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ADVANCED MATERIALS & ELECTROCHEMICAL TECHNOLOGIES

Large Area Cell for Hybrid Solid Oxide Fuel Cell Hydrogen Co-Generation Process

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Ceramatec, Inc.

May 24, 2005

This presentation does not contain any proprietary or confidential information

Project ID #PDP12

Overview

Timeline

- Project start date
  - May 2005
- Project end date
  - May 2007
- Percent complete: 0%

Budget

- Total project funding
  - DOE share
  - Contractor share
- No FY04 Funding
- Funding for FY05
  - None YTD

Barriers Addressed

- H_2 from natural gas or renewable liquids
  - A – Capital Cost
  - E – CO_2 emissions
- H_2 generation by water electrolysis
  - G – Capital Cost
  - H – System Efficiency
  - I – Grid Electricity Emissions
  - J – Renewable Integration
  - K – Electricity Cost

Partners

- Ceramatec, Inc.
- Hoeganaes
- Idaho National Laboratory
- University of Washington

Project Objectives

Project Objectives	Challenges	Overall Concept	Specific Activity	Team Members
* Low cost hydrogen generation * Cogeneration of hydrogen and electricity	* Thermal Management (operational limit) * Cell size (fabrication limit)	* Physical, chemical and thermal integration of fuel cell/electrolysis functions – allows operation at near thermal neutral condition * Large area cell fabrication by the use of porous metal substrate	Substrate alloy selection / fabrication	Ceramatec/ Hoeganaes
			Layer Deposition - Thermal Spray	INEEL
			Slurry coating and constrained sintering	Ceramatec/ U of WA
			Materials Selection Stack Test Process Model /Data Analysis	Ceramatec
			Cost Analysis	All

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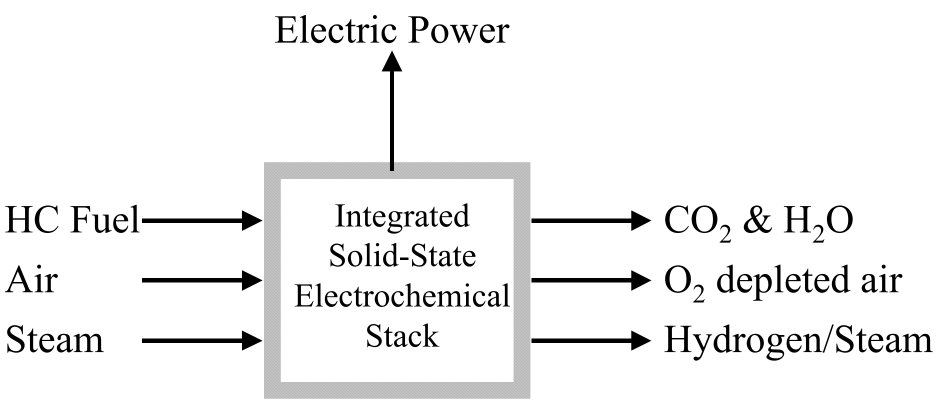
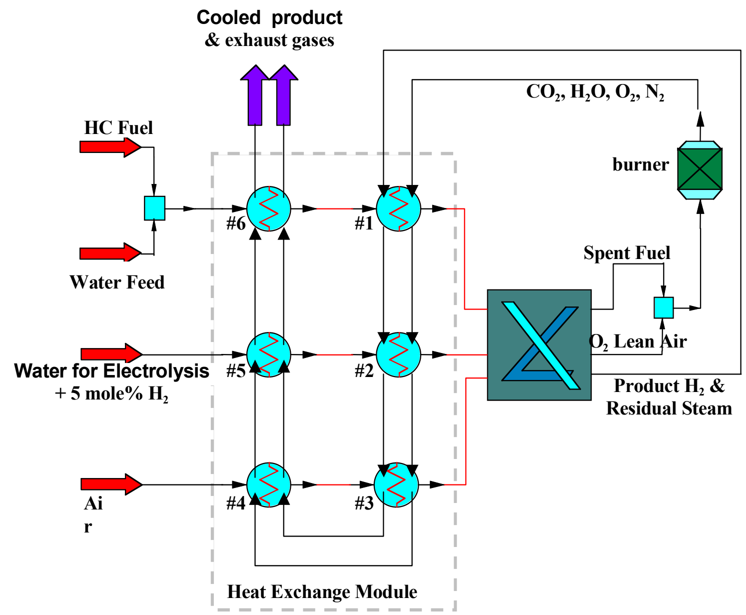
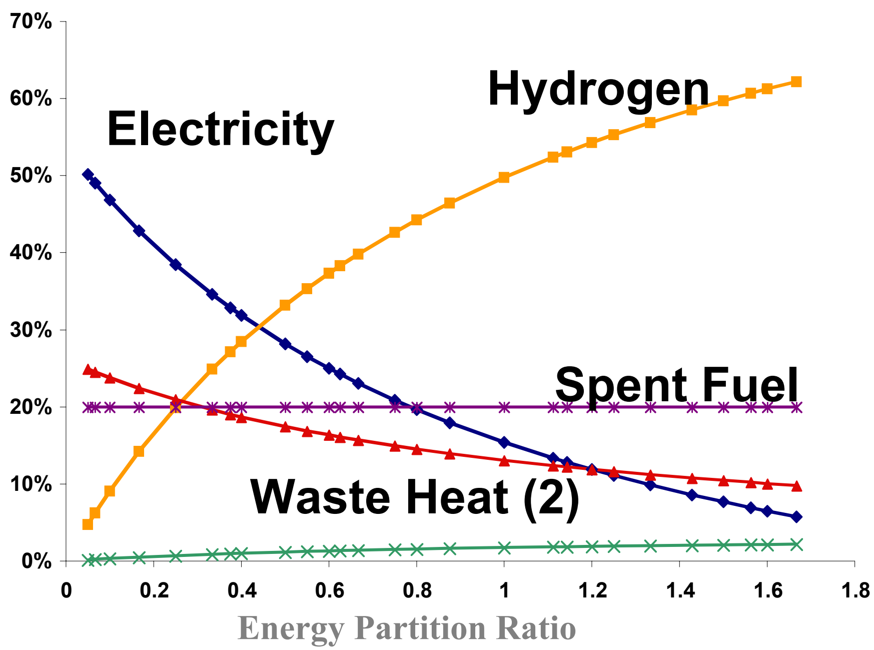
Process Objectives

Process objectives	Hybrid design features	Key benefits
Direct PEM grade H_2	Steam electrolysis	No shift or CO cleanup required
Electric power	Interleaved SOFC cells	**Co-generation of hydrogen and electricity**
Eliminate POx penalty	Electrochemical process	High Faraday and Nernst efficiencies
Thermal management	Thermal integration	Temperature/resistance uniformity, reduced thermal stress and air preheat duty, **large area cells**
Design flexibility	Cell function ratio	Selective energy partitioning, H_2:electric power ratio
Carbon sequestration	Nitrogen free reformate	Non-condensable free exhaust

Technical Approach







- Extension of NASA SBIR
- Leverage SOFC Development
- Integrated Hybrid Stack
- Continuous H_2 Cogeneration
- Natural Gas Fueled
- Optimized Thermal Management
  - Enables Large Area Cell

Technical Accomplishments/ Progress

- Demonstrated >100 nlph hydrogen production in stack at INL (DOE NE NHI program)
- Operated advanced high performance cathode supported LSGM electrolyte in electrolysis mode (DOE FE SBIR)
- Addressed seal accelerated corrosion issue under electrolysis conditions (DOE Membrane Seal SBIR)
- Characterized metal interconnect scale growth in dual (reducing/oxidizing) atmosphere conditions (DOE SECA CTP project)

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Future Work

- Begin project per proposed work scope
  - Review objectives with team members
  - Produce powder metal heats
  - Form sintered porous metal plate substrate
  - Pre-treat PM substrate for low resistance scale
  - Develop thermal spray deposition of cell layers
  - Develop thermal crack healing for gas tight membrane
  - Begin electrochemical characterization of PM supported cells in electrolysis mode

