tionary -
Fuel Cells

Presented at SECA Annual Workshop and Peer Review Meeting
May 11-13, 2004
Boston, MA

SIEMENS
Westinghouse

SECA Program at Siemens Westinghouse

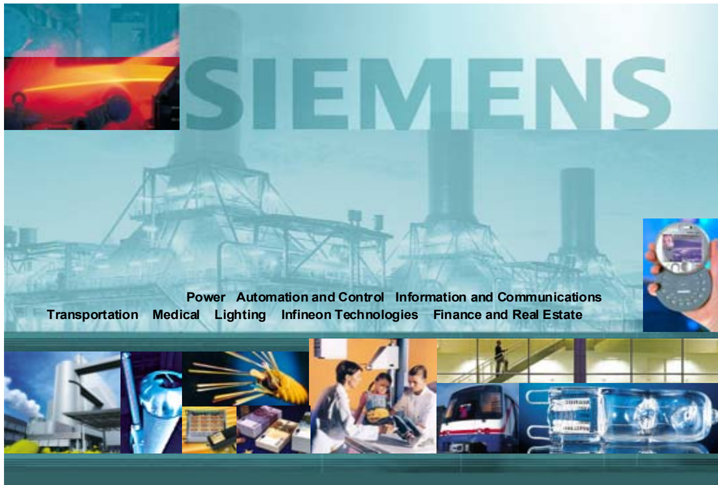
S. D. Vora

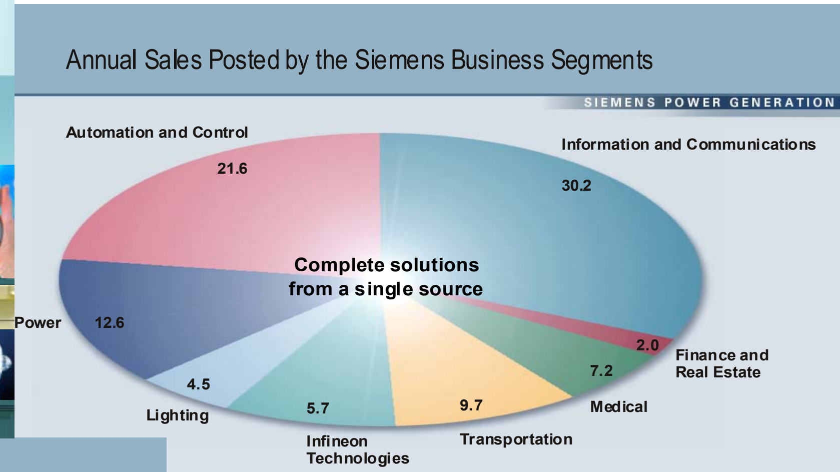
y 2004

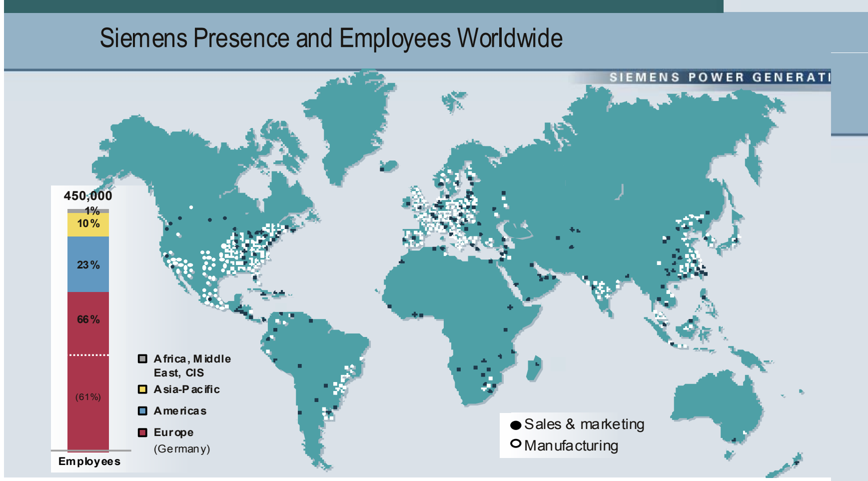
Siemens Westinghouse Power Corporation
May 11, 2004

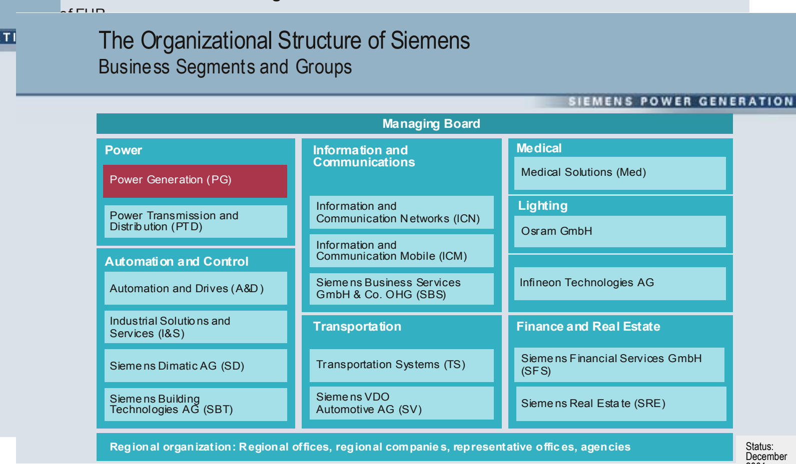
DOE Program Manager
Don Collins

SIEMENS Westinghouse









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Siemens AG
Power Generation

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Information and Communication Networks (ICN)

Automation and Drives (A&D)

Power Generation (PG)

Transportation Systems (TS)

Medical Solutions (Med)

Osram GmbH

Siemens Financing Services (SFS)

Information and Com Mobi

Industrials Solutions and

Siemens Automotive

Siem Busi Servi Gmb OHG

Power Generation

Fossil Power Generation

- Americas
- Europe, Middle East, Africa, Asia/ Pacific
- Operating Plant Services
- Gas Turbines
- Steam Turbines and Electric Generators

Instrumentation & Control

Industrial Applications

Stationary Fuel Cells

JV Framatome ANP
July 2000
Siemens 34%

JV Voith Siemens Hydro
April 2000
Siemens 35 %

Infineon Technologies AG (Siemens subsidiary)

Siemens Financing Services (SFS)

PG Worldwide Figures for FY2003, in billions €

Sales	€ 7 billion
Orders	€ 7.3 billion
Profit from operations	€ 1.2 billion
Employees	30,000

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Stationary Fuel Cells

SIEMENS Westinghouse

- 150 Employees
- Chartered to Commercialize SOFC Power Systems for the Distributed Generation Market
- Focused on Seal-less, Cathode Supported Tubular SOFC Design
- YSZ Electrolyte, 1000 ºC Operating Temperature
- Expertise in
    - High Temperature Materials
    - Ceramic Processing, Ceramic Powder, Cell and Module Manufacturing
    - Electrochemistry and Cell testing
    - Hydrocarbon Reformation
    - BOP Assembly
    - Systems Testing

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Stationary Fuel Cells - Accomplishments

SIEMENS Westinghouse

- Developed State-of the art, 150 cm Active Length (834 cm^2 active area), Cathode Supported Tubular SOFCs
- Demonstrated Lifetime of >60,000 Operating Hours with Voltage Degradation Rates < 0.1% per 1000 Hours and Thermal Cycle Capability of >100 Cycles
- Developed Internal Reformation Technology
- Designed, Manufactured and Tested Complete Atmospheric and Pressurized Hybrid SOFC Power Systems
- Replaced Electrochemical Vapor Deposition (EVD) process with Atmospheric Plasma Spray (APS) process for deposition of cell components

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Stationary Fuel Cells - Accomplishments

