SFC Stationary - Fuel Cells

Presented at Sixth Annual SECA Workshop
Pacific Grove, CA
April 18-21, 2005

SIEMENS Westinghouse

# SECA Program at Siemens Westinghouse

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April 2005

Siemens Westinghouse Power Corporation
April 18, 2005

DOE Program Manager
Don Collins

# Siemens Westinghouse Stationary Fuel Cells

SIEMENS Westinghouse

- 150 employees
- Chartered to commercialize SOFC power systems for the distributed generation market
- Focused on seal-less, cathode supported 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), seal-less, 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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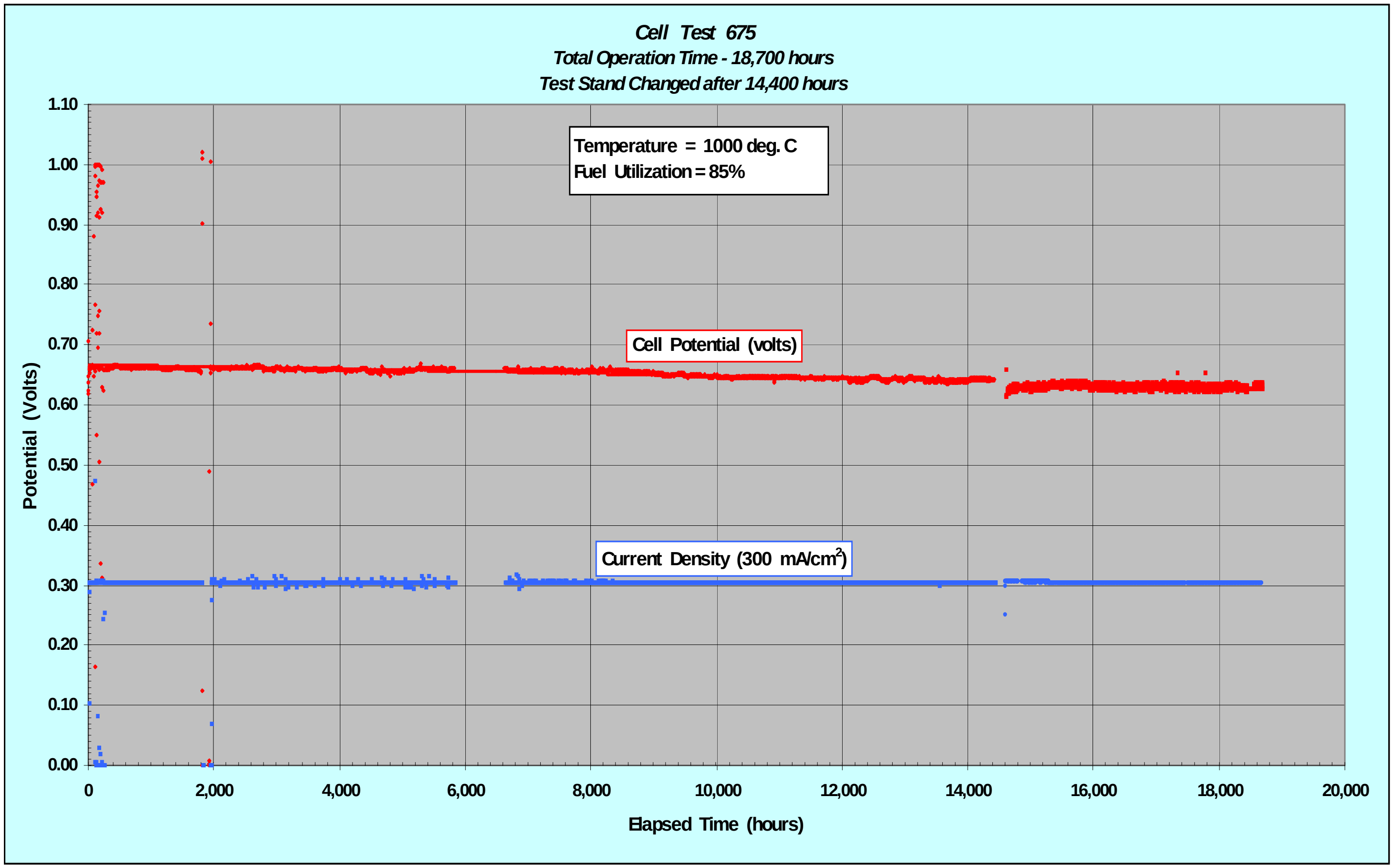
# Stationary Fuel Cells - Accomplishments

## Voltage Stability of Tubular APS Cell




**Cathode**

**Extruded**

**and**

**Sintered**

**IC, EL and Anode**

**APS**





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## Stationary Fuel Cells - Accomplishments

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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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# SECA Program - Objectives

SIEMENS Westinghouse

**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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# SECA Program - Technical Approach

SIEMENS Westinghouse

- **Improve cell performance through advances in**
  - ➢**Materials**
  - ➢**Processing**
  - ➢**Cell design**
- **Lower operating temperature (800ºC)**
- **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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# Siemens Westinghouse SECA Program - 10 Year Roadmap

