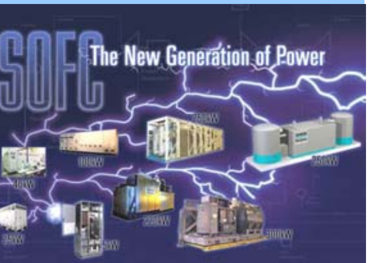
Stationary - Fuel Cells



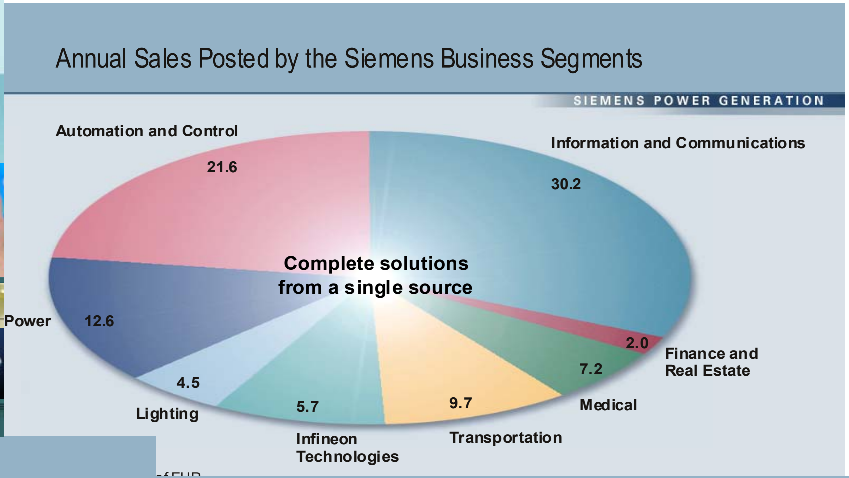
SECA Program at Siemens Westinghouse

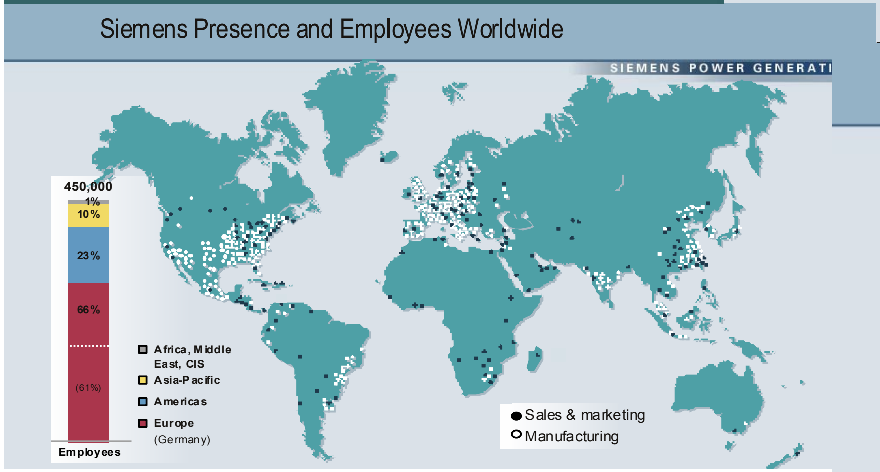
S. D. Vora

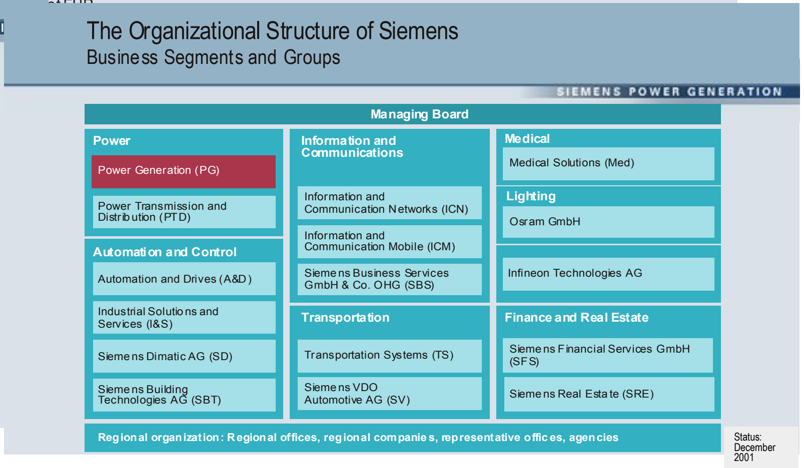
April 2003

Siemens Westinghouse Power Corporation

April 15, 2003







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Siemens AG
Power Generation

SIEMENS Westinghouse

- 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 Co Mo
- Industrials Solutions and
- Siemens Automotive
- Sie Bu Ser Gm OH
- Infineon Technologies AG (Siemens subsidiary)
- Siemens Financing Services (SFS)

Power Generation

Fossil Power Generation

- Americas
- Europe, Middle East, Africa, Asia/ Pacific
- Operating Plant Services
- Gas Turbine- and Combined-Cycle Plants
- Steam Turbine Plants and Electric Generators

Instrumentation & Controls

Industrial Applications

Stationary Fuel Cells

Ceramics and Porcelain
(Carved out in Q4 FY02)

JV Framatome ANP
since Jan. 2001
(Siemens share 34%)

JV Voith Siemens Hydro
since April 2000
(Siemens share 35%)

Siemens Power Generation
Employees 25,000

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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

- 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

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SOFC Power System Demonstrations with Tubular SOFCs

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100 kWe Atmospheric Combined Heat and Power (CHP) System

- 20,000+ hours with no measurable voltage degradation
- 46% electrical efficiency
- Grid and District Heating Connected

200 kWe Pressurized Hybrid (PH) System

- 3000+ hours
- 52% electrical efficiency

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Lower Product Cost ($/kWe)