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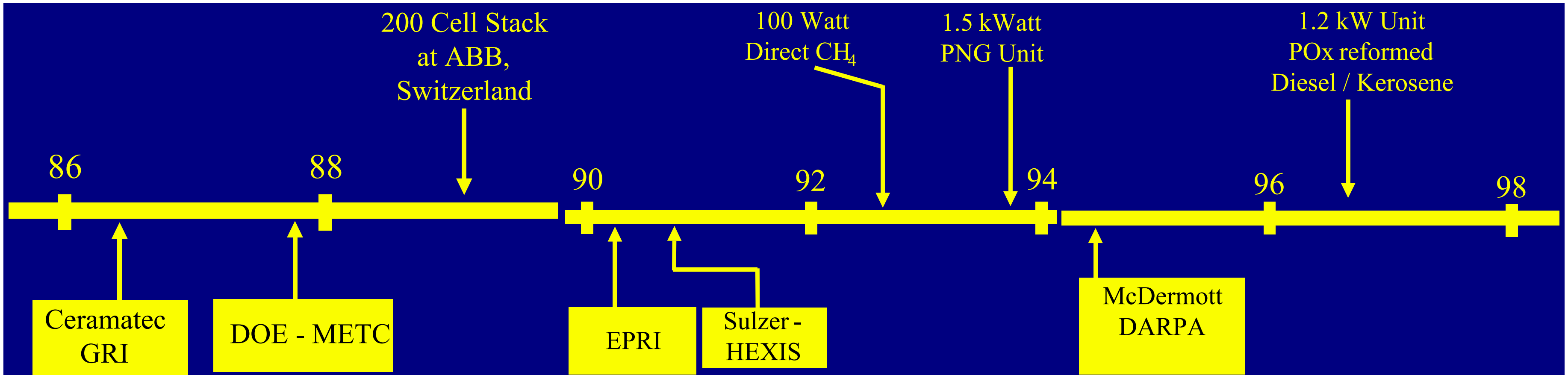
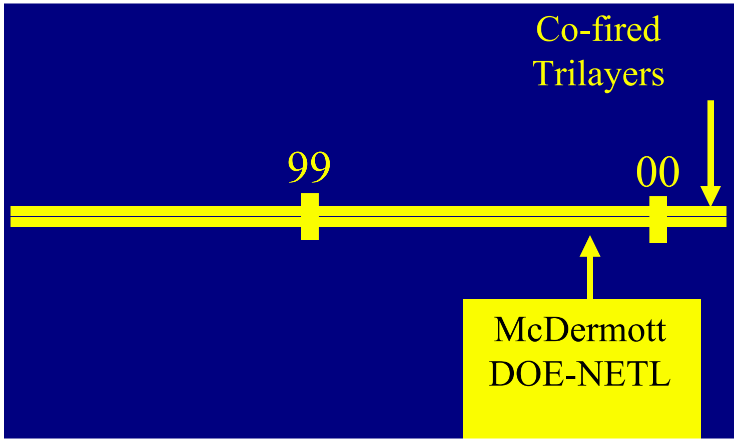
SOFC Electrolysis Technology Fit

- High temperature Solid Oxide Fuel Cells (SOFC)
  - Generation of electricity and heat
  - Hydrogen or hydrocarbon reformate fuels
- High Temperature Electrolysis (HTE)
  - Reversed SOFC current generates hydrogen from steam
- Commonality of SOFC & HTE
  - Material sets, fabrication methods, stack design, modeling
  - Performance
    - Seamless transition between operating modes
- Multi-mode technology for transition to hydrogen economy
    - Transitional technology
      - Distributed power generation using hydrocarbon fuels
    - End point technology
      - Hydrogen fuel production from renewable energy or nuclear energy

Ceramatec SOFC History

- 19 years of SOFC R&D





SBIR & SECA Contracts

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Recent SOFC-derived Contracts

- **DOE-FE - SBIR**

– High Temp. Heat Exchanger	Phase II	current
– Hydrogen Separation Membrane	Phase II	current
– Intermediate Temp. SOFC	Phase II	Aug 04 end
– SOFC Insulation Material	Phase II	awarded
– Glass composite seals	Phase I	awarded
– Improved Cathodes for SOFC	Phase I	complete
– Pre-ceramic polymer seal for SOFC	Phase I	complete

- **DOE-FE (non-SBIR)**

– Metal Interconnects for SOFC (SECA)	Phase II	current
Initial work done under an SBIR-Phase I		
– SECA industrial team participation	Phase I	4 Years
Cummins-SOFCo team subcontract		

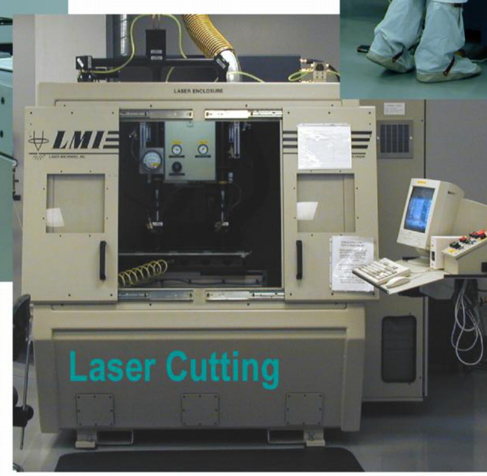
Recent SOFC-related Contracts

- **NASA - SBIR**
  - Integrated SOFC System Phase II current
    - Electrolysis/SOFC hybrid cogeneration of H_2 & Power
- **Air Force SBIR**
  - Integration of JP-8/diesel reformer and SOFC Phase II awarded
- **DOE-FE SBIR**
  - Environmental Barrier Coating Phase II

    Application of metal interconnect technology from Phase I SBIR and Phase I SECA

Investments in R&D Infrastructure

- 90,000 ft^2 Manufacturing and R&D Facility
- Start to Finish Ceramic Processing
  - Lab-Scale to Pilot-Scale to Production
  - Class 10,000 Clean room
- Well equipped Materials R&D Characterization Laboratory



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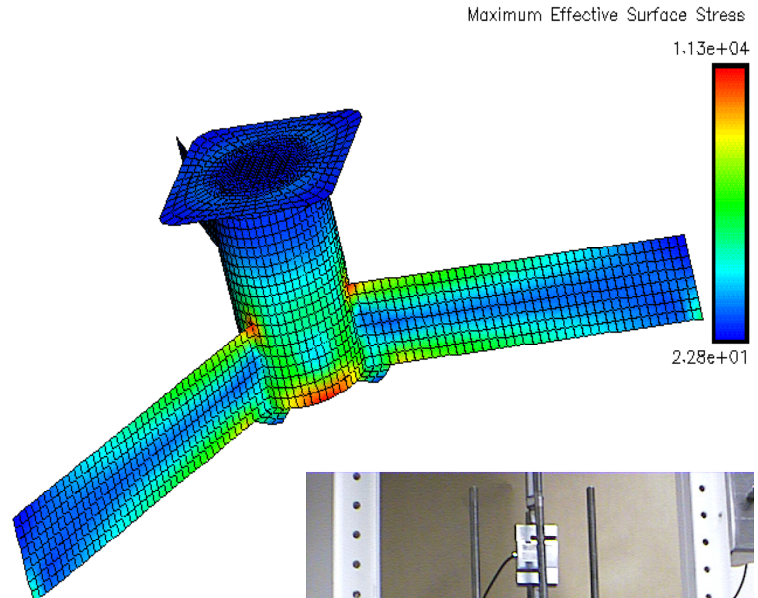
Investments in Background Technology

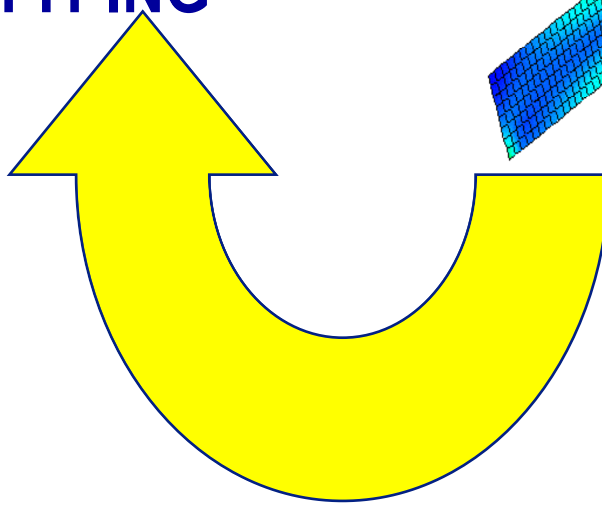
- Nearly $100 million invested over 20 years
  - DOE & DOD funding
  - Utility R&D Groups
    - EPRI & GRI
  - Industry consortium
    - NorCell - Norsk Hydro, Saga Petroleum, Elkem, NTNF
  - Ceramatec partners
    - McDermott/SOFCo
    - Air Products
  - Ceramatec
- Technology and facilities available to this project.