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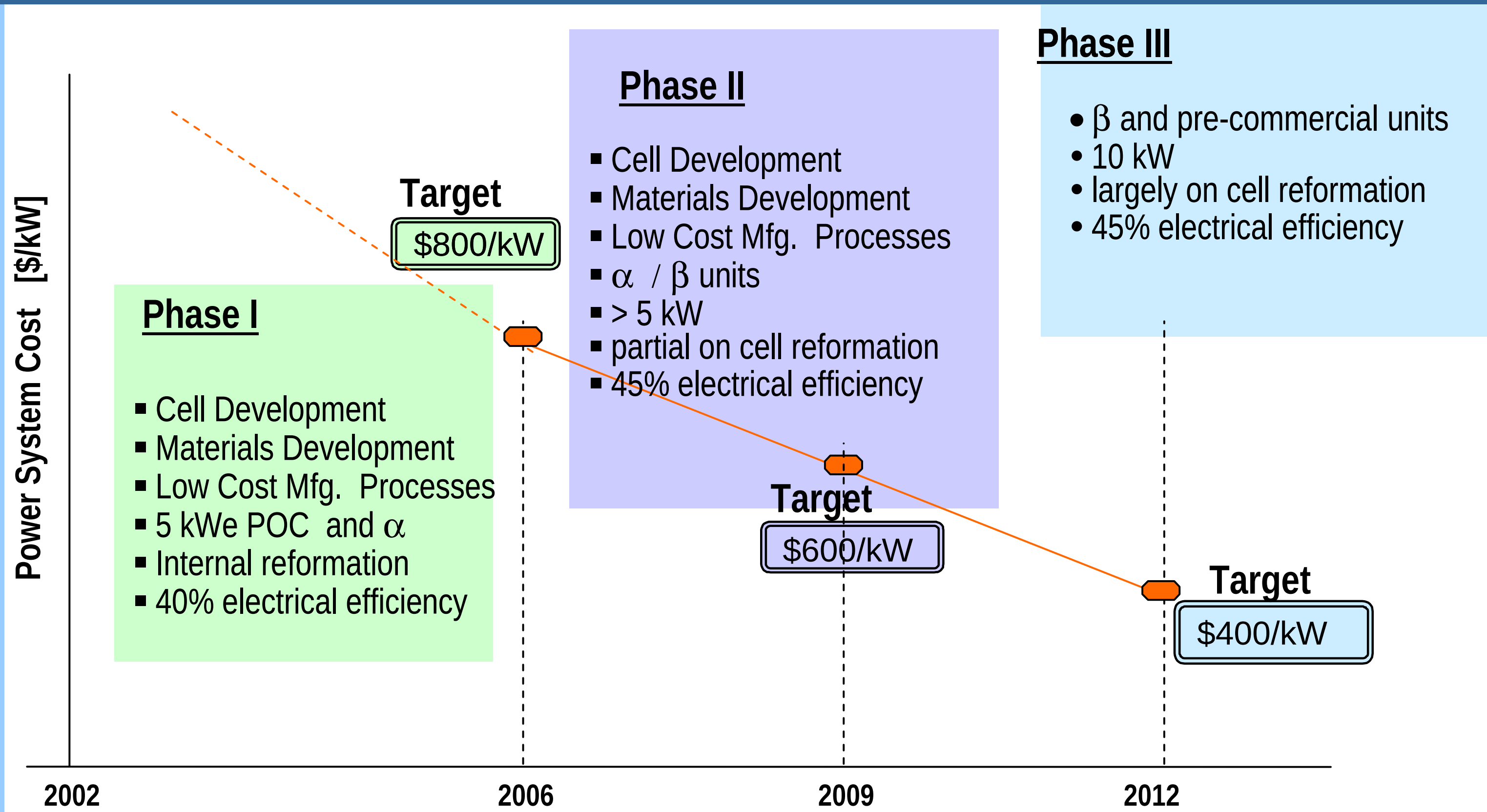






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# Cell Power Enhancement





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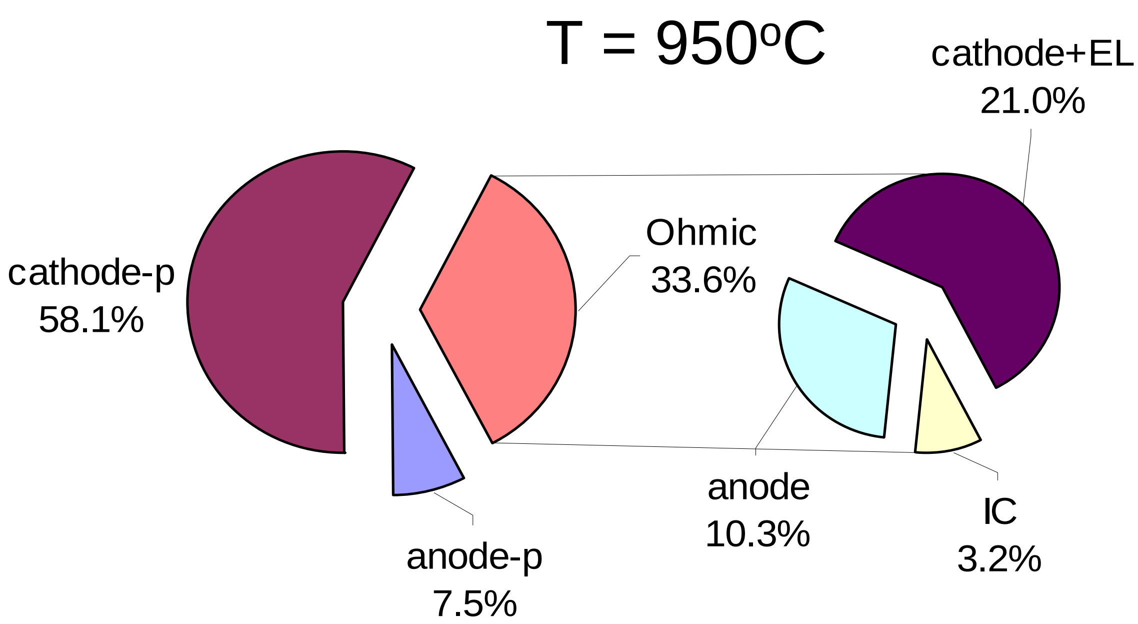
# Cell Power Enhancement – Key Contributors