Cost ↓

Power Density ↑

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SECA Program Objectives

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

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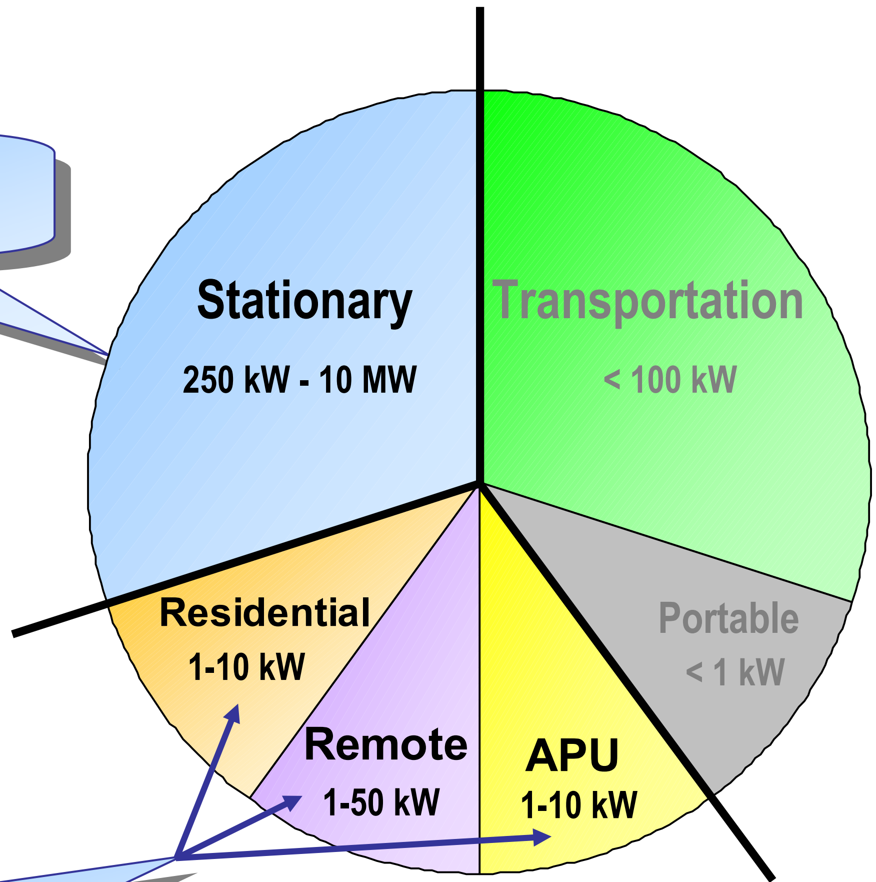
Present Focus



SECA

Focus on New Market Segments;
Cost Target < $400 /kW

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SECA -10 Year Roadmap

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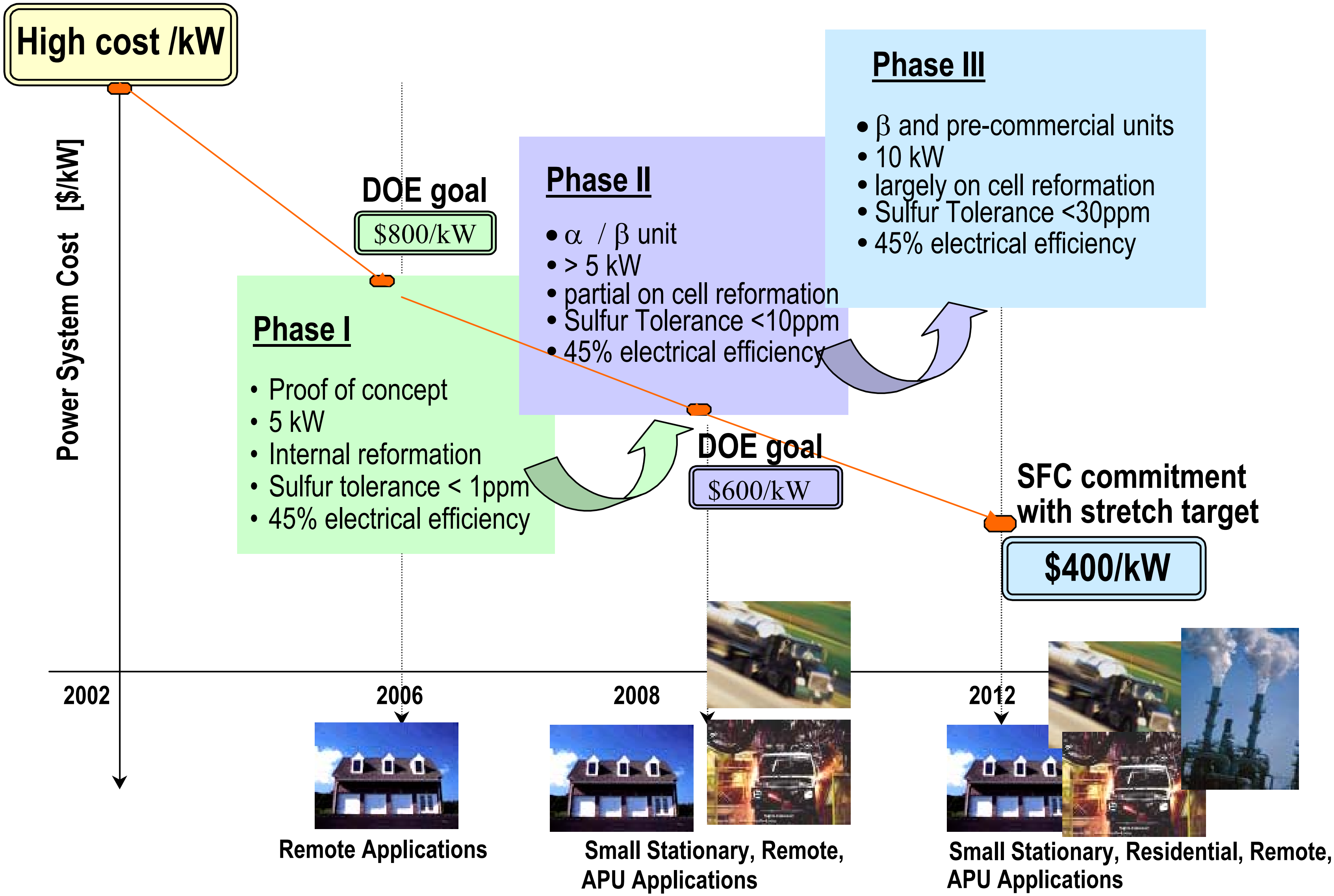