Ceramatec's Core Activities – Integrated Engineering, Processing and Prototyping

DESIGN & ENGINEERING



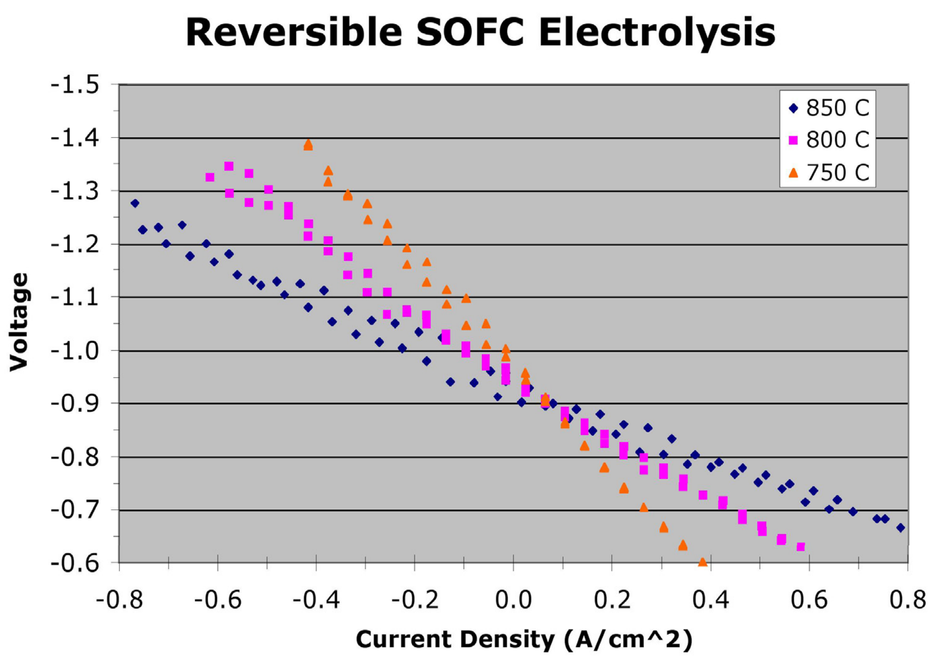
DESIGN VALIDATION & PROTOTYPING



PROCESSING DEVELOPMENT
(Lab to Pilot Production)

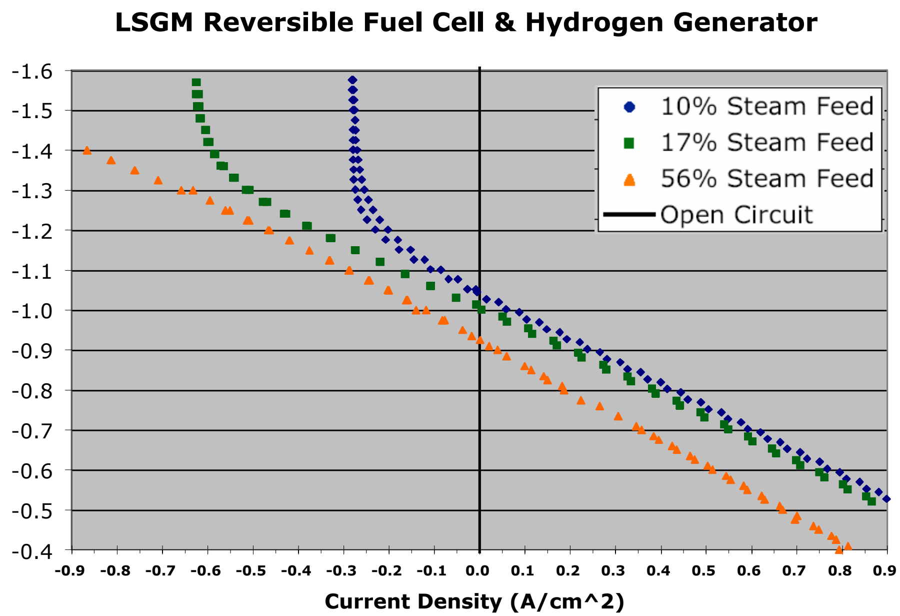
TESTING

SOFC Performance in Reversible Mode



Performance symmetry about OCV not changed by operating temperature

Performance symmetry is limited by reactant availability



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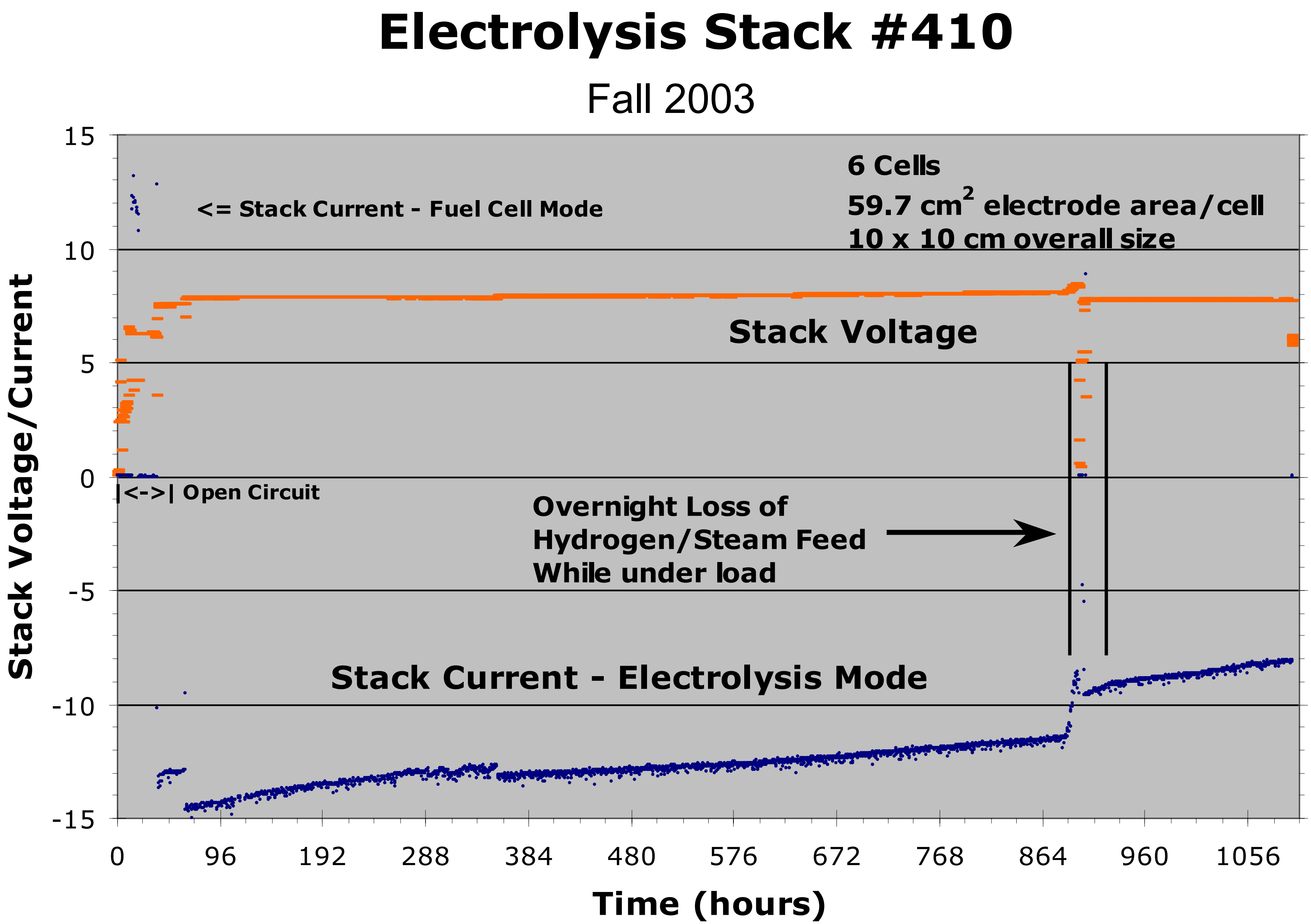
Inaugural INL Project Stack Test