SIEMENS Westinghouse

**The electrical performance of Siemens Westinghouse cells is primarily influenced by the cathode–electrolyte interface**





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# Strategies for Cell Power Enhancement

SIEMENS Westinghouse

- Materials
- Processing
- Cell design

## Cell Power Enhancement

- **Lower cathode polarization**
  - **Increase charge-transfer reaction sites**
    - Replace existing cerium oxide interlayer with a composite interlayer
  - **Lower EL densification temperature**
    - Optimize electrolyte plasma spray process to lower densification temperature
  - **Increase cathode conductivity**
    - Change dopants to increase low temperature conductivity of LSM cathode
- **Lower ohmic resistance**
  - **Increase cathode conductivity**
    - Change dopants to increase low temperature conductivity of LSM cathode
  - **New cell geometry**
    - High Power Density (HPD) cell with integral ribs



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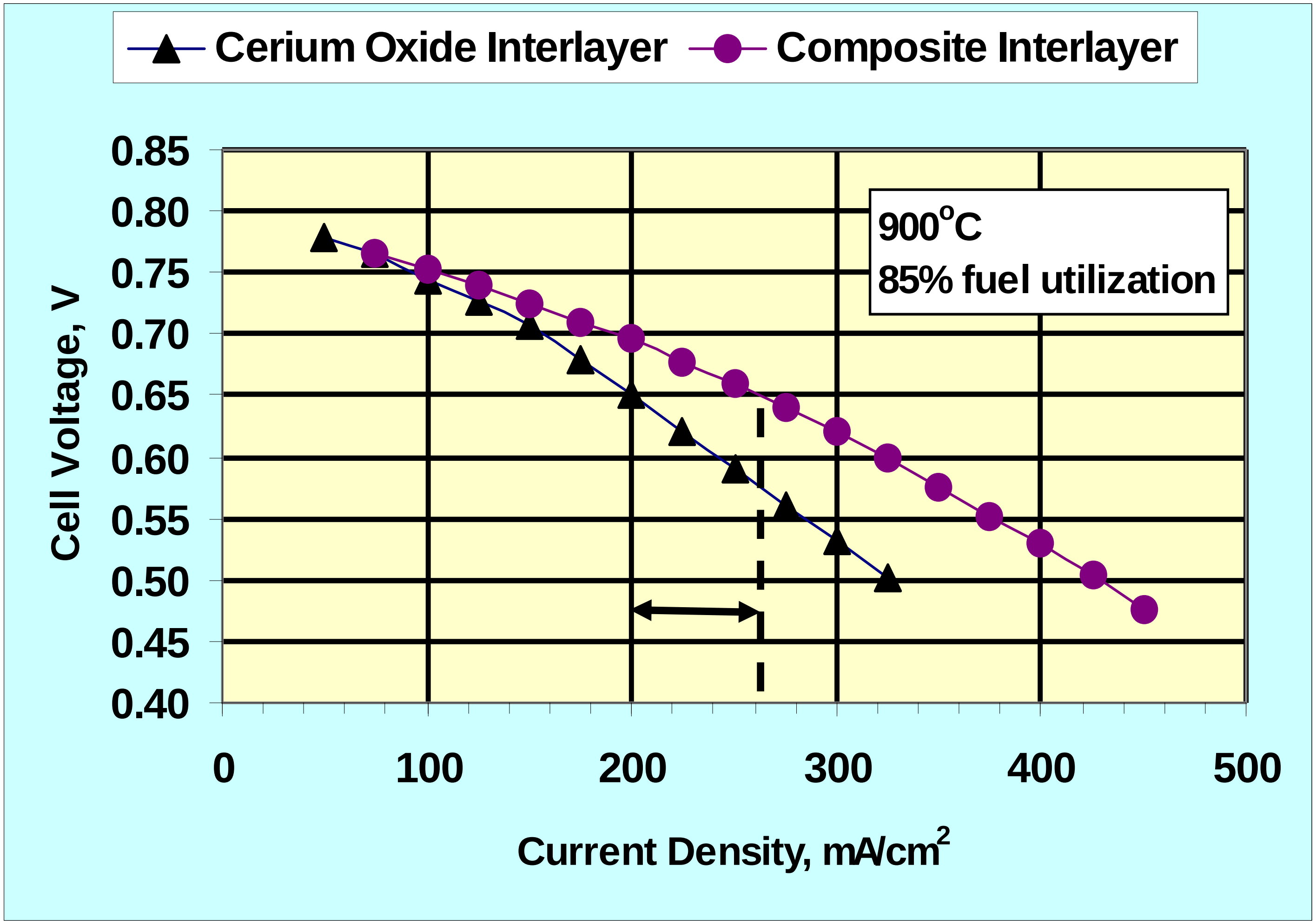
# Performance Enhancement with Improved Cathode-Electrolyte Interface - Effect of Interlayer