Stationary - Fuel Cells

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Siemens Westinghouse SECA Team

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		
Zircar Refractory Ceramics	Dominion		

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

- 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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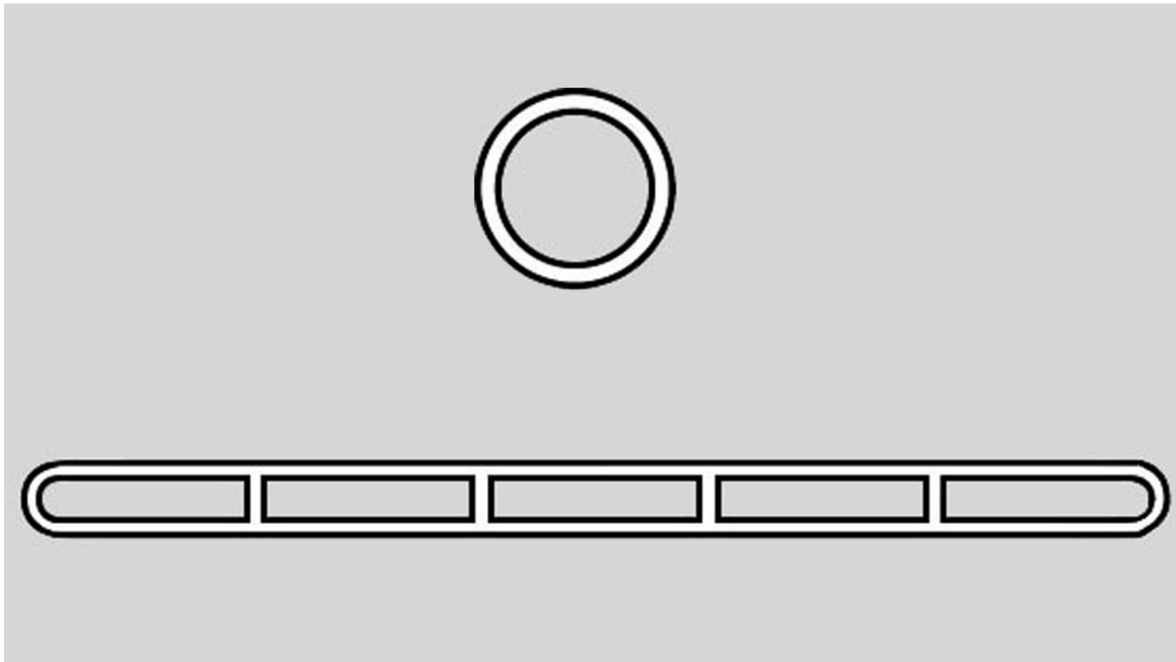
High Power Density (HPD) Cathode Supported Planar Concept



2.2 cm Cylindrical (Present)

Cathode Supported Planar

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

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Development of HPD Cell Design

- Computational Thermal Model of HPD Cell Developed to Optimize Cell Design and Dimensions
- Theoretical Performance Estimated by Electrochemical modeling

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Evolution of Cell Design

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Standard Cylindrical

HPD5R0-2002

HPD5R1-2003

HPD10 >2003

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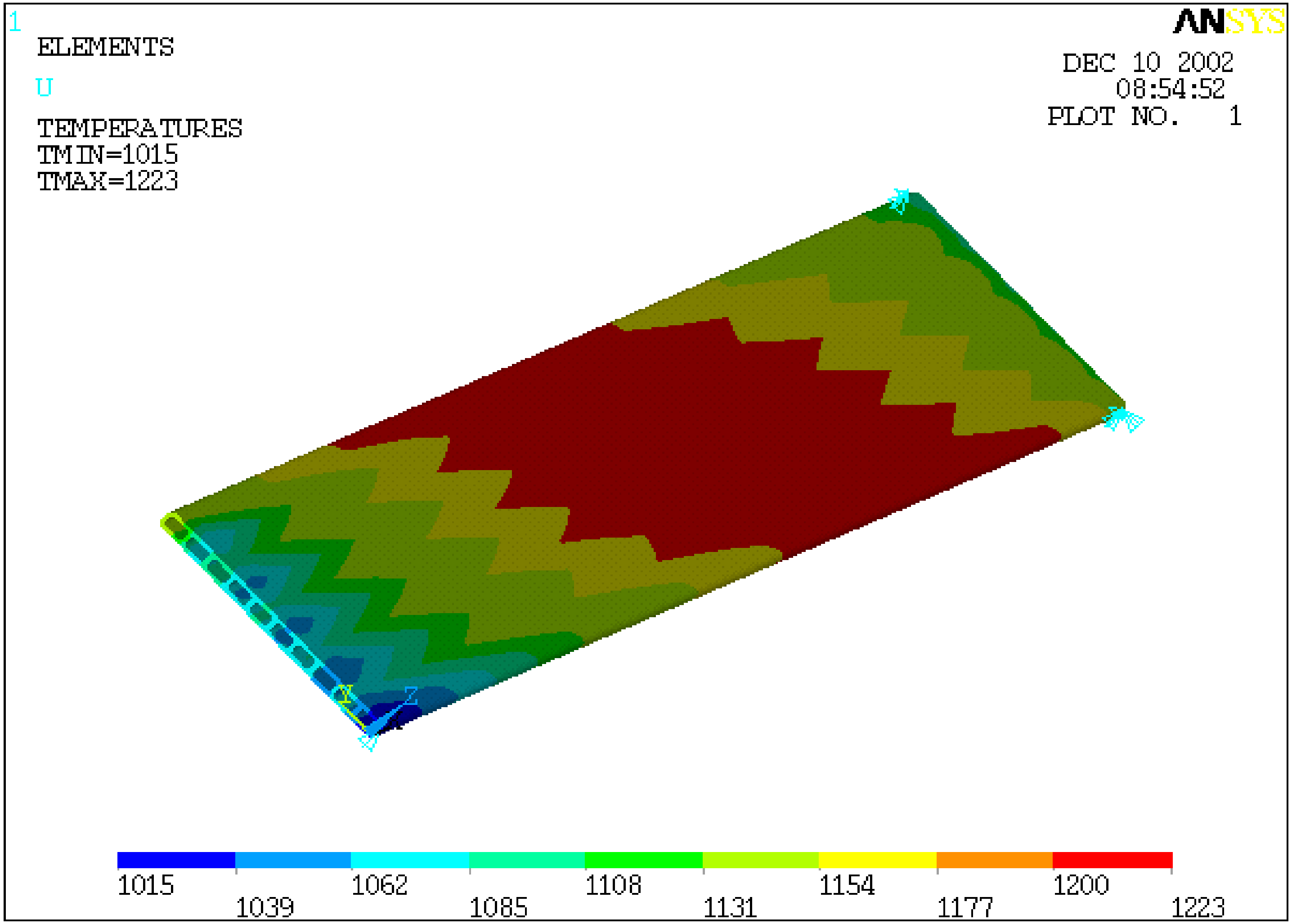
Temperature Distribution in HPD10 Cell