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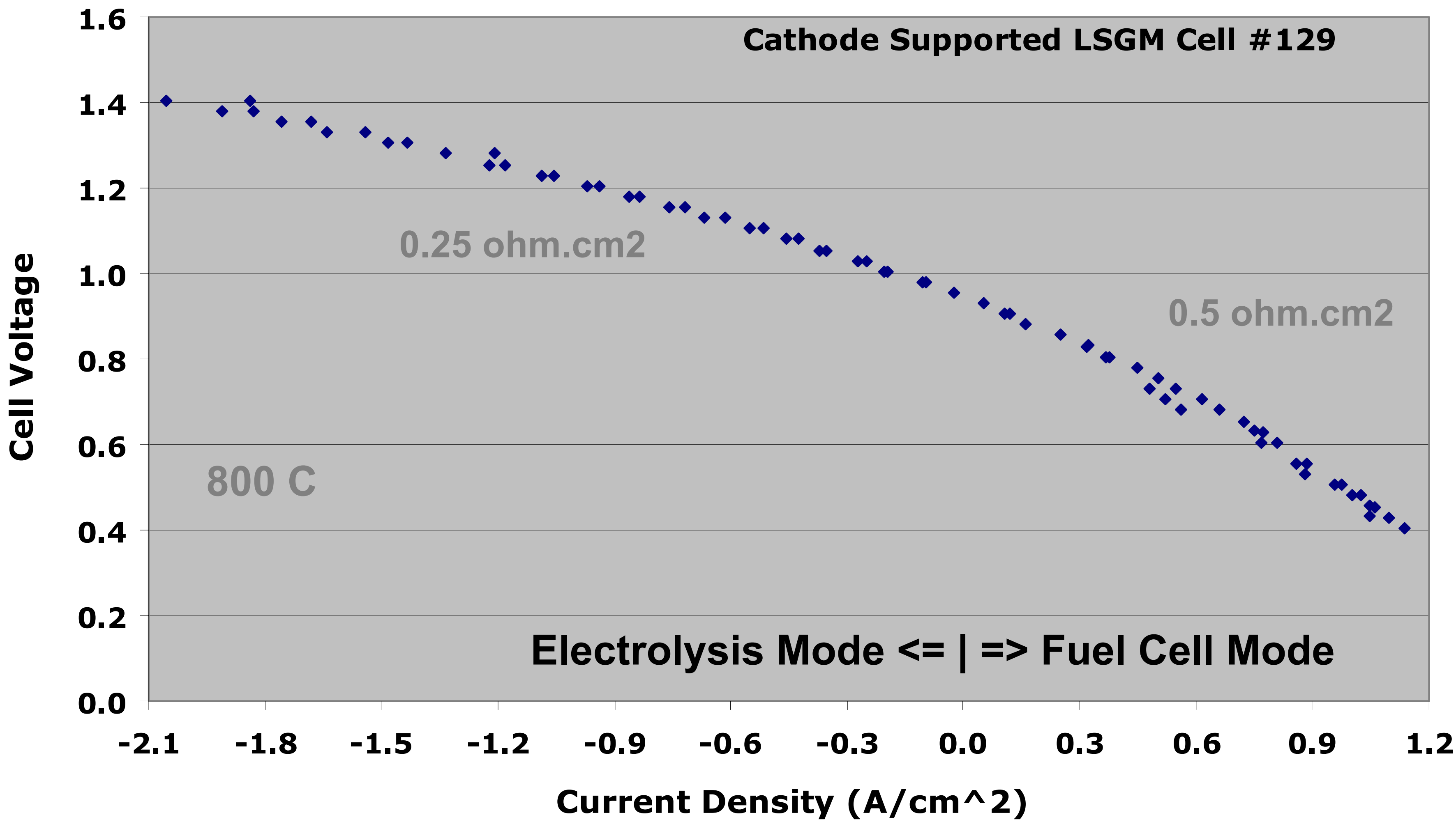
Cross Program Derived HTE Advance

DOE-FE SBIR: Intermediate Temperature Fuel Cell (LSGM)



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Thermal Management Impacts Cell Size

- Heat rejection limits size of SOFC
  - $T\Delta S$ term is exothermic in SOFC mode
  - $T\Delta S$ term is endothermic in electrolysis mode
  - I^2R is exothermic for both modes
  - Models show counteracting $T\Delta S$ and I^2R terms simplifies operation in electrolysis mode
- Current fabrication methods also limit size
- Large area fabrication route needed for electrolysis cells (e.g. 1 m^2 active area cells)

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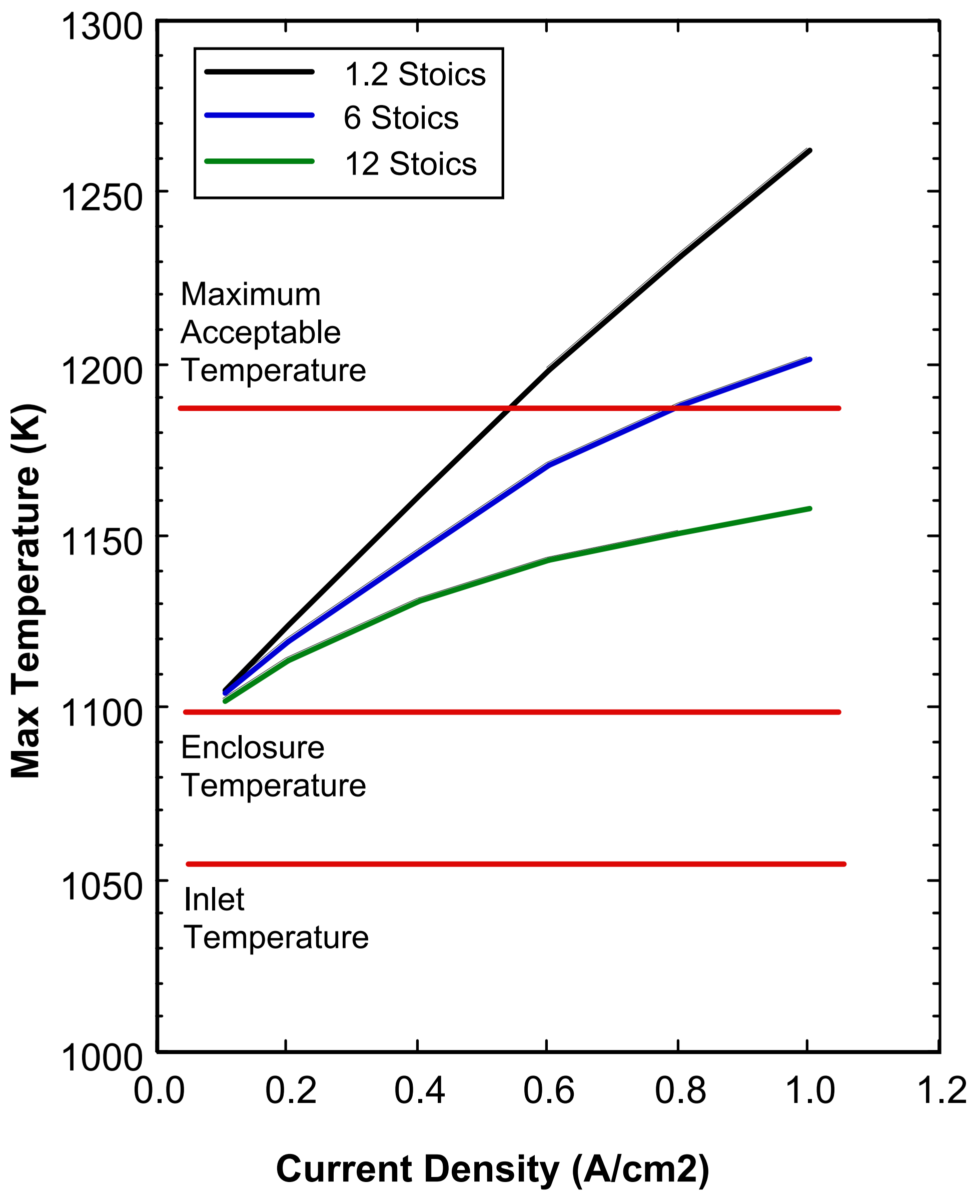
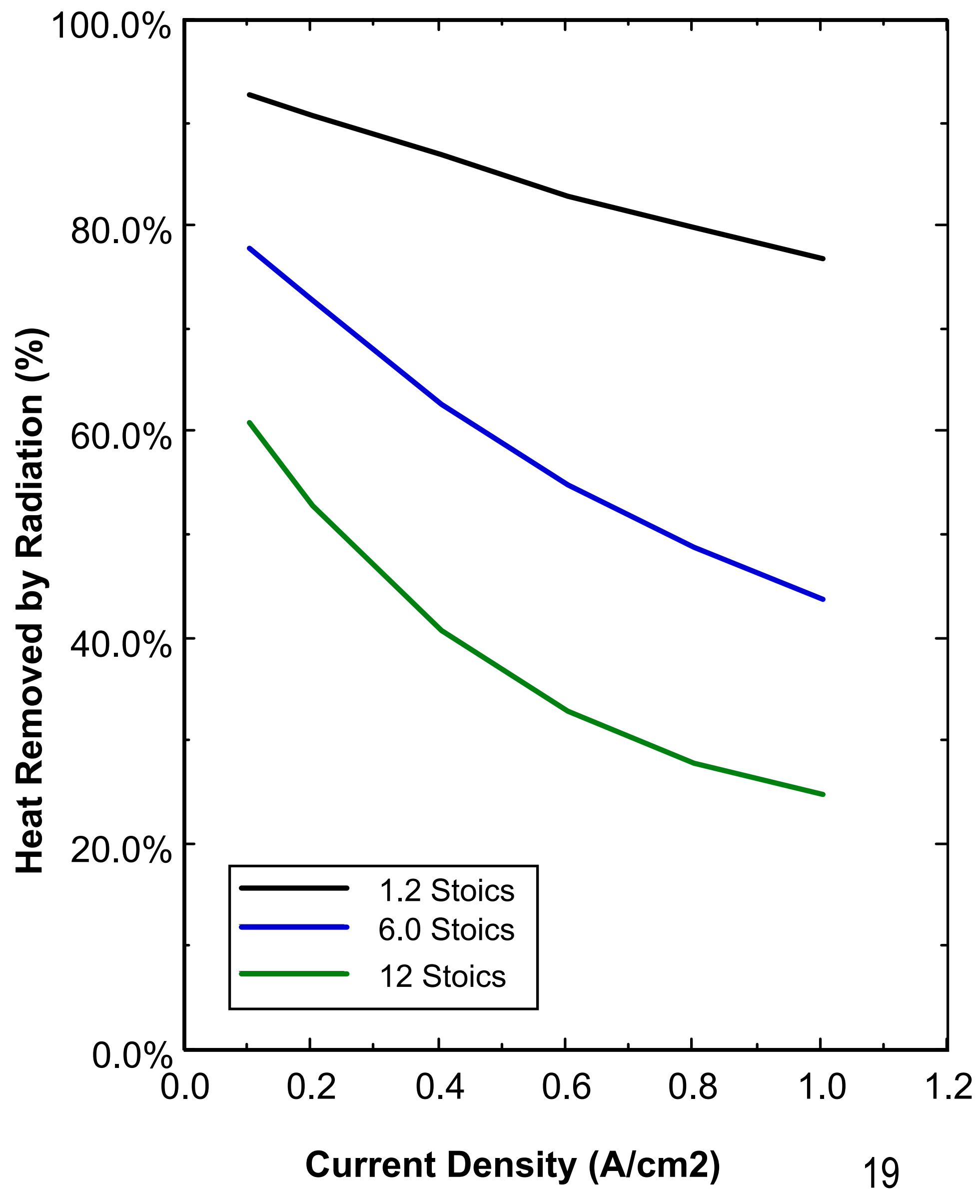
Excess Air Required to Cool 10cm Metal Icon Stack