SIEMENS Westinghouse

**Power enhancement through material change**

**Over 30% Power enhancement at 0.65 V**

**Tubular cells**





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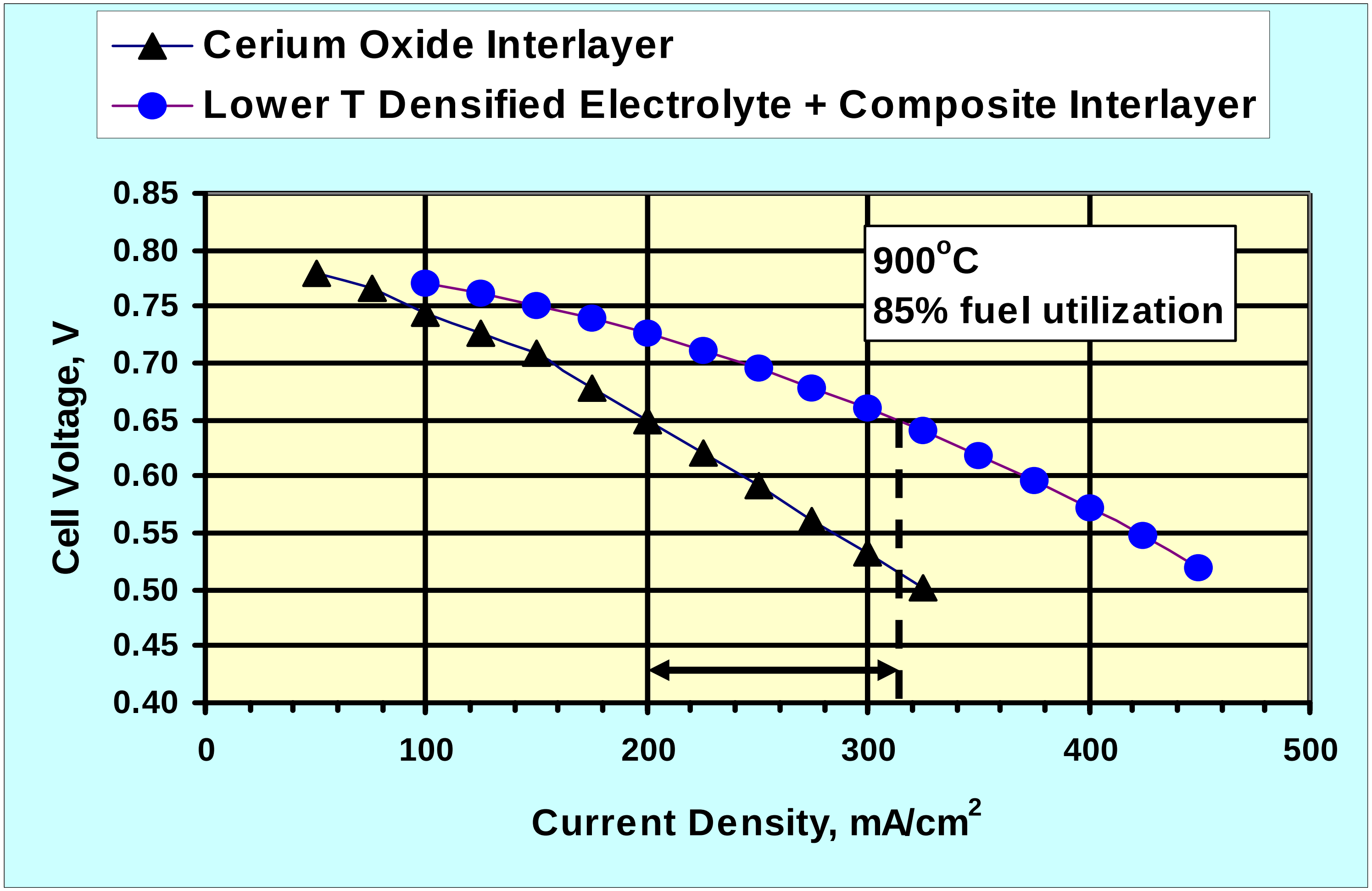
# Performance Enhancement with Improved Cathode-Electrolyte Interface Effect of Interlayer + Lower T Densification

SIEMENS Westinghouse

Power enhancement through material and processing change

>50% Power Enhancement at 0.65 V

Tubular cells





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# Higher Conductivity Cathode