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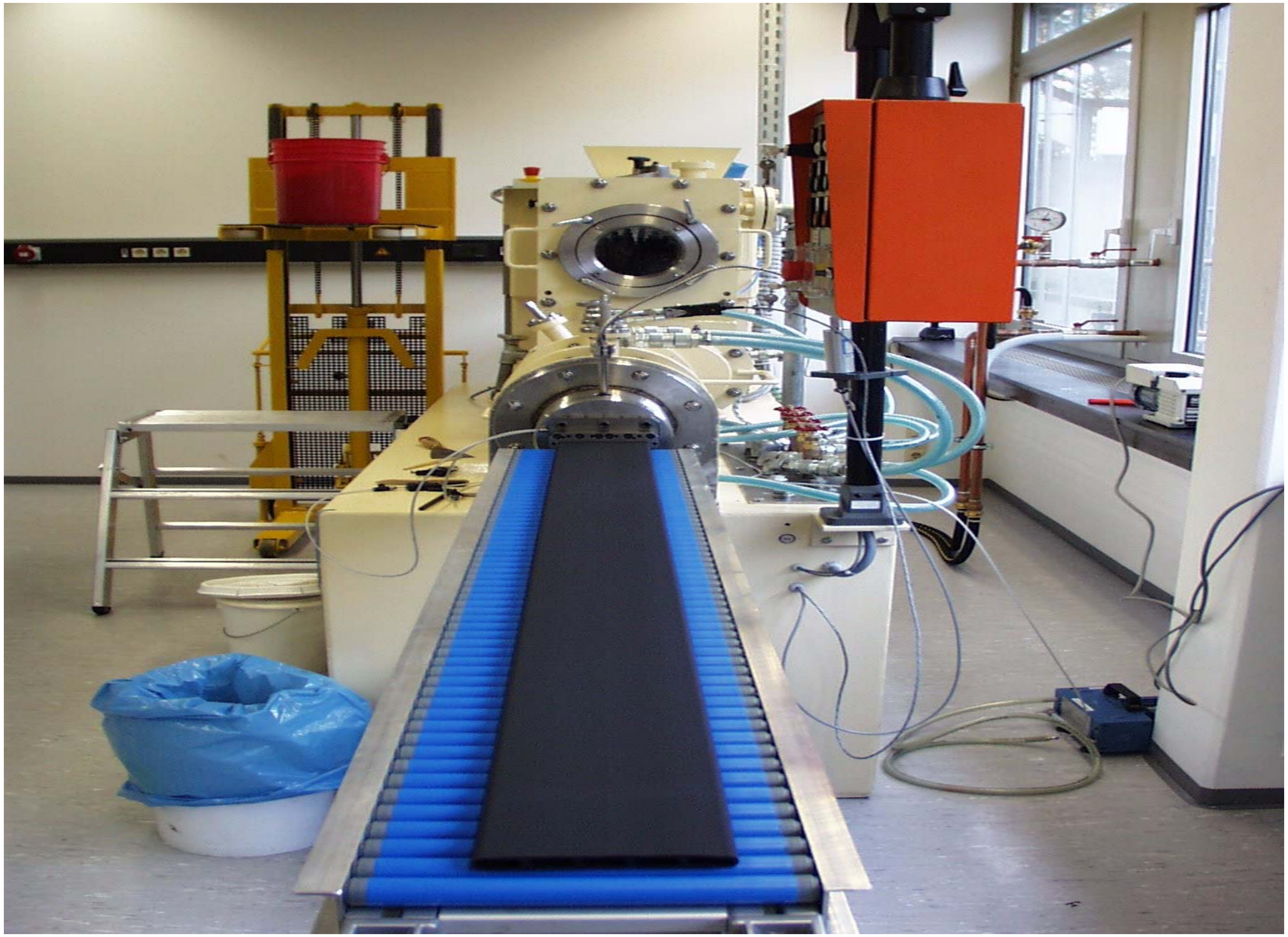
Extrusion of HPD Tube