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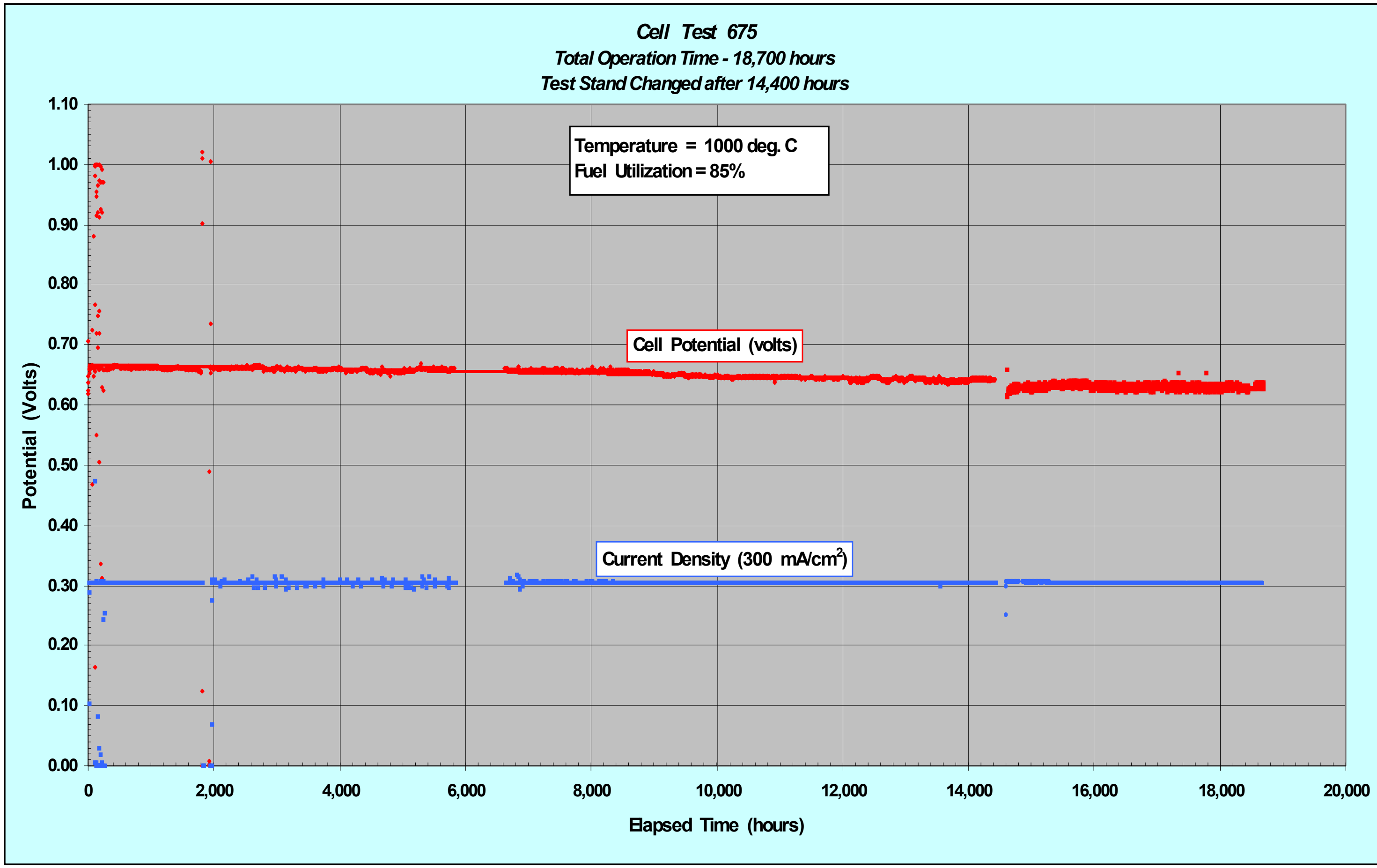
Voltage Stability of Tubular APS Cell



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APS cell performance

- Demonstrated performance equivalent to EVD cells
- Demonstrated thermal cyclic stability - can withstand multiple thermal cycles
- Demonstrated voltage stability - voltage decline of approx. 0.1% per 1000 hours

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Highest Priority for Commercialization

Lower Product Cost ($/kWe)

Cost	↓	($/unit)
Power Density	↑	(kWe/cell)

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SECA Program Objectives

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Develop SOFC System Prototypes with a net Power Output of 5-10 kWe for Stationary and Transportation Applications with a Cost Target of < $ 400/kWe.

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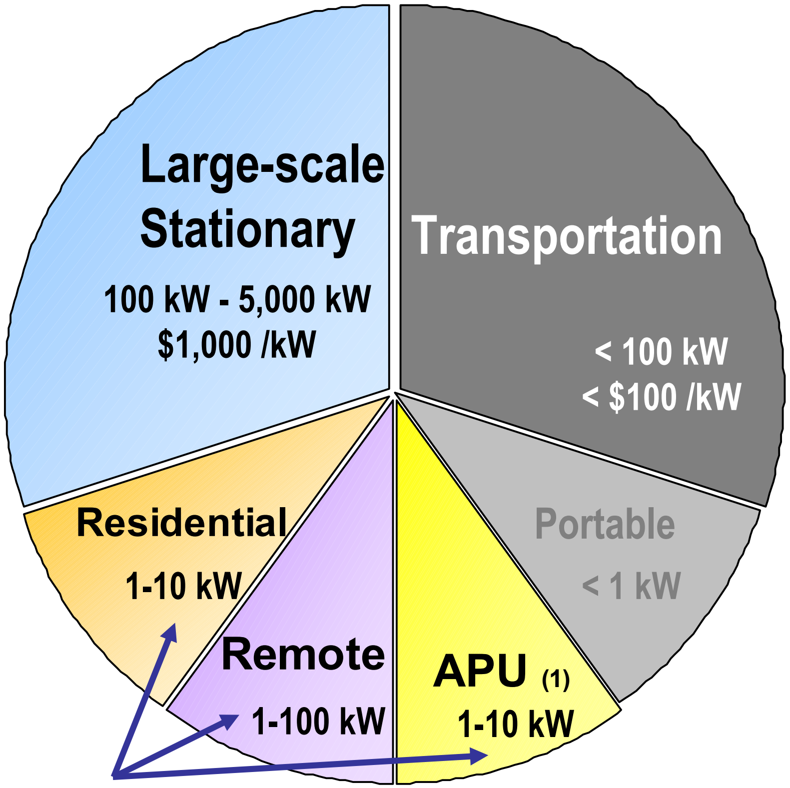
Projected Fuel Cell Market in 2012...
$1 Billion

Current SFC Focus



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Emerging Market Segments
Cost Target $400/kW

(1) Auxiliary Power Units

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Siemens Westinghouse SECA Team

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Technology Team	Customer / Market Team		
	Remote/Residential	Transportation	Military
Siemens Westinghouse	Fuel Cell Technologies	Ford	Newport News
Fuel Cell Technologies	Lennox	Eaton	Eaton
Blasch Precision Ceramics	Trane		

Key Team Members provide Market Access and Industry Specific Expertise To broaden Market Opportunities and New Applications

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SECA Program Technical Approach

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- Improve Cell Performance through High Power Density (HPD) Cathode Supported Planar Cell - New Cell Geometry
- Improve Cell Performance by Reducing Activation Polarization at Interfaces - New Cell Materials
- Lower Operating Temperature (800ºC) - New Cell Materials
- On-cell Reformation - Elimination of Internal Reformers
- Low Cost, High Volume Manufacturing Process Development
- Low Cost Module Materials - Helped by Lower Operating Temperature
- BOP Design Simplification - Parts Elimination