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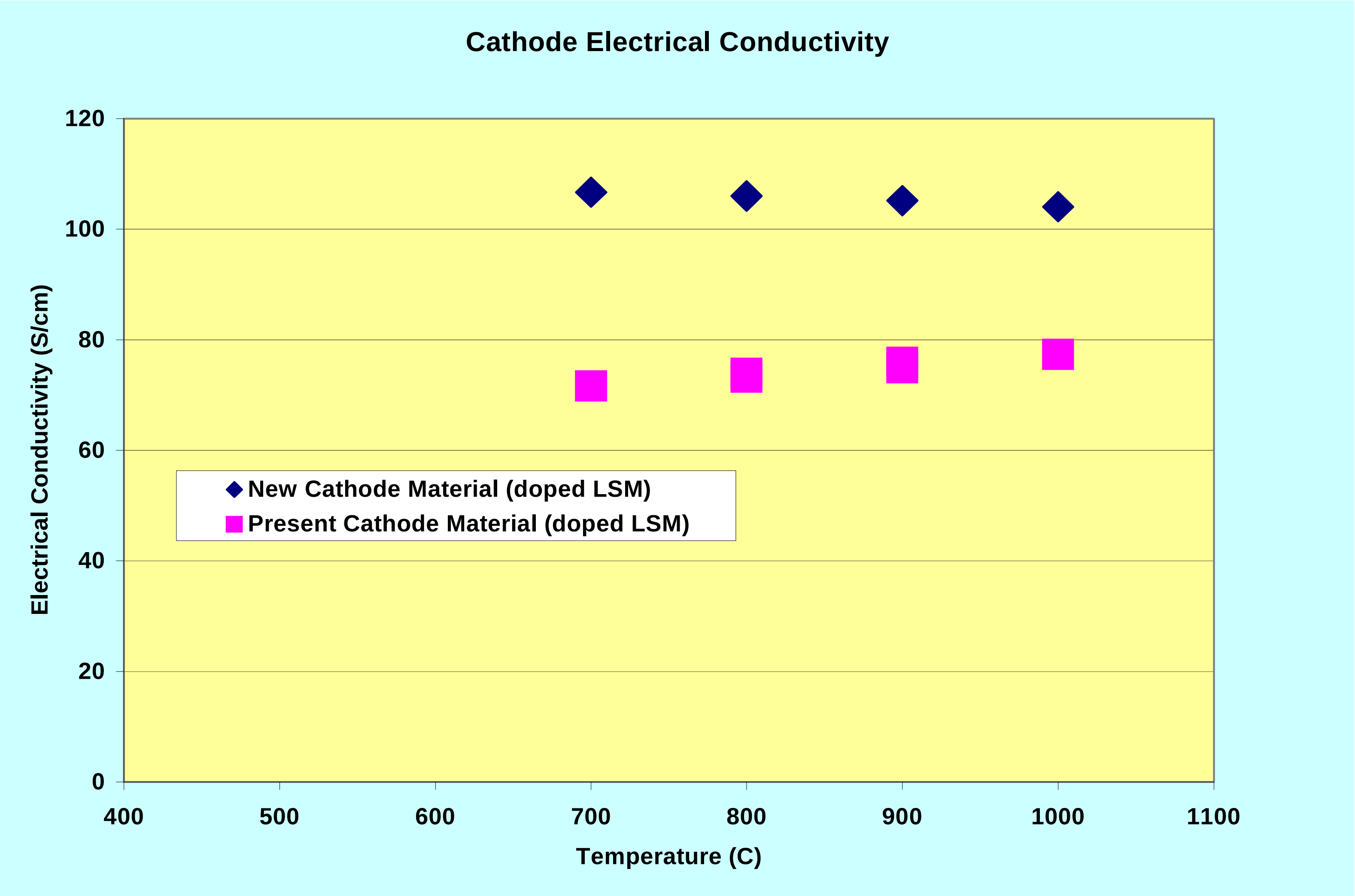
**Power enhancement through material change**

**Cathode conductivity increased by 50 % at 900 °C**

**Cell testing initiated**

**Overall 5-10% power enhancement expected**









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# Radially Graded Anode

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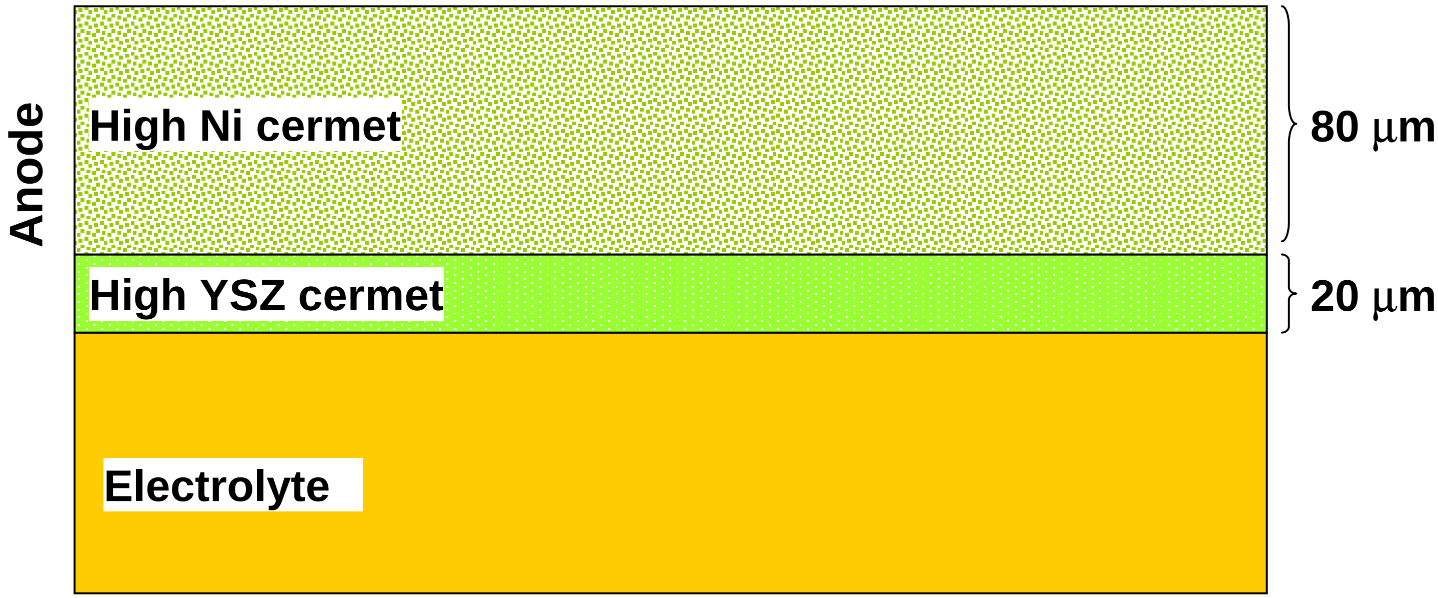
**Power enhancement through processing change**