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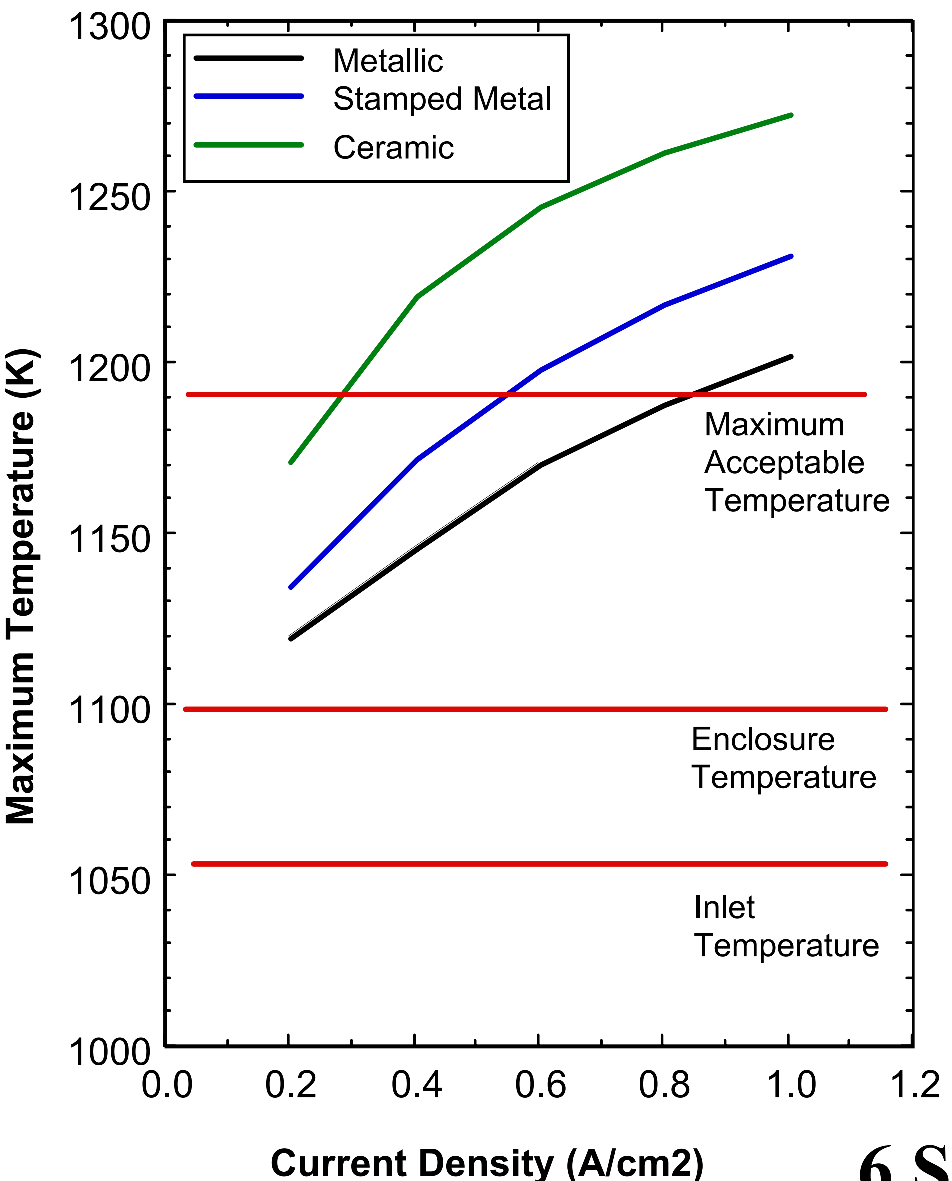
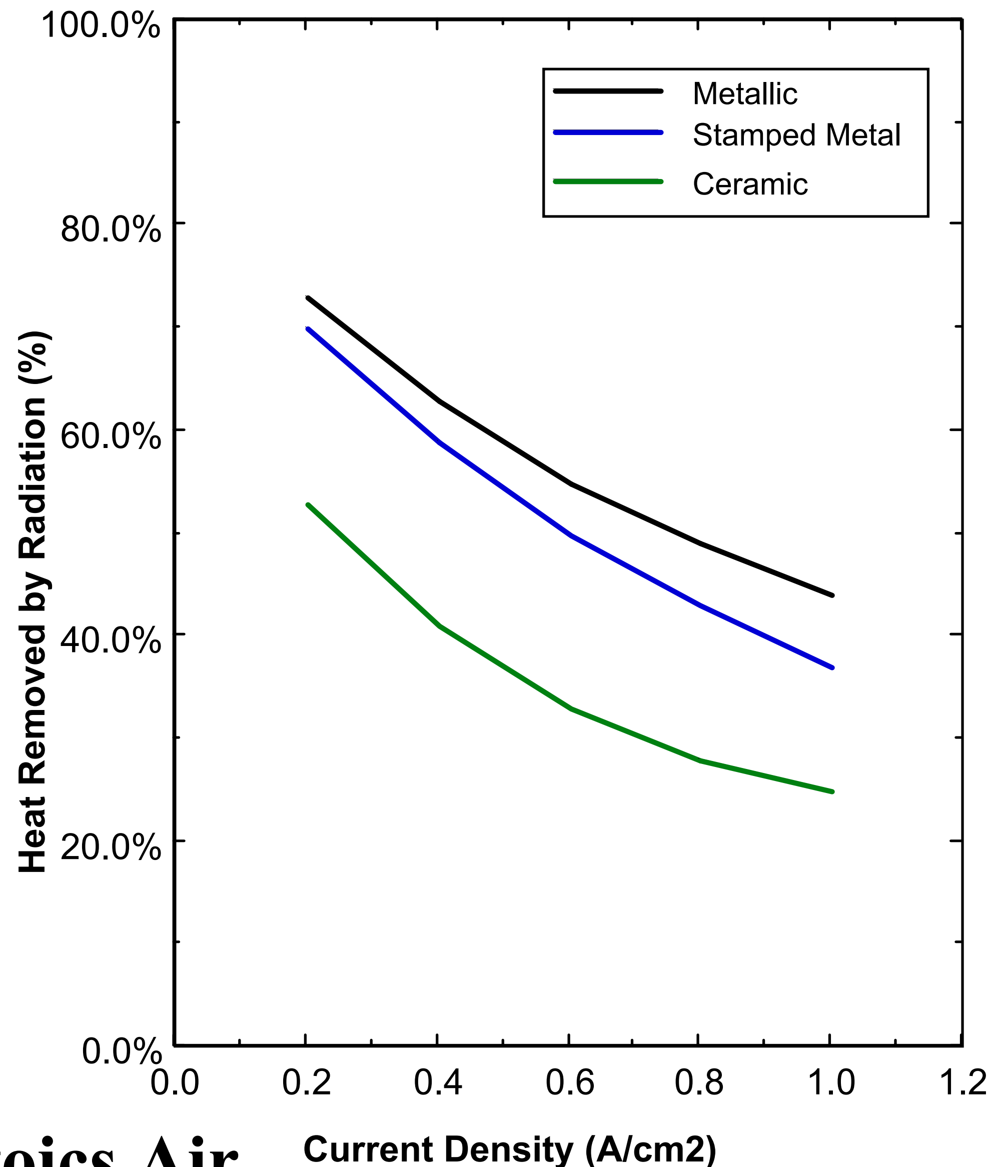
Effect of Interconnect Material on Stack Cooling