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SECA -10 Year Roadmap

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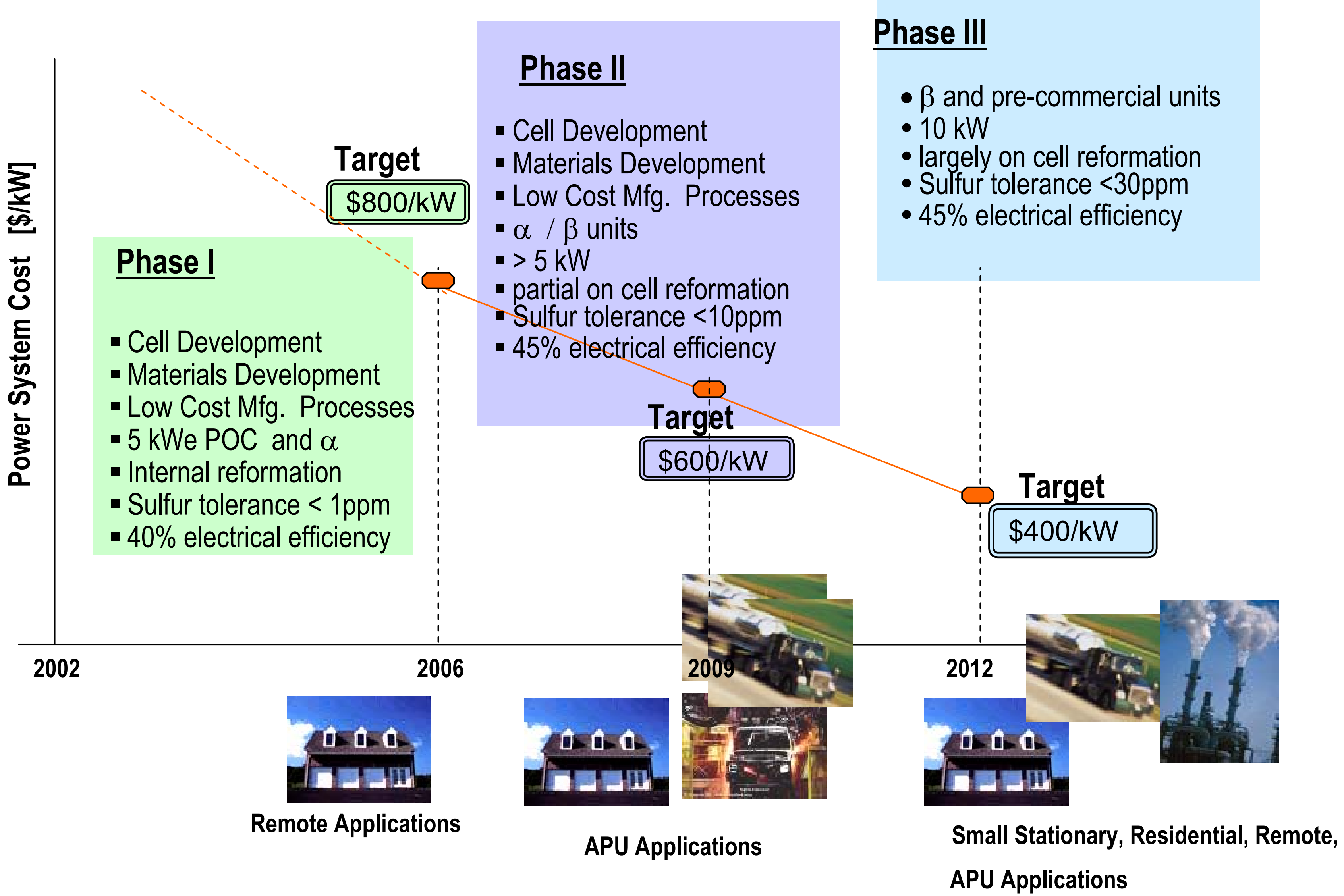

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High Power Density (HPD) Cathode Supported Seal-less Planar Concept

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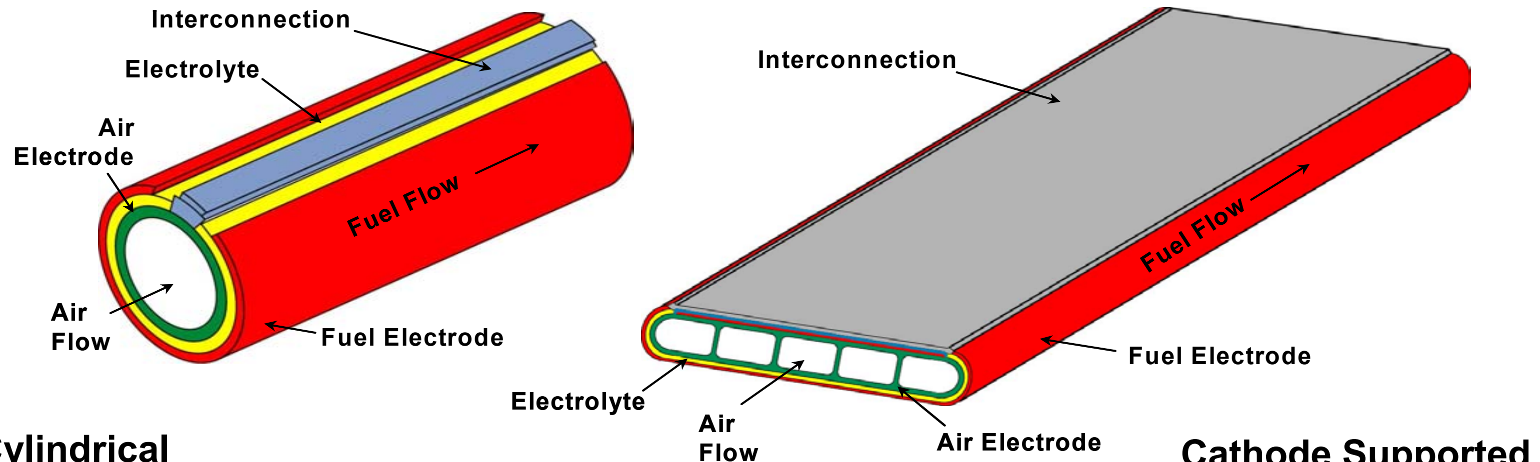

Cylindrical (Present)

Cathode Supported Seal-less Planar

- **Maintains Seal-less design**
- **Eliminates air feed tubes**
- **Reduction in resistance**
- **Increase in cell power (power density and surface area)**
- **More compact stack**

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Development of HPD Cell Design

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- Computational model of HPD cell cross-sectional geometry developed to optimize cell design and dimensions
- Performance estimated by Electrochemical modeling – NETL/FLUENT SOFC model
- First level selection of cell geometry based on performance and cell economics
- Second level selection of cell geometry based on structural integrity under predicted mechanical and thermal stresses