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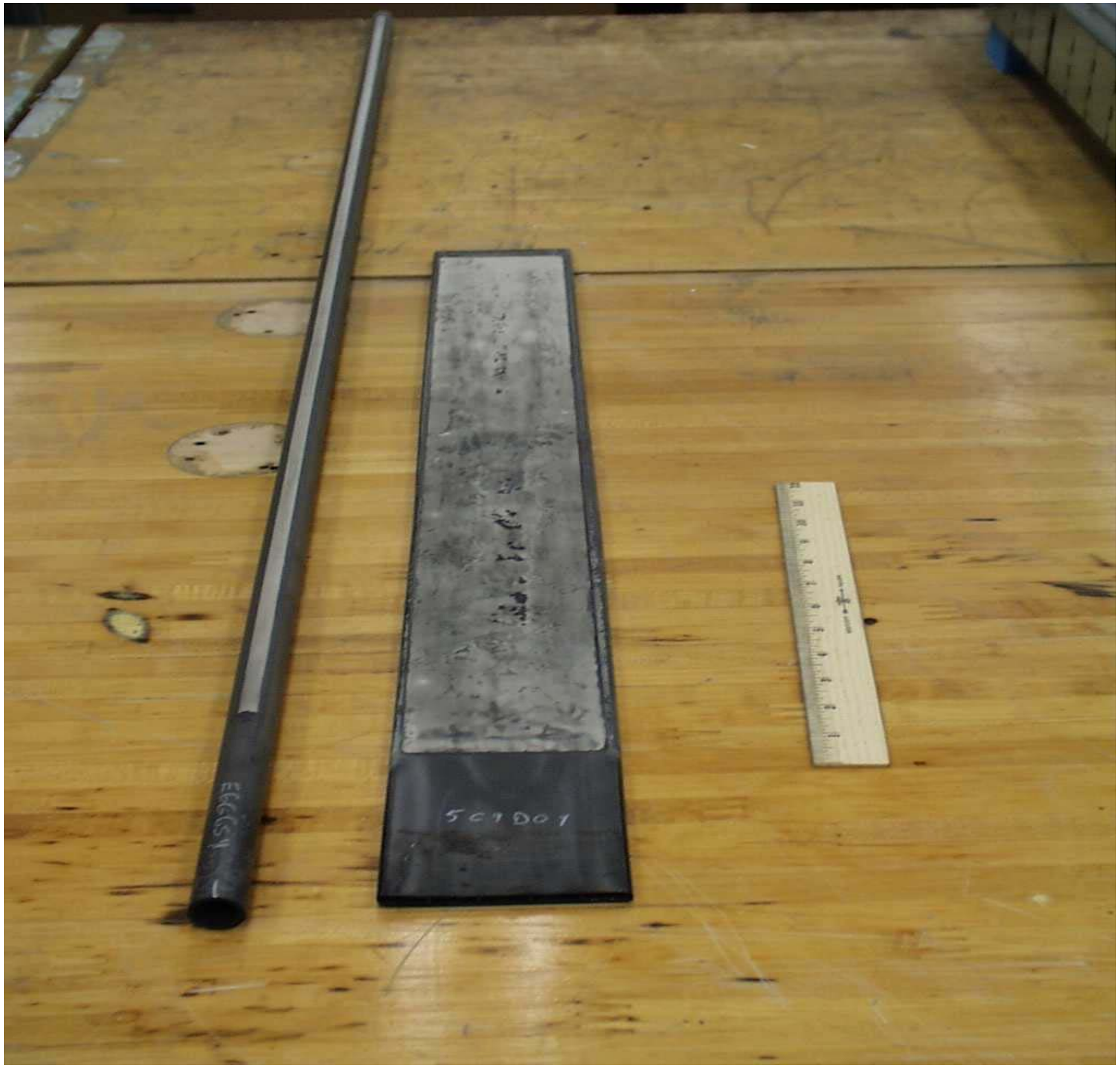
Tubular and HPD Cells



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April 2003

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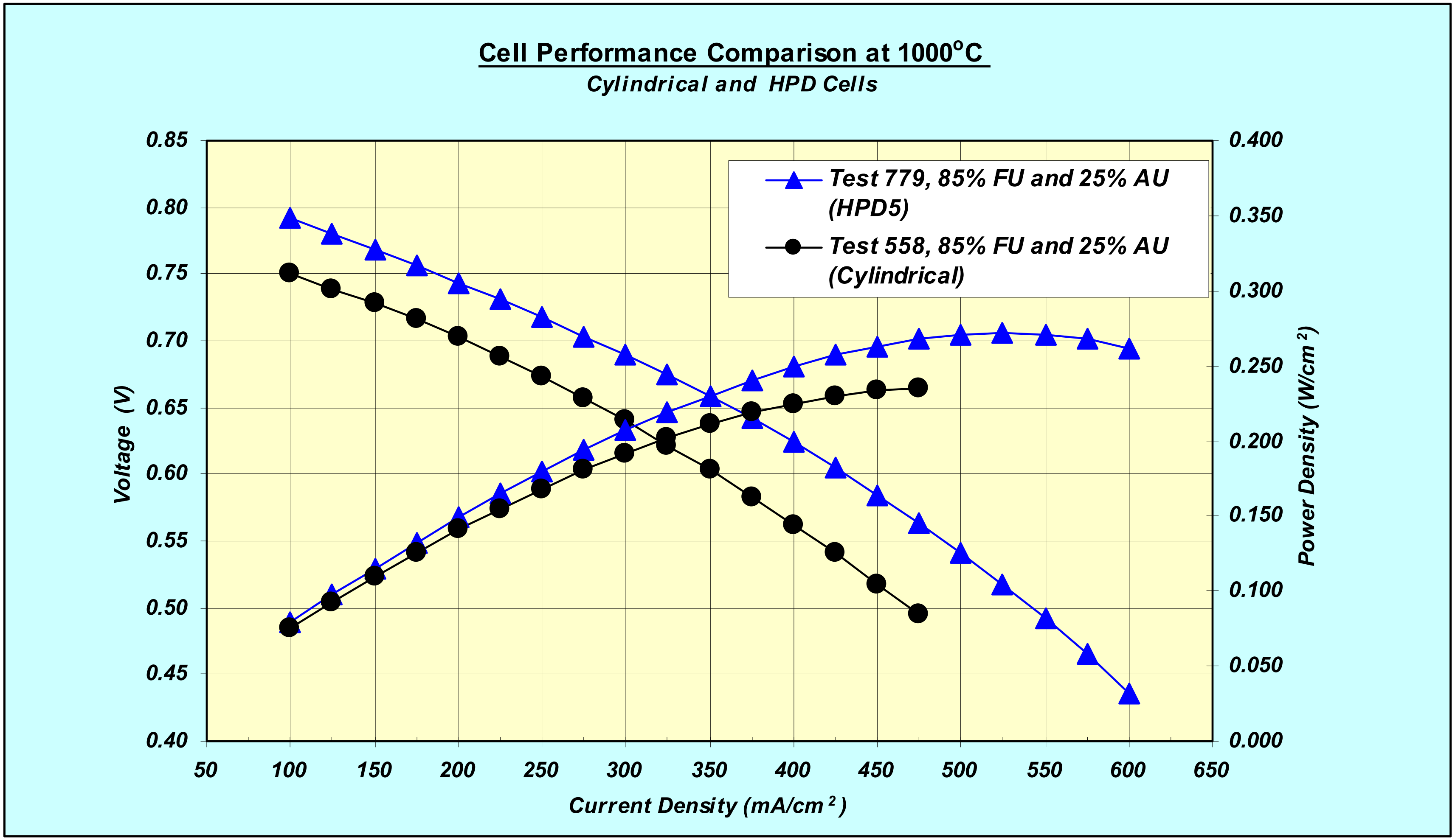
Performance Comparison - Tubular Vs. HPD5