6 Stoics Air

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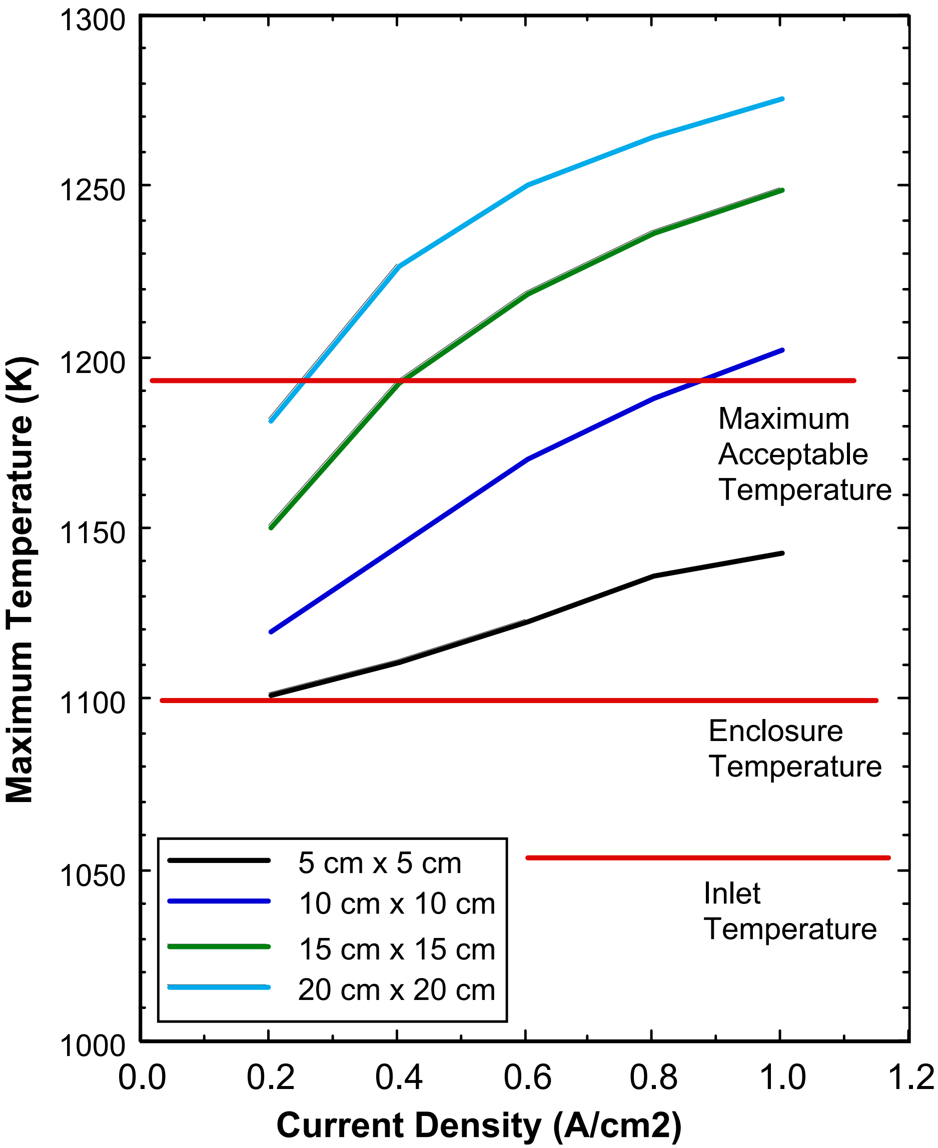
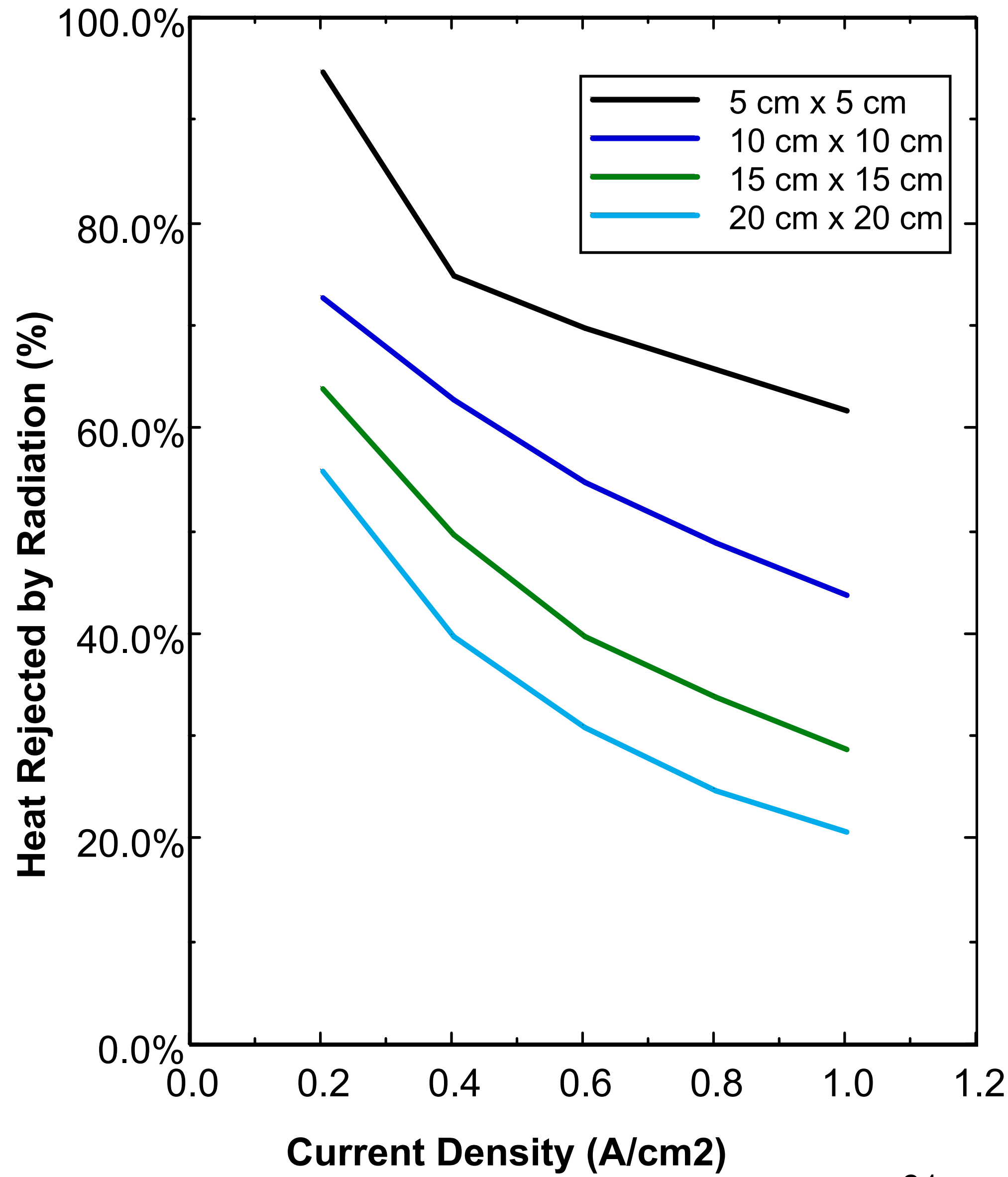
Difficulty in Cooling Stacks of Large Area Cells