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HPD Cell Design Options

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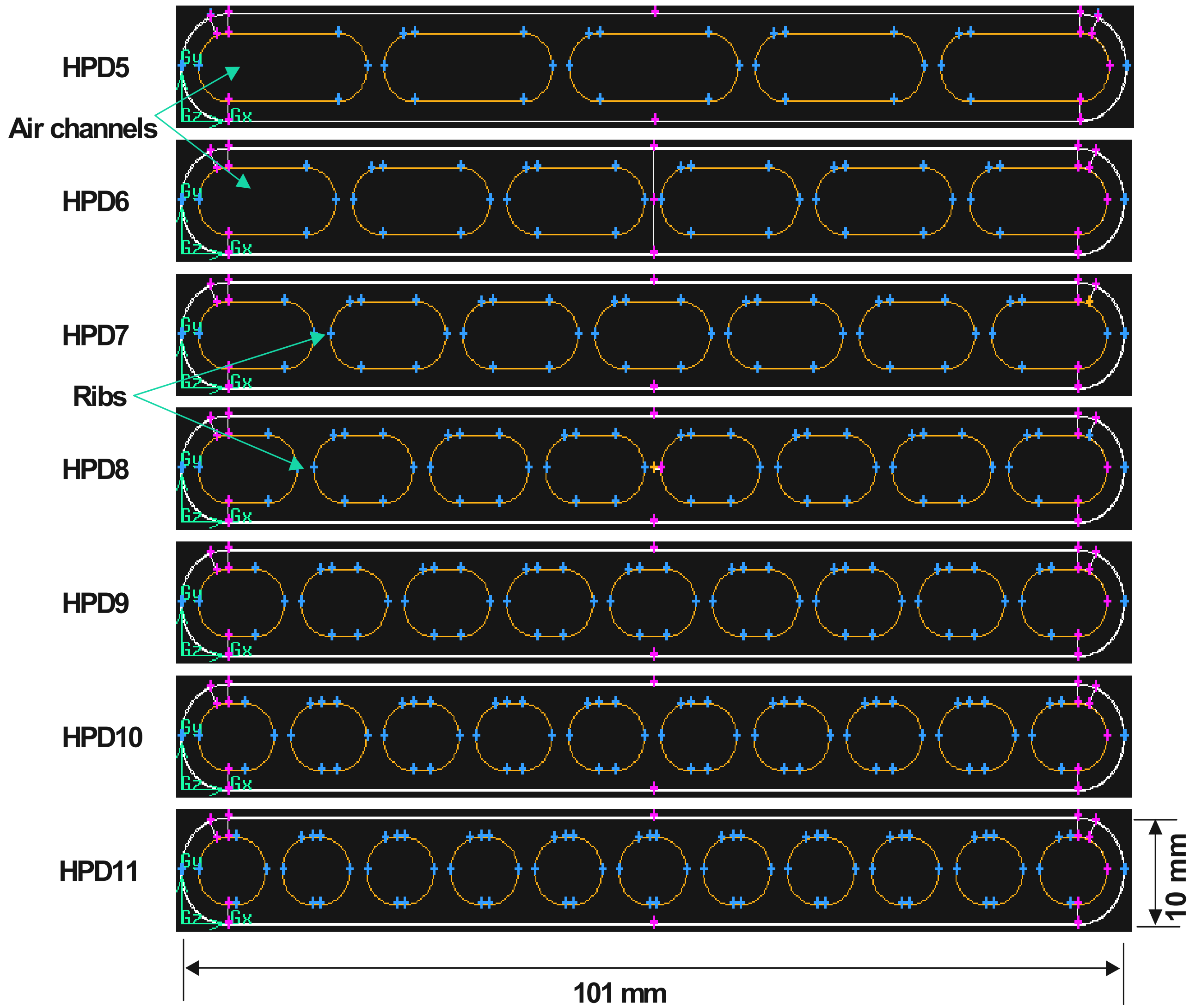

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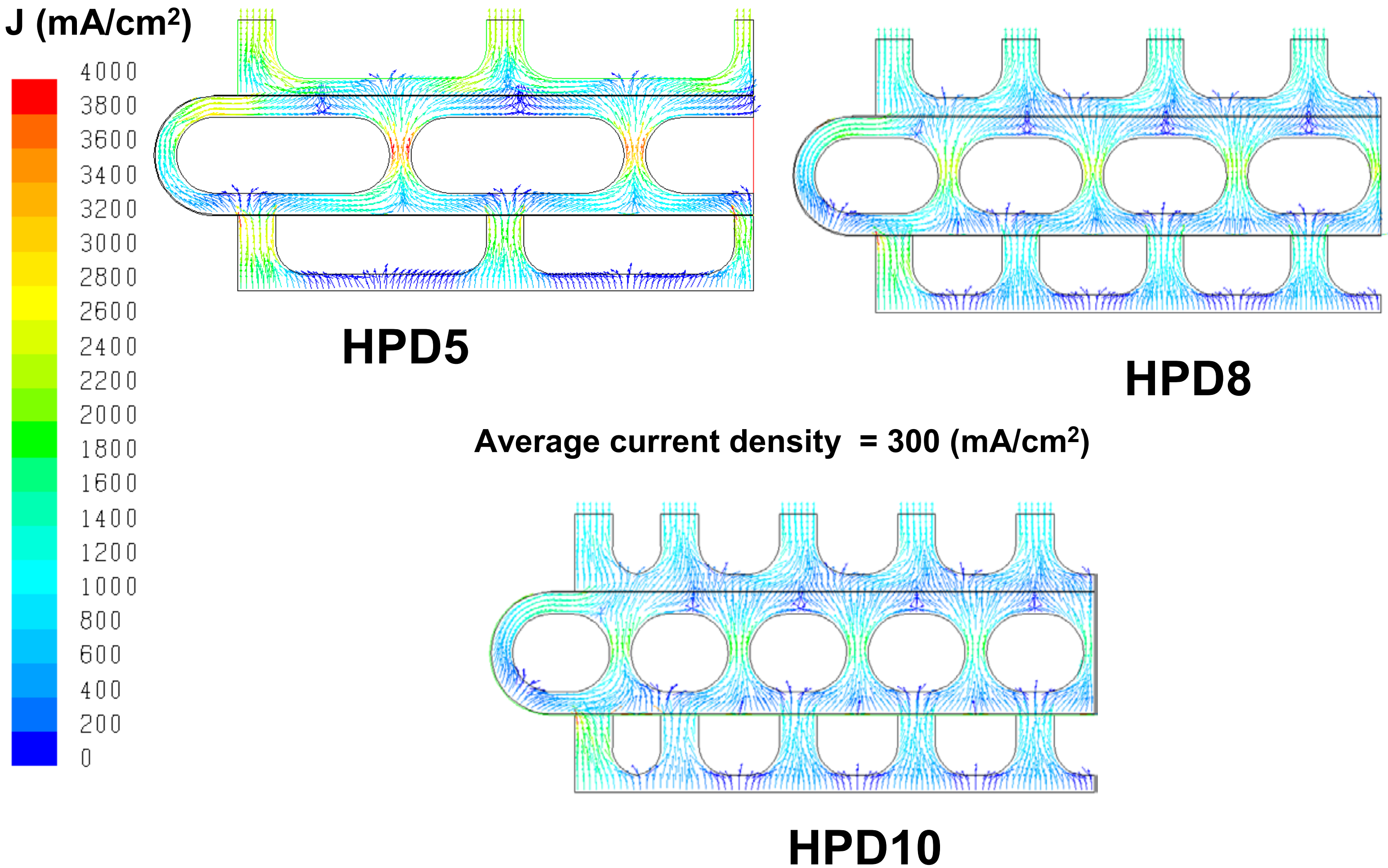
Current Density Distribution in HPD Cells



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HPD Cell Design

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- Selected HPD5 as a baseline to develop cell and bundle fabrication processes and conduct electrical performance testing
- Selected HPD10 to explore the upper bounds of cell fabrication
- Reduced HPD active cell length to 75 cm to maintain same active area as 150 cm cylindrical cells for ease of performance comparison

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HPD Cell Fabrication

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- Developed extrusion method for cathodes. Closed end cap can be attached or integral
- Dedicated APS robotic system installed
- Developed APS parameters for interconnection, electrolyte (YSZ) and the anode
- Fabricated bundles with up to 11 HPD5 cells
- Additional process optimization/cost reduction opportunities being explored