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Cell Power Enhancement

- Developed Mixed Ionic and Electronic Conducting Composite Interlayer
- Lowered Activation Polarization at the Cathode-Electrolyte Interface - Enhanced Cell Performance at Lower Temperatures

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Performance Comparison - Std. Interlayer Vs. Composite Interlayer (Tubular Cells)

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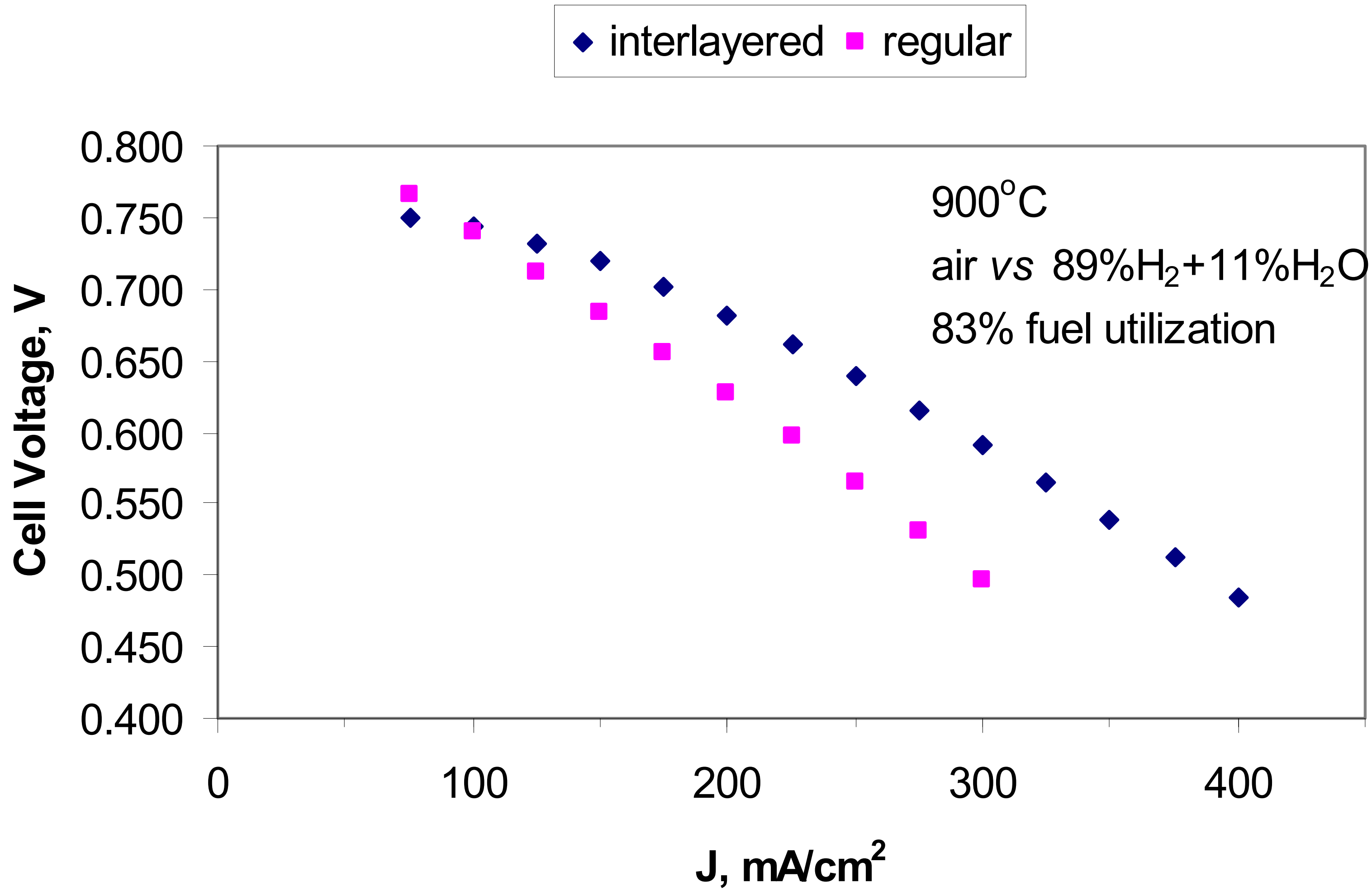