**Cell testing initiated**

**Overall 3-5 % power enhancement expected**







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

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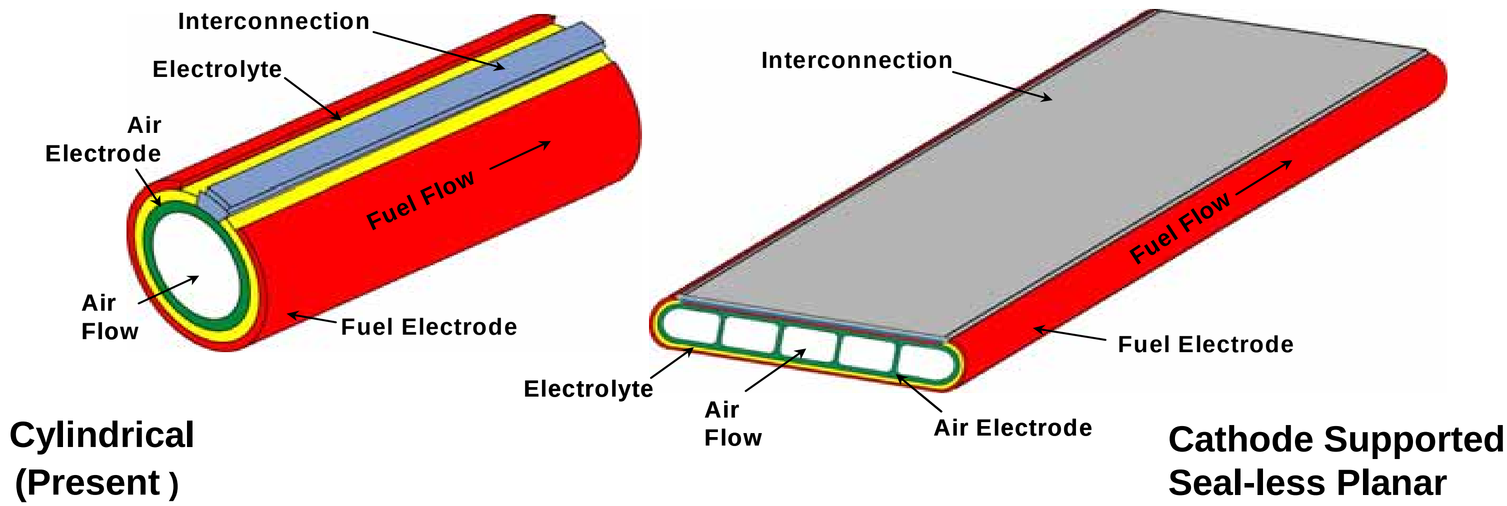
**Power enhancement through cell design**




- Maintains seal-less design
- Potential to eliminate air feed tubes
- Reduction in ohmic resistance
- Increase in cell power density
- More compact stack





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# HPD Cells

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- Selected HPD5 (five channels) as a baseline to develop cell and bundle fabrication processes and conduct electrical performance testing
- Selected HPD10 (ten channels) to explore the upper bounds of cell fabrication
- Current HPD cell active length is 75 cm
- Optimization/further improvement of cell design ongoing