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Robotic APS System

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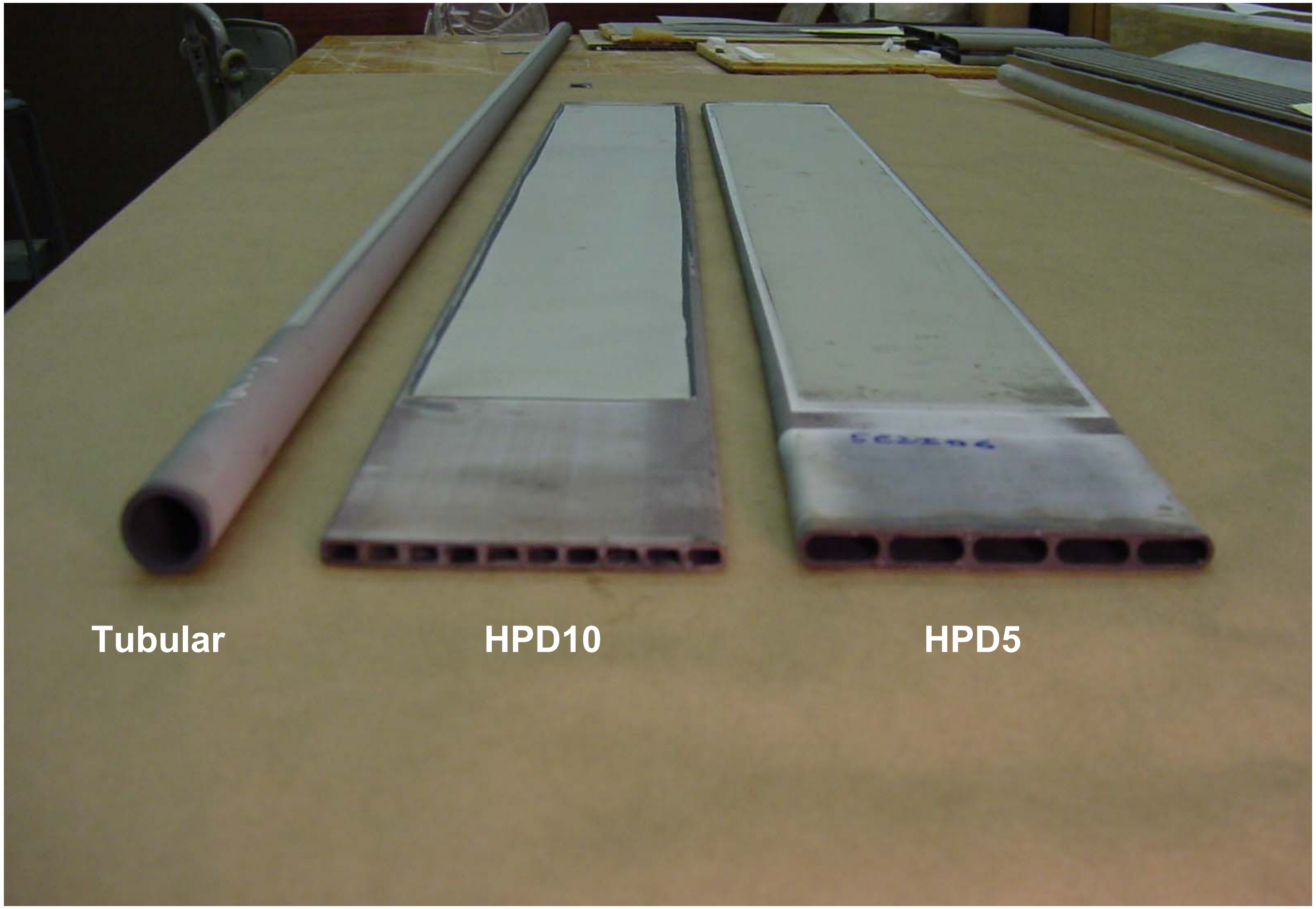
Tubular and HPD Cells



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Performance Comparison – Cylindrical Vs. HPD5

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= 1000 C
% Fuel Utilization

% higher power
sity relative to
drical cells (at
V) demonstrated
IPD5

et in 2012:
% higher
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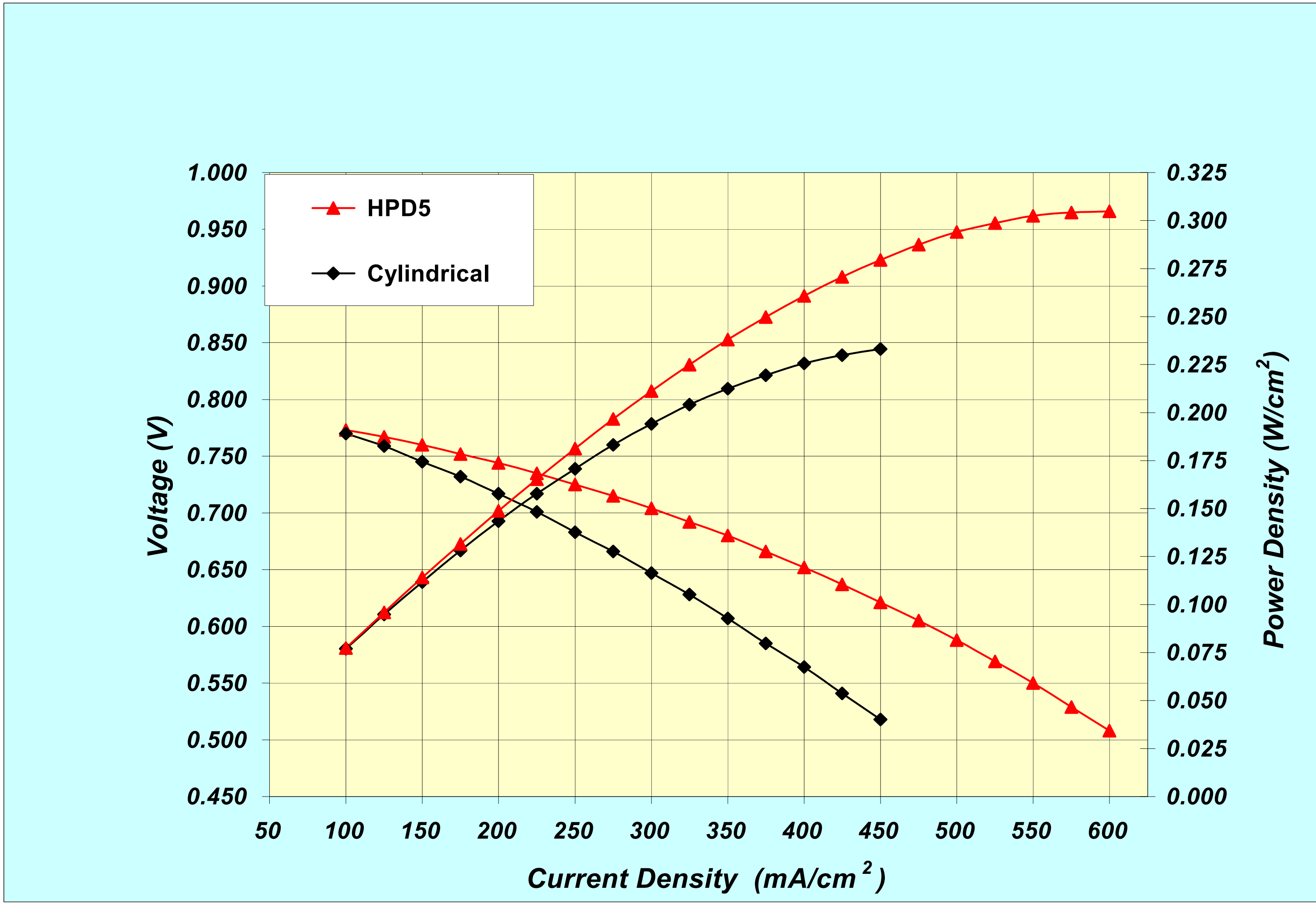
drical cells
HPDX



