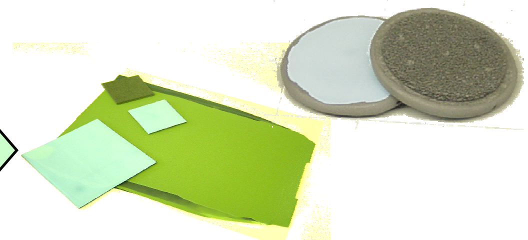


Stack test

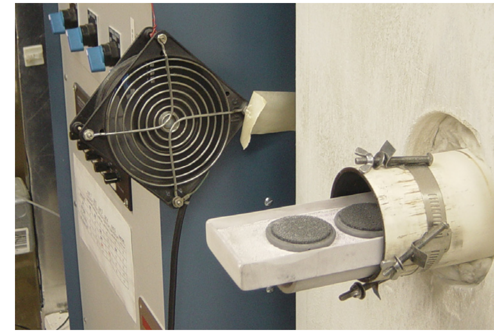
TuffCell design and fabrication process address SOFC shortcomings



Tape cast cell layers
(w/o cathode)



Laminate and cut
tapes & foam



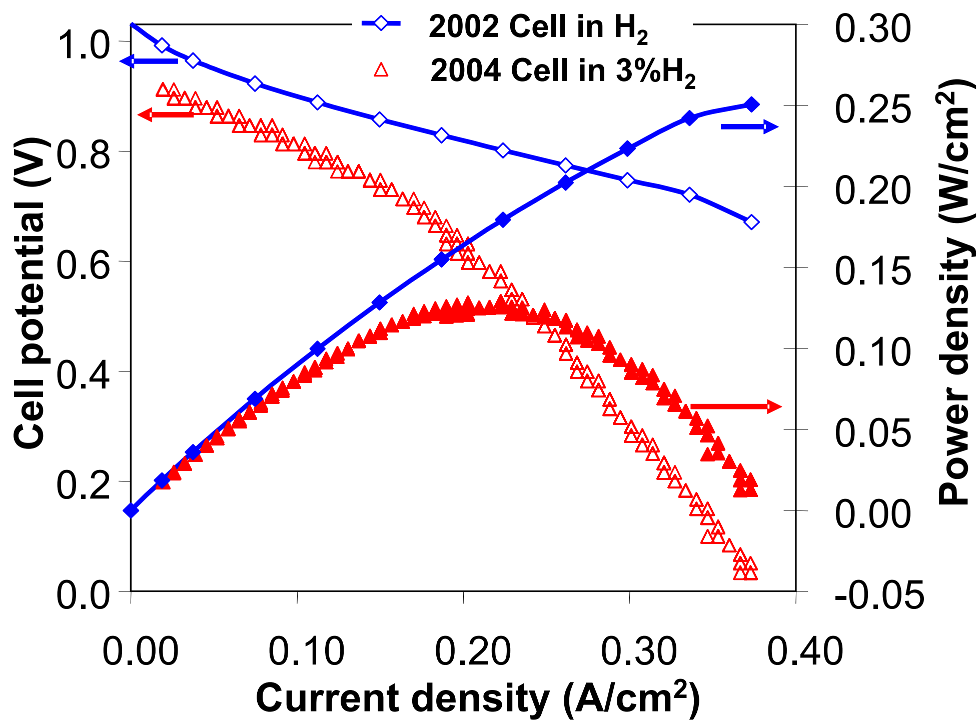
Sinter in single high-temperature process

Braze gas tubes
Slurry-coat cathode

- Thin layers of expensive ceramics
- Brittle ceramics bonded to tough metallic layers
- Single, programmed high temperature process
- Single electrical contact plane between cells
- Self-sealed fuel chamber *(NEW)*

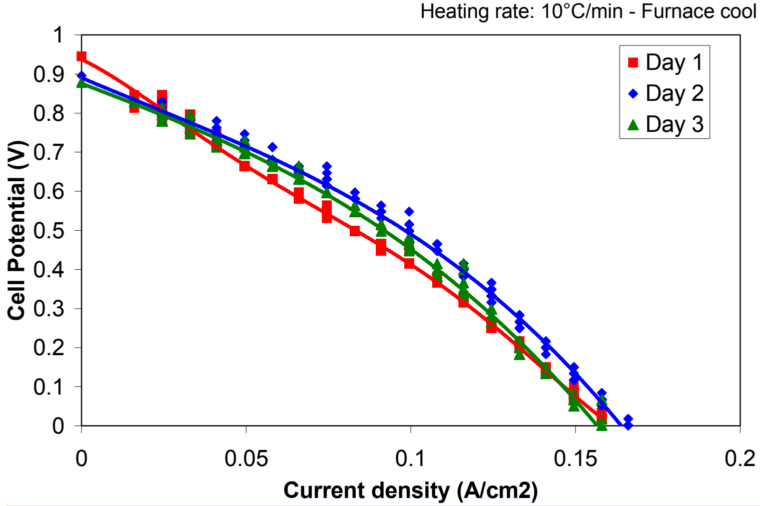
New sealed design test shows comparable performance to previous TuffCell tests