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Performance Comparison - Tubular Vs. HPD

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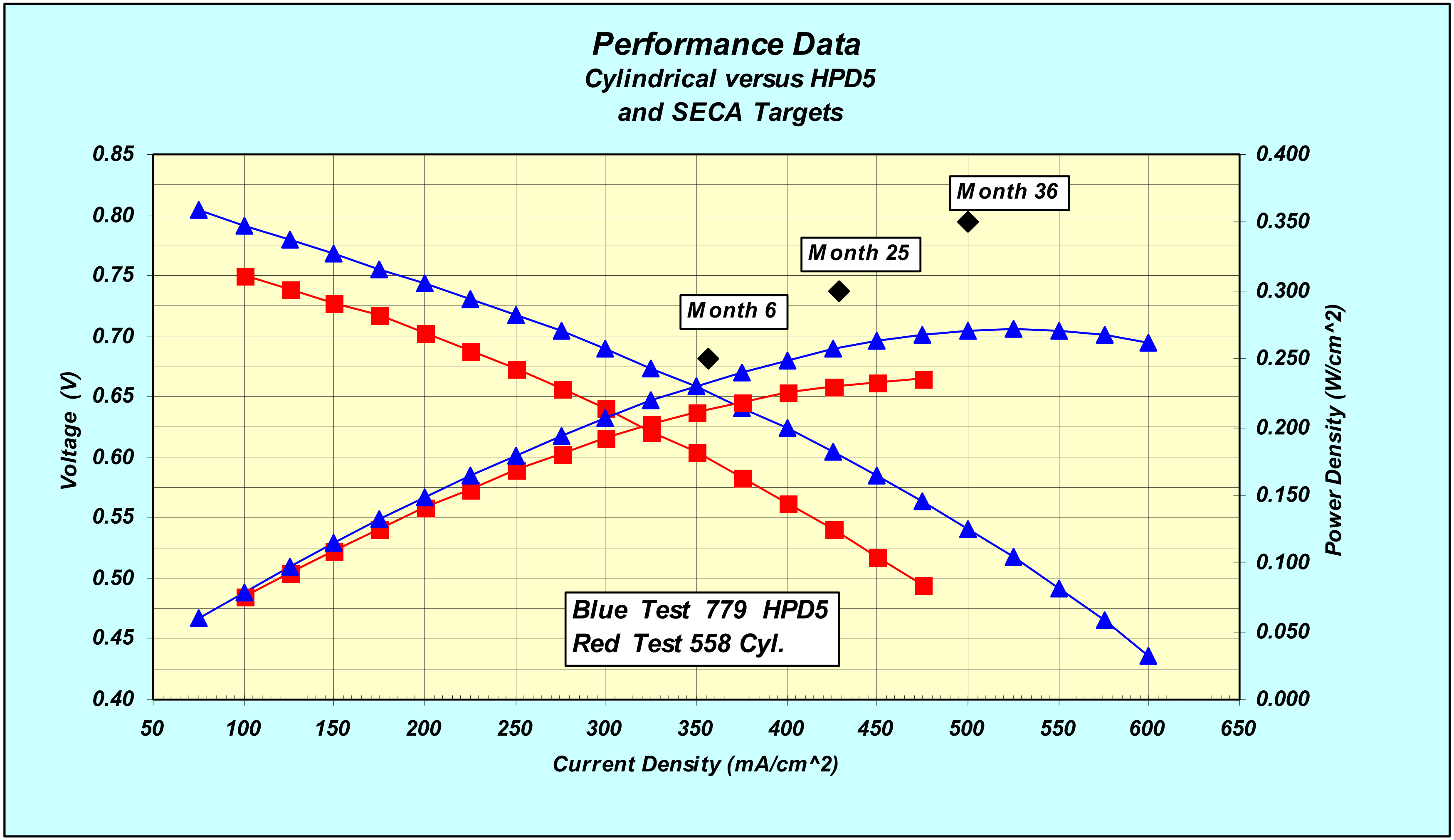

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Cell Development - Summary

- Reduction in Ohmic Resistance through HPD Design
- Reduction in Activation Polarization through Composite Interlayer
- Target Power Increase for HPD Cells Compared with Tubular Cells - 2X at Half the Length
- Improves Packing Density

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Selected LSGM (Mg and Sr doped lanthanum gallate) for Evaluation

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LSGM As Low Temperature Electrolyte

- **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 Cost Reduction due to Lower Operating Temperature**

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Characterization of Properties of LSGM and Compatible Materials

- Electrical Conductivity
- Thermal Expansion Coefficient
- Dimensional Stability
- Chemical Reactivity of LSGM with Cathode Substrate at Operating Temperature
- Electrochemical
- Feasibility of Plasma Spraying LSGM Film on Cathode Substrate

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Selection of LSGM and Compatible Materials

- Electrolyte: LSGM
- Cathode: Doped Lanthanum Manganite
- Interconnection: Doped Lanthanum Chromite
- Cathode Interlayer: Mixed Ionic and Electronic Conductor
- Anode Interlayer and Anode: TBD