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HPD5 – Voltage Stability

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able Voltage
1000 C

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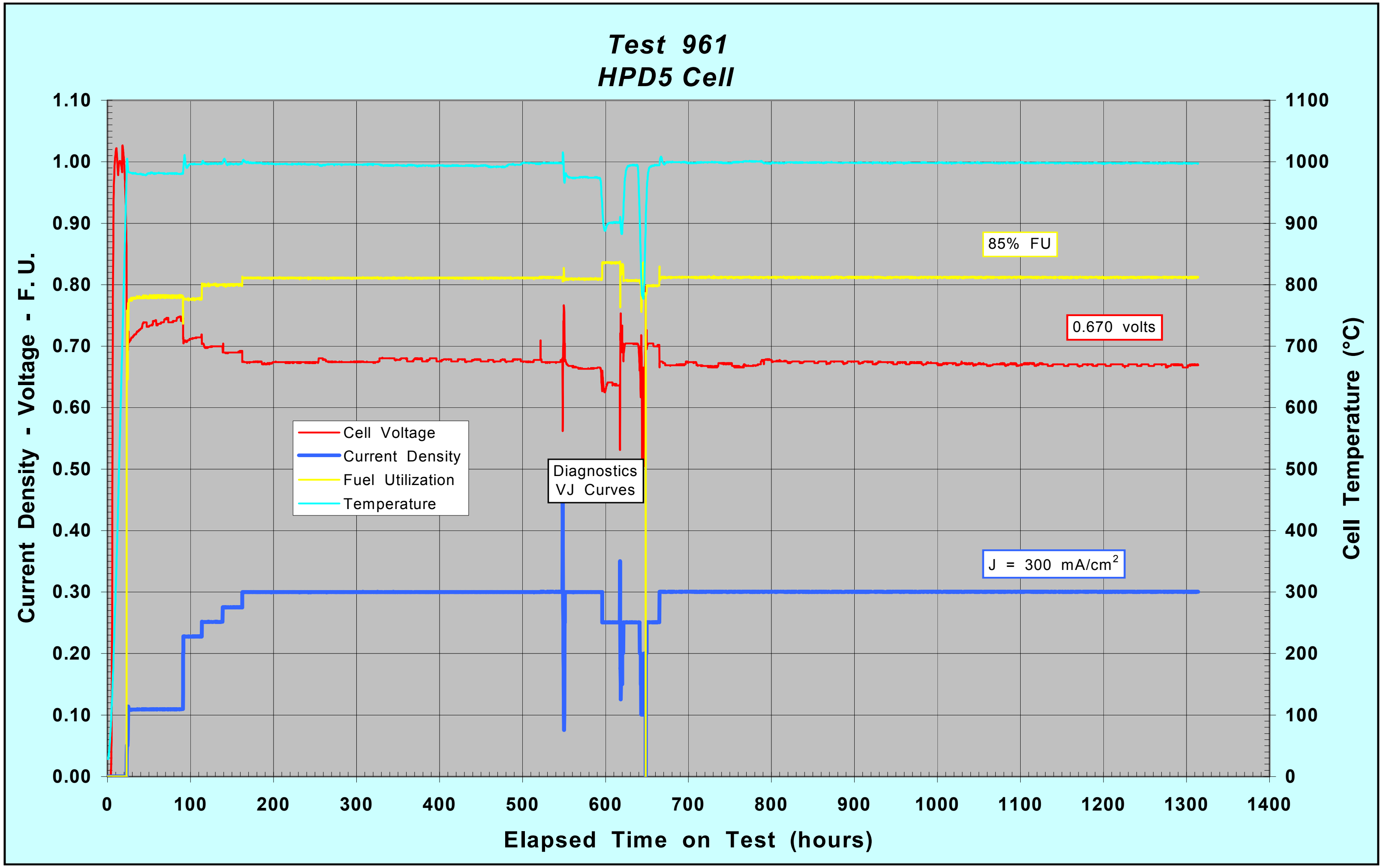

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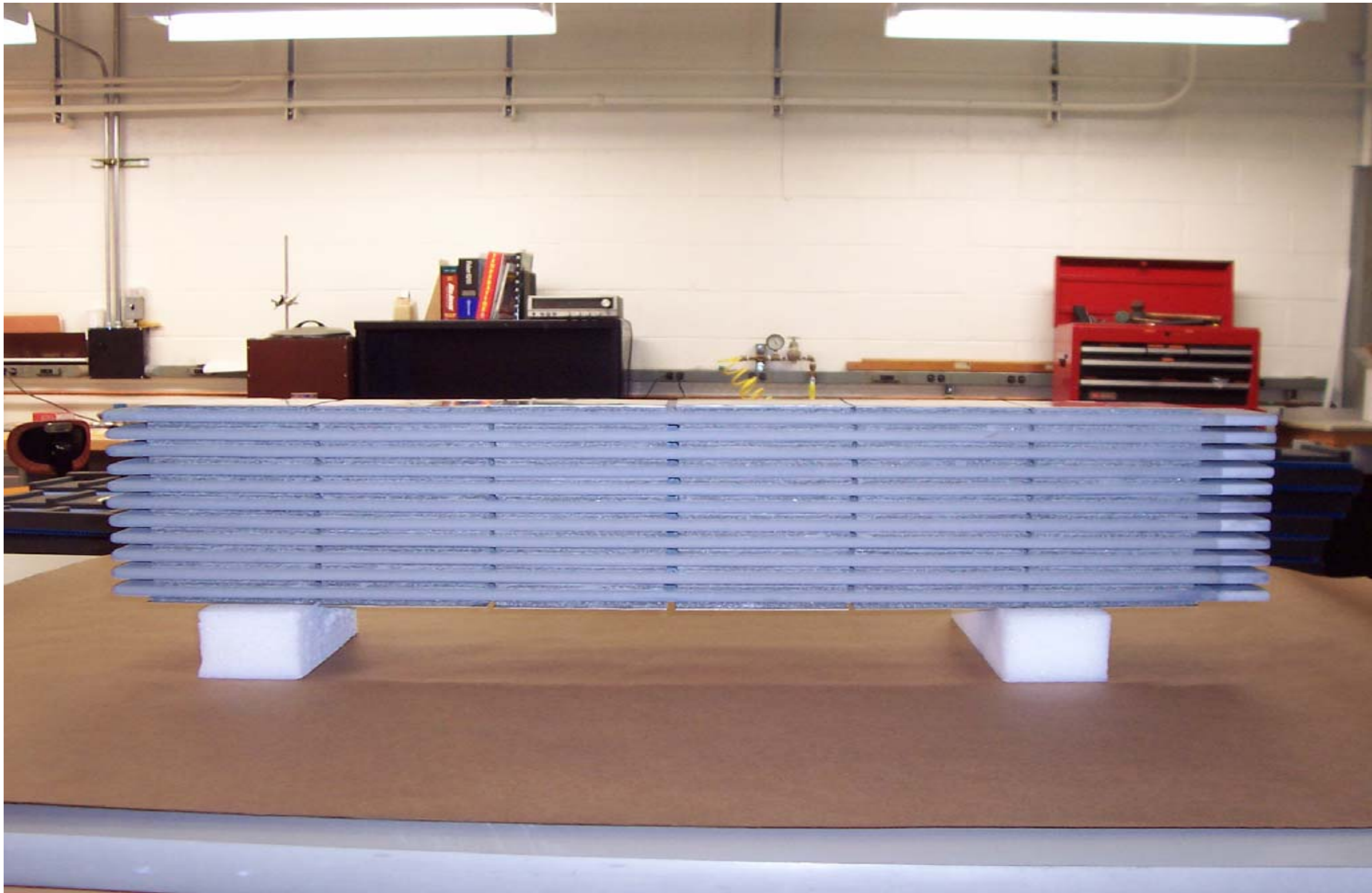
HPD5 Cell Bundle - 11 Cells



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Cell Power Enhancement

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ective

rove
900 °C
ormance of
electrolyte

- Evaluating Controlled Atmospheric Plasma Spraying (CAPS) to lower post plasma spray densification temperature
- Evaluating composite interlayers at the cathode-electrolyte interface to reduce activation polarization
- Evaluation carried out on cylindrical cells – results are applicable to HPD cells

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Electrolyte Microstructure Comparison