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# Tubular and HPD Cells

**Active length**

**Tubular: 150 cm**
**HPD: 75 cm**




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# HPD Cell Testing

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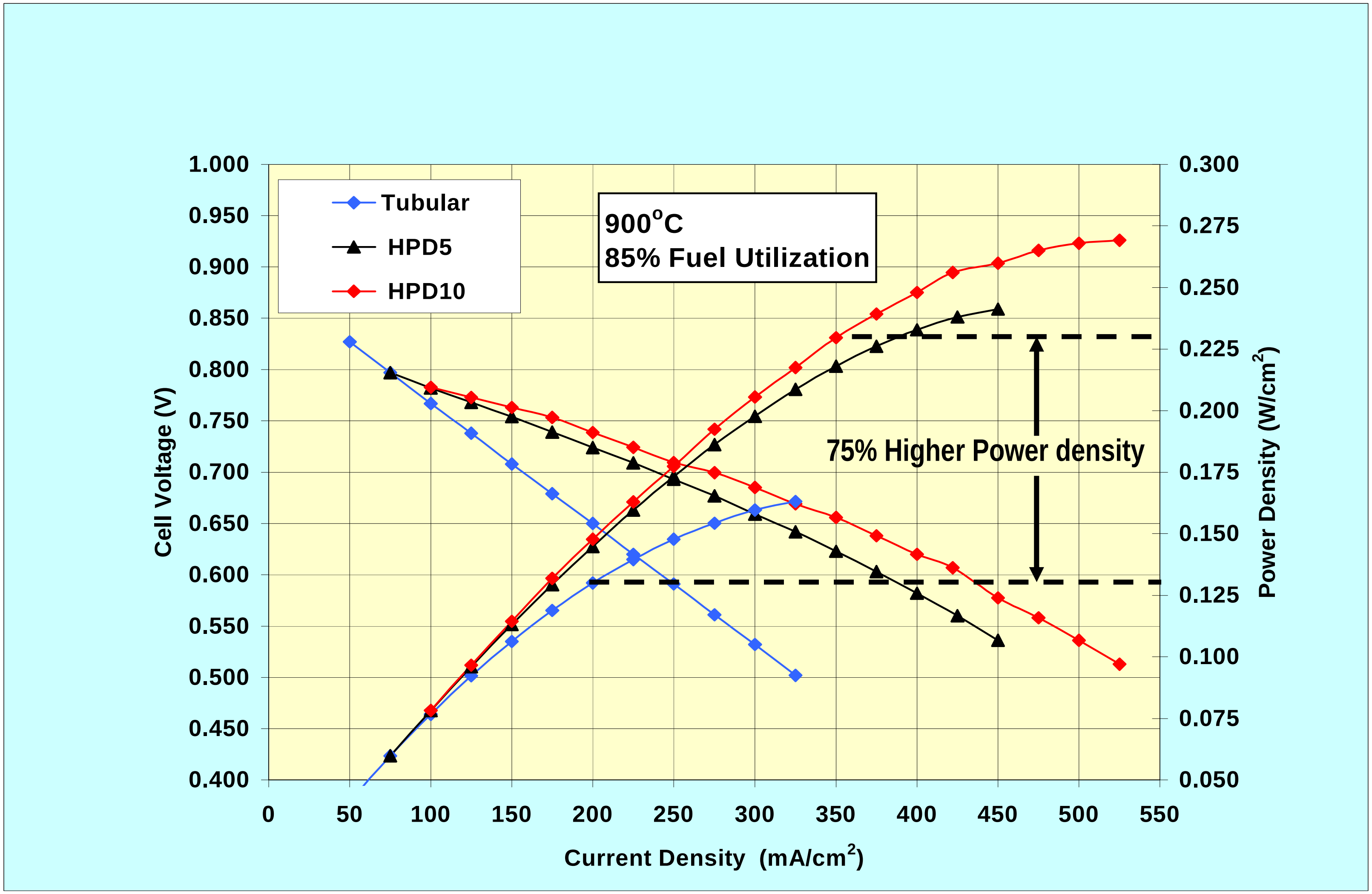
**Both HPD cells have composite interlayers**

**Power enhancement through cell design and materials**

**75% Power enhancement for HPD10 over tubular cell at 0.65 V**





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# HPD5 – Voltage Stability

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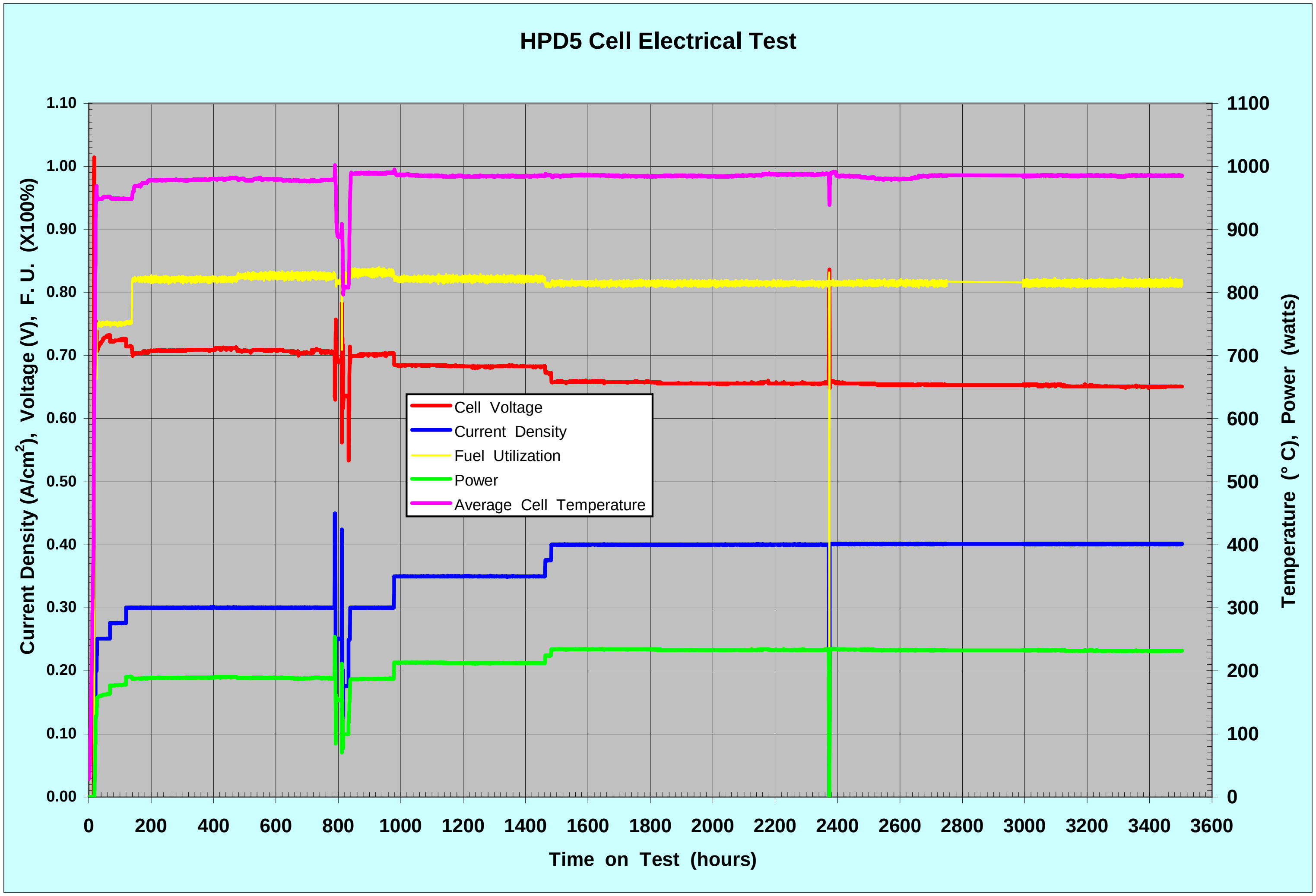
**Exceeded program goal of stable voltage for 3000 hours at 1000 ºC**