High Temperature Electrolysis Operation At V_{tn}

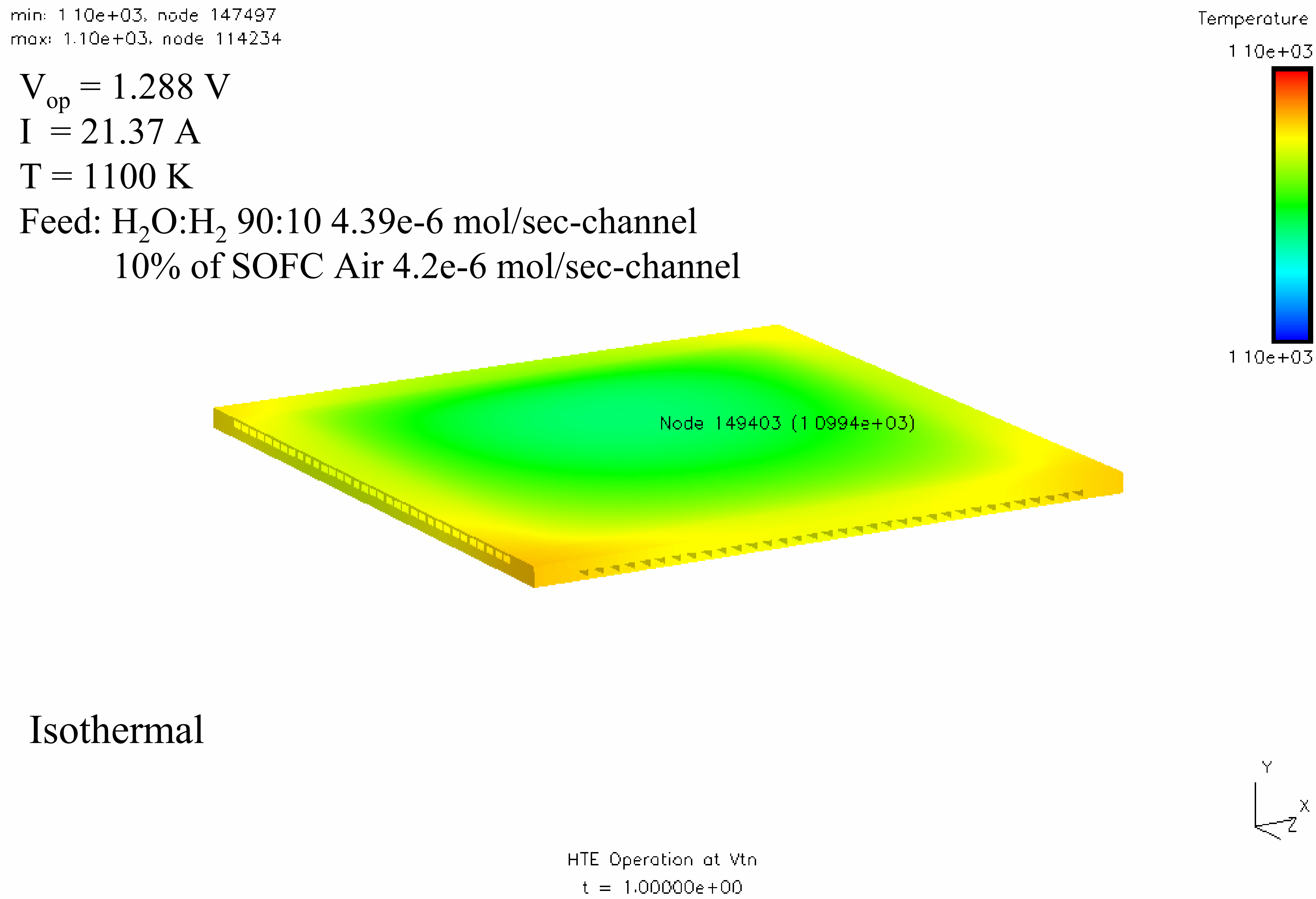
$V_{op} = 1.288$ V

$I = 21.37$ A

$T = 1100$ K

Feed: H_2O:H_2 90:10 4.39e-6 mol/sec-channel

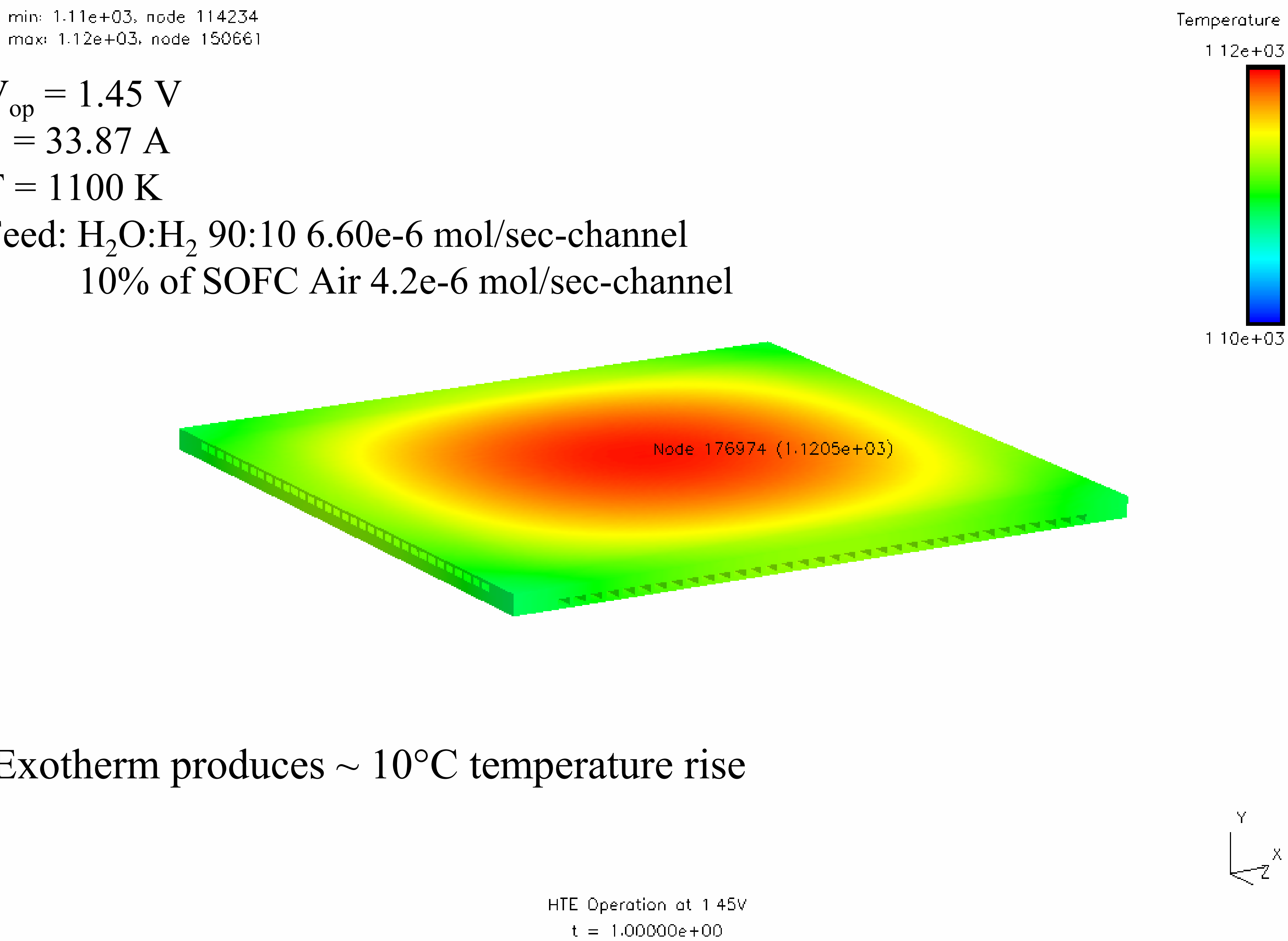
10% of SOFC Air 4.2e-6 mol/sec-channel



Isothermal

HTE Operation Above V_{tn}

V_{op} = 1.45 V
I = 33.87 A
T = 1100 K
Feed: H_2O:H_2 90:10 6.60e-6 mol/sec-channel
10% of SOFC Air 4.2e-6 mol/sec-channel