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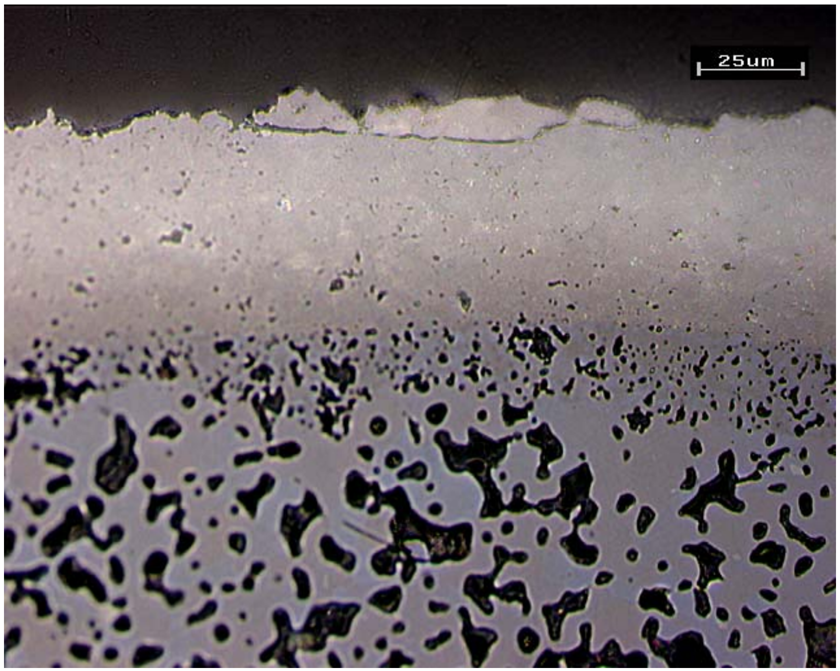
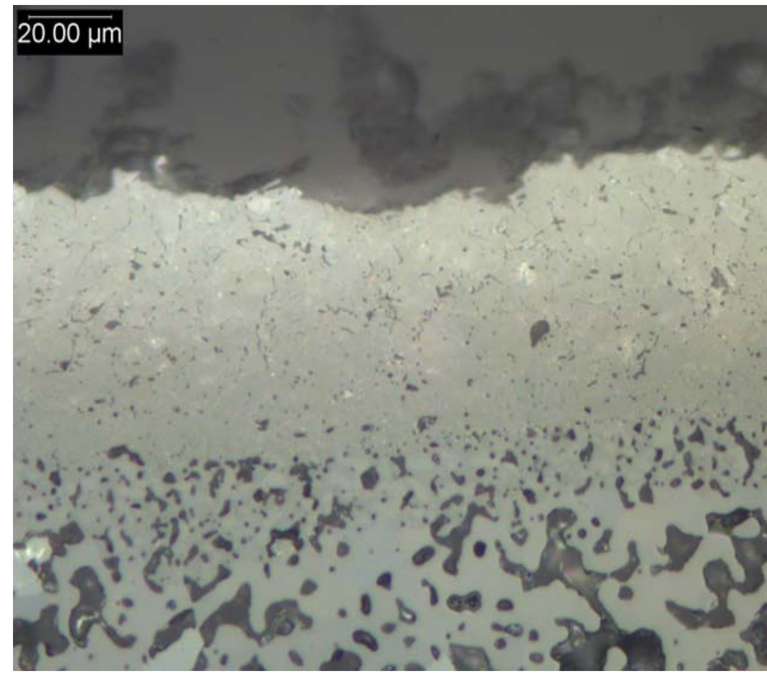
Electrolyte

Interlayer

Cathode





CAPS + Composite Interlayer

EL Densification - 1250°C, 6 hrs

APS + Composite Interlayer

EL Densification - 1350°C, 6 hrs

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Performance Comparison - APS + Composite Interlayer Vs. CAPS + Composite Interlayer (Cylindrical Cells)

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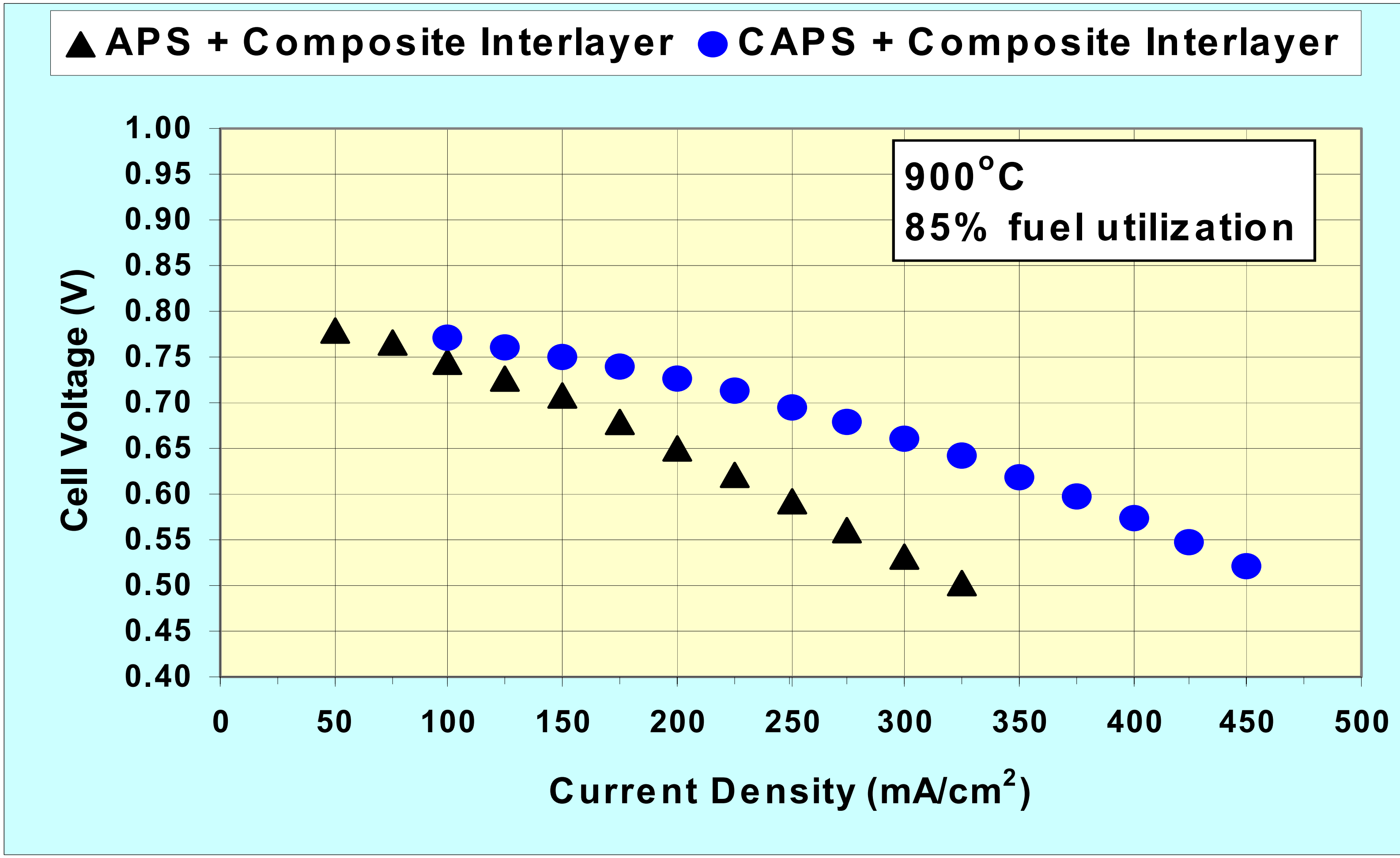
% higher power
ity relative to
(at 0.65 V and
C) demonstrated
APS + cathode
ayer

icability to HPD
needs to be
onstrated



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Low Temperature (800 ºC) Electrolyte