Over 10 compositions of Cathode and Interconnection were selected for Screening

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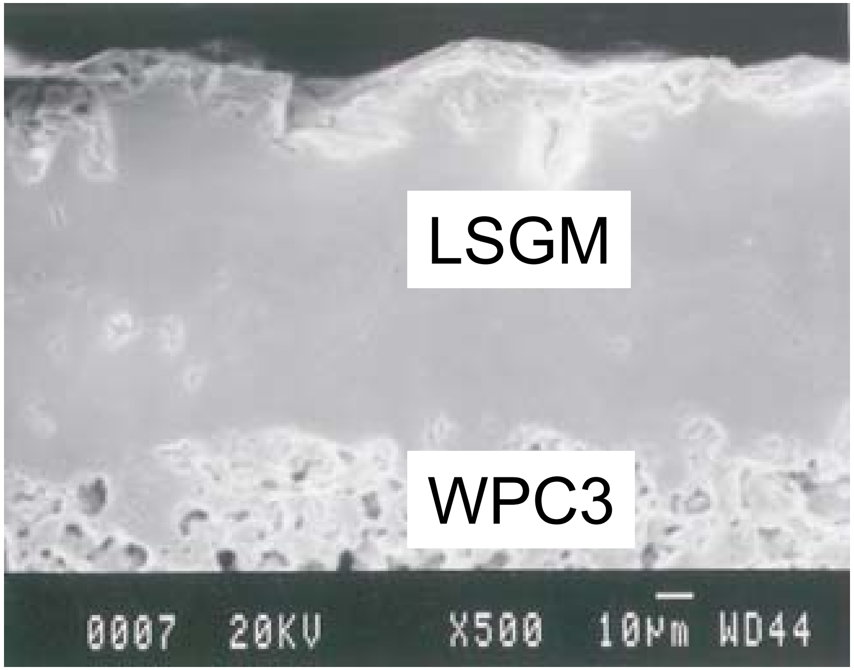
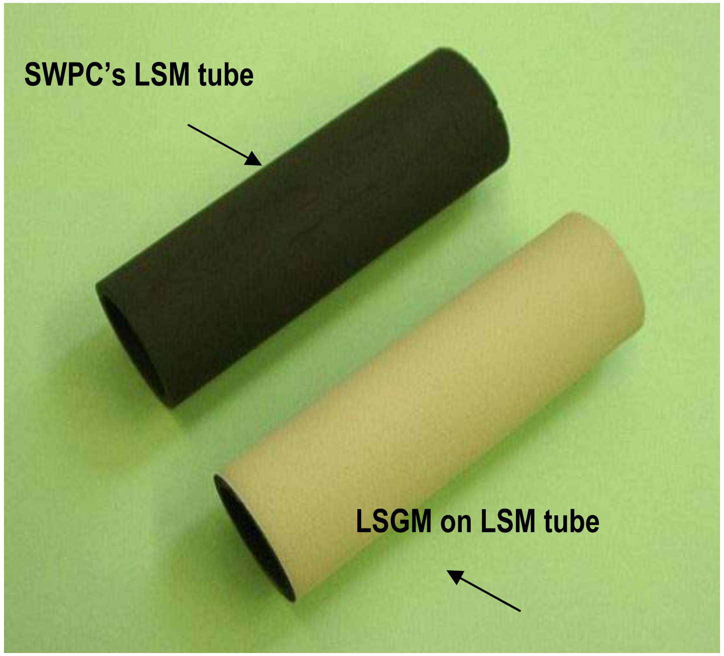
Plasma Spraying of LSGM Layer on Cathode Substrate

As sprayed





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Low Temperature Electrolyte - Summary

- **Selected Electrolyte and Cathode Compositions**
- **Prepared Powders for Cell Preparation and Electrochemical Characterization**
- **Initiated Feasibility Study of Plasma Spraying LSGM on Cathode**

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Low Cost High Volume Manufacturing

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- Initiated Feasibility study of All Sintered Cell
  - Higher Material Utilization
  - Reduced Manufacturing Steps
  - Higher Throughput
- Initiated Feasibility Study of Low Pressure Plasma Spraying (LPPS)
  - Higher Material Utilization
  - Lower Densification Temperature
  - Higher Throughput

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Low Cost Module Materials (With Blasch)

- Initiated Development of Low Gas Permeable Ceramic Stack Housing
- Initiated Feasibility Study of Lower Purity Insulation (Possible Due to Lower Operating Temperature)

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Generator Design and BOP Simplification (With FCT)

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Model
Showing
FCT Alpha
Prototype

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Generator Design and BOP Simplification (With FCT)

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FCT Recirculator Design in Testing

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Generator Design and BOP Simplification (With FCT)

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SOFC The New Generation of Power

Prototype Combustor and Flame Holder Designs

Stationary Fuel Cells

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Summary

- Incorporating Lessons Learned from Alpha Demonstration Units.
- Beta Unit with Full Length (834 cm^2 active area) Tubular Cells Being Designed with an Objective to Maintain Commonality Between Beta and SECA Units.
- Design of SECA Unit with HPD Cells Initiated.

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SECA Program Summary

- Contract for First 2 years Signed in September 2002
- HPD5 Selected as Baseline Design for Development and Test
- HPD10 Undergoing Evaluation
- LSGM vs. YSZ Evaluation Initiated
- LPPS, Thin-film Sintering Processes being Evaluated as Alternative to Atmospheric Plasma Spraying
- Low Cost Module Materials Being Investigated
- Generator Design and BOP Simplification Initiated

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Future Work

- Continue Development of Cell Design and Cell Fabrication
- Make a Decision on LSGM Vs. YSZ for POC Unit
- Develop Generator Design for POC unit

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Stationary Fuel Cells

- Siemens Westinghouse Stationary Fuel Cells converted from R&D department to a business unit with a pilot manufacturing facility
- First environmental friendly commercial product CHP 250

  (no SOx; no CO; NOx < 1ppm)

- New Commercial factory (Milestones):

  1-Site Selection/Groundbreaking ☑
  2-Finalized Manufacturing Building ☑
  3-Implemented Manufacturing Equipment ☐
  4-Qualified Production Processes ☐
  5-Start Commercial Shipments ☐

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Stationary Fuel Cells - Manufacturing Facility

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Munhall, Pennsylvania Location…180,000 sq. ft. - Phase I Building

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