Exotherm produces ~ 10°C temperature rise

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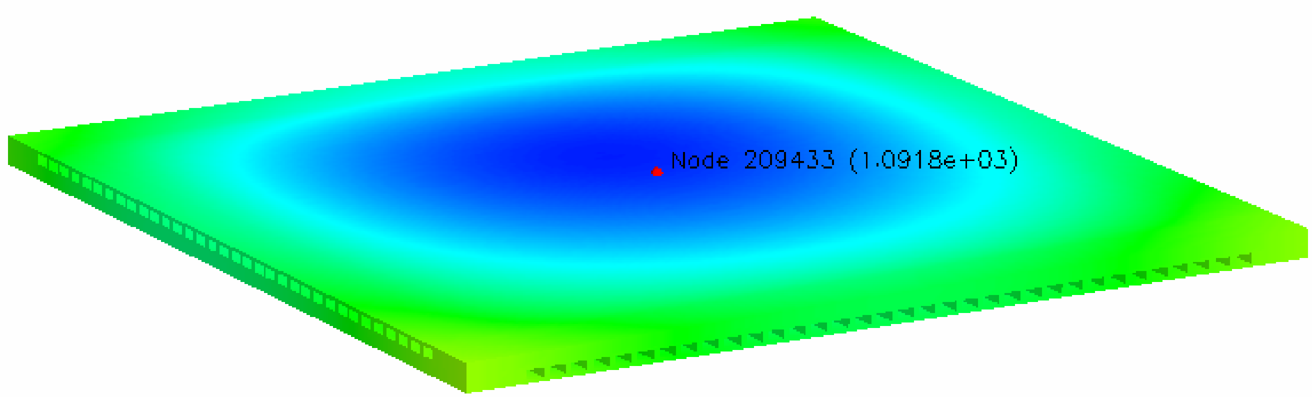
HTE Operation Below V_{tn}

min: 1.09e+03, node 148765
max: 1.10e+03, node 114234

Temperature
1.10e+03
1.09e+03

V_{op} = 1.15 V
I = 11.49 A
T = 1100 K
Feed: H_2O:H_2 90:10 3.00e-6 mol/sec-channel
10% of SOFC Air 4.2e-6 mol/sec-channel



Endotherm produces ~ 8°C temperature drop

Y
X
Z

HTE Operation at 1.115V
t = 1.00000e+00

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SOFC Operating Point

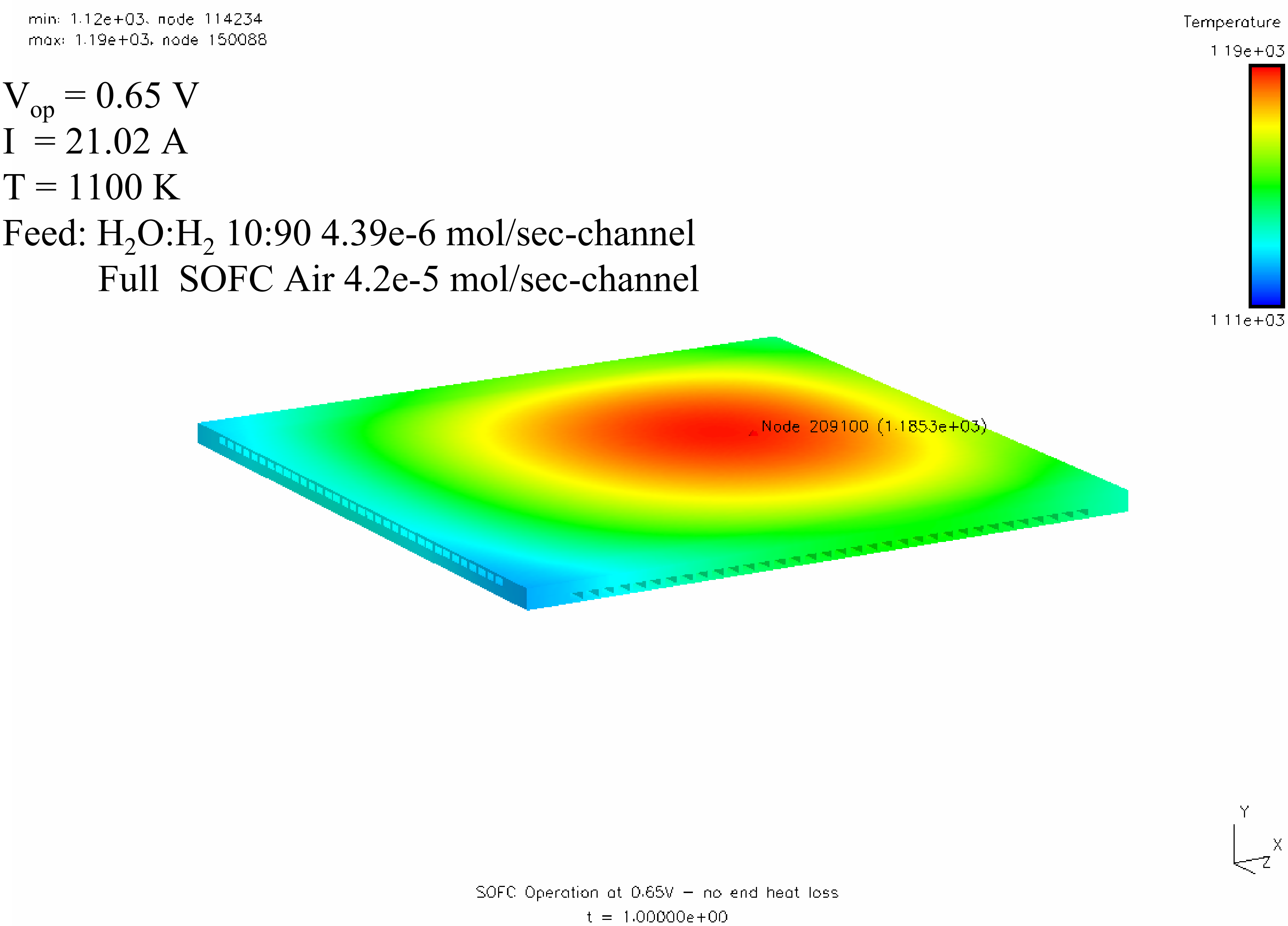
V_{op} = 0.65 V

I = 21.02 A

T = 1100 K

Feed: H_2O:H_2 10:90 4.39e-6 mol/sec-channel

Full SOFC Air 4.2e-5 mol/sec-channel



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Project Summary

- DOE Hydrogen Production & Delivery Research
  - 4 Team Members
    - Ceramatec, lead, cell testing, metal coating
    - Hoeganaes, metal powder and foams
    - INEEL, thermal spray processing
    - Univ. of Washington, constrained sintering
  - Develop processes scalable to 1m^2 active area
  - Cell design based on thermal spray process using porous powder metal substrate
  - Industry Cost Share > 20%
  - Non-nuclear power based electrolysis
    - Distributed co-generation of hydrogen and electric power
    - DOE Power Park concept

Publications and Presentations

Related Electrolysis Programs (None yet on this program)

National Hydrogen Association SBIR Workshop April 1, 2005

ASME 3rd Int. Conf. On Fuel Cell Sci. Ypsilanti, MI, May 2005

University of Utah Graduate Seminar – Feb 2005

Joint IEA/AIE Workshop, San Antonio Nov 2004

European SOFC Forum, Lucerne Switzerland, Jul 2004

NURETH-11, Avignon France, Oct 2005

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

Fire.

Hydrogen which has leaked into air is easily ignited by any hot or clean metal surface. This is a concern in and around the room temperature piping. Leaks in the high temperature portions of the process will burn of course, but in areas designed for high temperatures. In addition, leaks there cannot build up in concentration as they react in a diffusion flame sheet as quickly as the hydrogen can diffuse to oxygen. A potentially greater hazard is a cold leak that spreads to a large area before igniting, which could overpressure parts of the structure.

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Hydrogen Safety

Our approach to deal with this hazard is:

- Outside cylinder storage & pressure relief
- Metal piping – leak test
- Point of use flow restriction orifices
- High capacity ventilation system
- Fusible link valve closure
- Hydrogen/Combustible gas sensor/alarm
- Power failure gas cutoff
- Sprinkler system

Questions?

- Contact: Rich Bechtold at 301-429-4566, richard.bechtold@qssgroupinc.com or Melissa Lott at 301-560-2214, Mlott@qssgroupinc.com