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- **Sr- and Mg- doped $LaGaO_3$ (LSGM)**
  - **APS selected to deposit dense layer**
  - **Cathode, interconnection, anode and interlayer compositions compatible with LSGM developed**
- **Scandia doped Zirconia (ScSZ)**
  - **APS selected to deposit dense layer**

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LSGM As Low Temperature Electrolyte

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- **High Electrolyte Oxygen-ion Conductivity: σ(LSGM@800°C)= σ(YSZ@1000°C)**
- **Excellent Chemical and Structural Compatibility with Perovskite Cathode Substrate**
- **Higher Cell Performance over a Wider Temperature Range**
- **Potential of Cost Reduction in Module Components due to Lower Operating Temperature**

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Low Temperature Electrolyte - Status

- Developed a process to make plasma sprayable LSGM powder
- Developed understanding of issues to be resolved to obtain a dense LSGM layer on cathode substrate
- Additional work needed before a full length cell with LSGM electrolyte can be fabricated

- Cylindrical cells fabricated with ScSZ electrolyte
- Performance under evaluation

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Low Cost High Volume Manufacturing

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- Net shape forming of stack components (Blasch Ceramics)
- Sintering of interconnection, electrolyte and anode
  - Higher Material Utilization
  - Reduced Manufacturing Steps
  - Higher Throughput
  - Lower capital Investment

Feasibility studies initiated

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Proof-of Concept (POC) System

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- Primary objective is to successfully demonstrate the operation of an HPD cell stack
- Stack: SWPC Scope; BOP:FCT scope
- 44 HPD5 cells – YSZ electrolyte
- Split stack generator
  - Two Stacks
  - Two cell bundles per stack
  - 11 cells per bundle
- Target power: 5 kWe net AC
- Target efficiency: 40%
  - Low PCS efficiency: 85% vs. 92% for larger systems
  - Relatively higher BOP power consumption than larger systems
- Internal Reformation
- Selected stack components will be fabricated by Blasch Ceramics using net shape forming
- Modular Design Approach
  - Streamlined assembly process, higher level of parallel effort
- Target Start-up: Fall 2004

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BOP Design, Testing and Assembly (FCT)

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- Incorporated Lessons Learned from Alpha Demonstration Units with Cylindrical Cells.
- Beta Unit with Full Length (834 cm^2 active area) Cylindrical Cells Designed and Tested with an Objective to Maintain Commonality Between Beta and SECA Units.

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Alpha → Beta → SECA

Alpha

Volume: 1.90 m³

88 Cylindrical Cells
(75 cm Active Length)

2002-2003

Beta

Volume: 1.90 m³

48 Cylindrical Cells

(150 cm Active Length)

2003-2004

SECA POC

Volume: 0.86 m³

44 HPD5 Cells

2004

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SECA Product Plan

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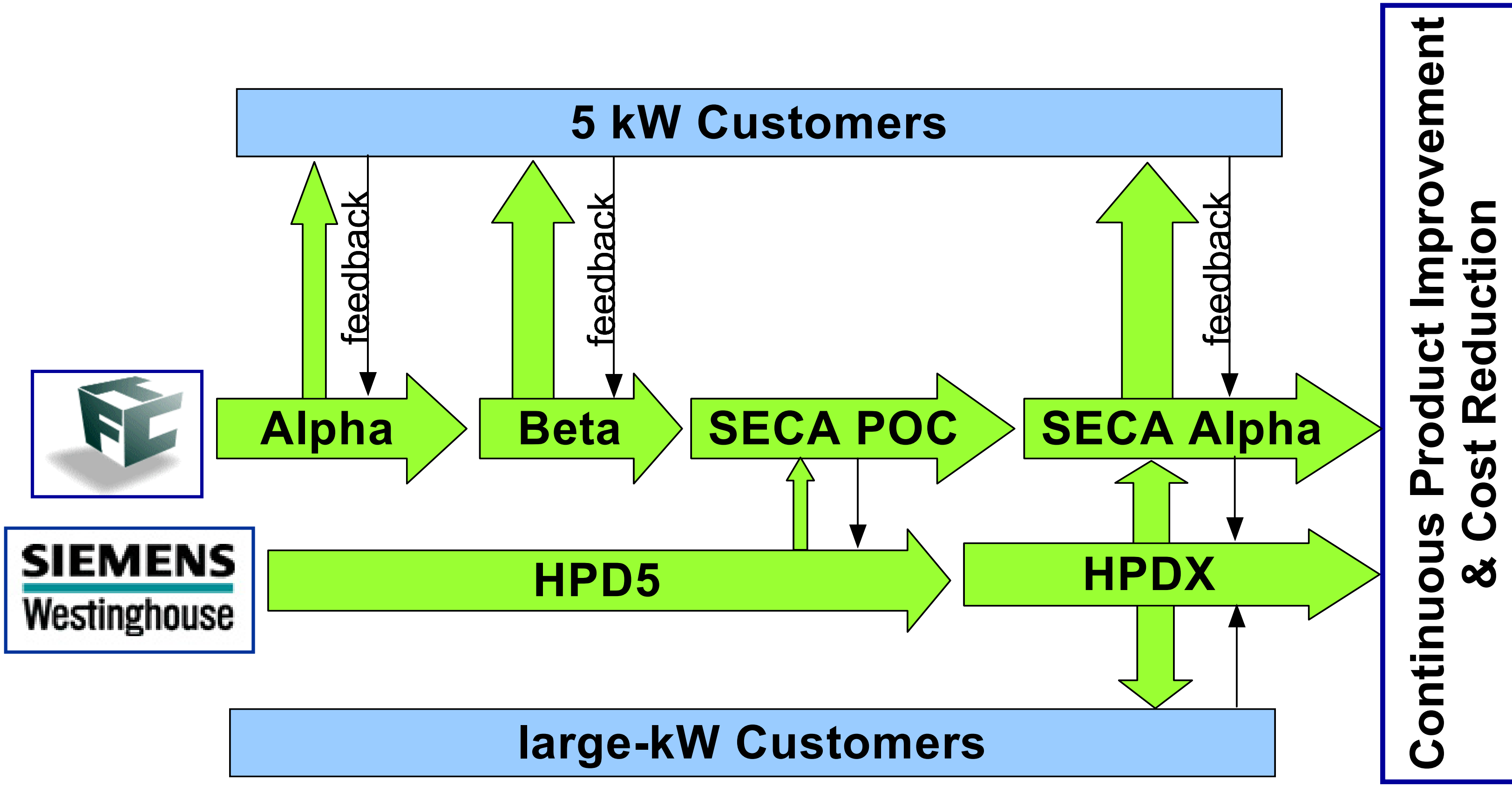

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Summary

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- Contract for First 2 years Signed in September 2002
- Fabricated HPD5 cells and demonstrated higher power density over cylindrical cells
- Optimization of HPD cell design through modeling on-going
- HPD cell bundling process developed – Further cost reduction opportunities explored
- Increased power density of YSZ electrolyte cells at 900 ºC through improved cathode-electrolyte interface - Further reduction in operating temperature with YSZ electrolyte possible
- Alternate low temperature (800 ºC) electrolytes under evaluation
- POC design completed
- Use of low cost module materials planned in POC
- BOP of POC being tested in FCT Beta units
- Planned POC startup: Fall 2004

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Future Work (Phase 1)

- Continue Optimization of HPD Cell Design and HPD Cell Fabrication
- Continue Evaluation of LSGM and ScSZ as 800 ºC Operating Temperature Electrolytes
- Continue Performance Improvement of YSZ Electrolyte Cell at Lower (800 –900 ºC) Temperatures
- Assemble and Test POC System in Fall 2004
- Incorporate POC System Lessons Learned and Cost Reduction Developments in Alpha System Scheduled at the end of Phase 1 (2006)

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Acknowledgements

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- Blasch Precision Ceramics

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