- **New design: 0.14 mA/cm² @ 0.76 V**
- **Previous test: 0.26 mA/cm² @ 0.77 V**
- **Two-cell stack achieved 2.0 volt OCV**



Thermal Cyclability of Single Cell TC-15

800°C 3.5%H2, 3%H2O / air
Heating rate: 10°C/min - Furnace cool

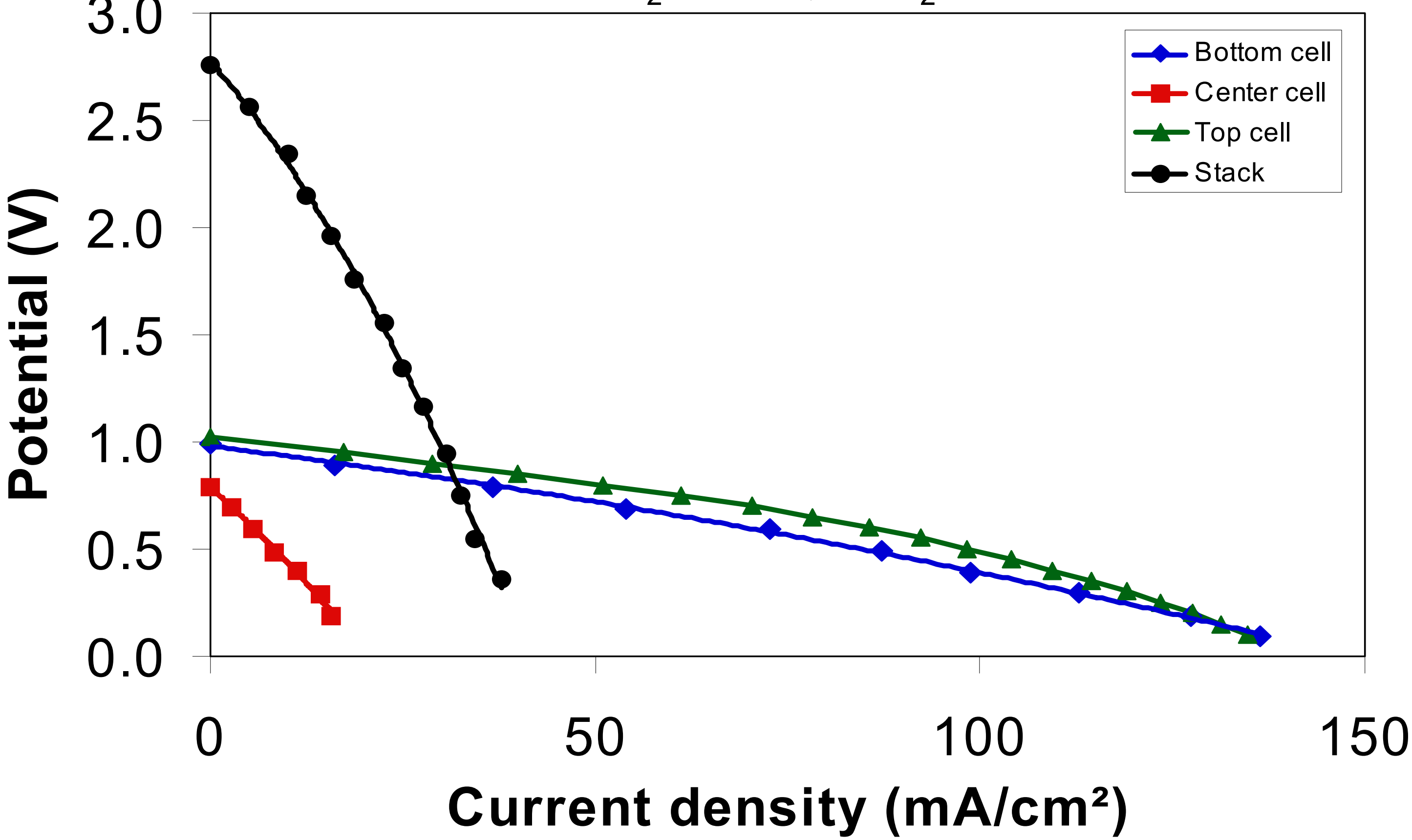


- **Thermal cyclability tests have begun with single cell stack units**

First 3-cell stack:

- Stack reached open circuit potential
- Stack polarization test :

50% H_2/He fuel, 3%H_2O – air at 800°C



Reviewers' comments from FY '04 meeting

- **Comment 1: "Need successful scale-up / stack test to attract additional non-DOE investment."**
  - The new seal concept has simplified stack building. Single cell and multi-cell stacks are presently being fabricated, tested & improved.
- **Comment 2: "Focus on improving power density."**
  - The co-firing process produces a reduced Ni anode. This makes it more difficult to control the anode microstructure to produce high power densities. As the overall sintering process is becoming finalized, more attention is being paid to optimizing the anode microstructure and performance.
- **Comment 3: "This concept could revolutionize SOFC design."**
  - The metal supported SOFC concept is beginning to catch on with SOFC developers.
  - The new seal concept overcomes major sealing hurdles in building SOFC stacks.

Future Plans – FY '06 and Beyond

- **<u>Improve single cell performance</u>**
- **Demonstrate stack thermal cyclability with <30 min startup time**
- **Provide sample cells to**
  - Motorola for low power cell tests
  - Idaho National Laboratory for High Temperature Steam Electrolysis
- **Demonstrate long term stack/cell performance tests**
- **Transfer technology for scale-up and system integration**

Acknowledgments

- **Funding from the U.S. Department of Energy, Energy Efficiency, Renewable Energy: Hydrogen, Fuel Cells & Infrastructure Technologies Program is gratefully acknowledged**

- **Nancy Garland, DOE Technology Development Manager**

Publications and Presentations

- J. D. Carter, R. Kumar, D. Myers, and J. Ralph, in 2004 Fuel Cell Seminar Poster and Abstract (M. Binder ed.), Courtesy Associates, San Antonio, TX, 2004.
- J. D. Carter, T. A. Cruse, J. M. Ralph, and D. J. Myers, in 2003 International Conference on Powder Metallurgy and Particulate Materials (R. Lawcock and M. Wright, eds.), Metal Powder Industries Federation, Las Vegas, Nevada, 2003, p. 101.
- J. D. Carter, J.-M. Bae, T. A. Cruse, J. M. Ralph, R. Kumar, and M. Krumpelt, Solid oxide fuel cell with enhanced mechanical and electrical properties, U.S. Patent Application No. US2003/0232230 A1 (Dec. 18, 2003).
- J. D. Carter, T. A. Cruse, J.-M. Bae, J. M. Ralph, D. J. Myers, R. Kumar, and M. Krumpelt, in 2002 MRS Fall Meeting, Vol. 756 (P. Knauth, J.-M. Tarascon, E. Traversa, and H. L. Tuller, eds.), Materials Research Society, Boston, Massachusetts, 2002, p. 545.
- J. D. Carter, J. M. Ralph, J.-M. Bae, T. A. Cruse, C. Rossignol, M. Krumpelt, and R. Kumar, in 2002 Fuel Cell Seminar (M. Williams and J. Milliken, eds.), Courtesy Associates, Palm Springs, CA, 2002, p. 874.

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

The greatest hydrogen hazard in this project is the possibility forming a flammable (4%< %H_2 < 75%, by volume) or an explosive (18%< %H_2 < 59%, by volume) mixture with air in a closed volume at ignition temperature (>500°C). This could happen in two instances within the project. The SOFC is sintered in hydrogen in a closed tube furnace at temperatures ranging from 800°C to 1400°C. Also, during cell or stack testing, hydrogen flows through a closed anode chamber in the TuffCell. In either case, if hydrogen is introduced into the closed chamber at the concentrations listed above without purging the air, ignition could occur.*

**W. F. Baade, U. N. Parekh, and V. S. Raman, in Kirk-Othmer Encyclopedia of Chemical Technology, 2001, John Wiley & Sons, Inc., http://www.mrw.interscience.wiley.com/kirk, Accessed in 2005*

Hydrogen Safety

Our approach to deal with this hazard is:

When hydrogen concentrations greater than 4 vol% are introduced into our system, it is first purged with nitrogen, helium, argon, or a non-flammable regen gas (<4% H_2/ He) for sufficient time to remove oxygen out of the chamber down to parts per thousand levels. The sintering furnaces are tested for purge times using a residual gas analyzer, and automatic programs were set to flow nitrogen for the required time. In the cell and stack test experiments, the cells are heated with regen gas flowing through the anode chamber and the hydrogen is introduced if the theoretical open circuit potential is achieved. Both experiments are contained within fume hoods with high exhaust rates that prevent the accumulation of hydrogen within the hood.