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# HPD10 – Voltage Stability

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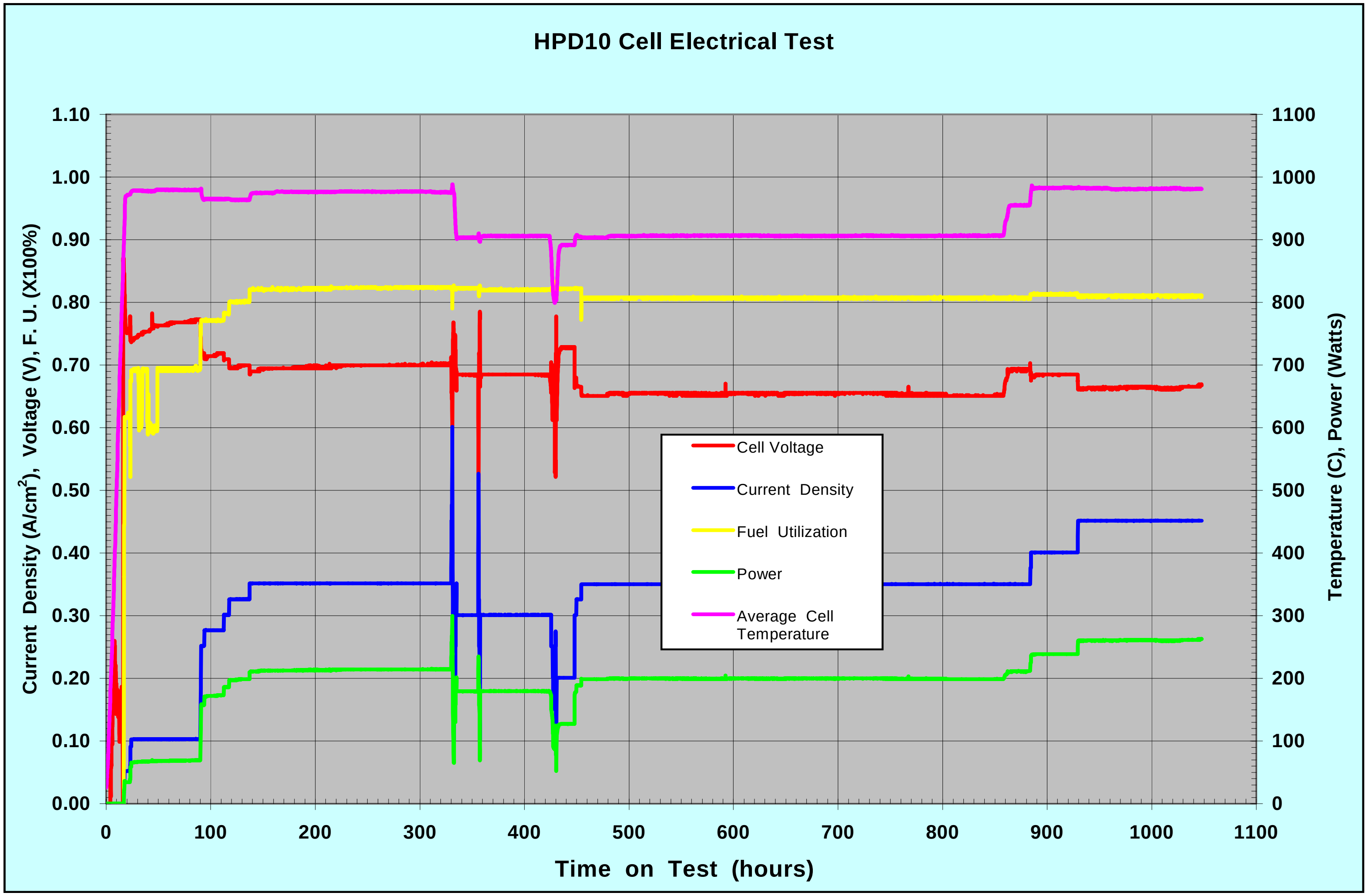


**Stable Voltage for over 1000 hours with increasing current density**

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# Cell Power Enhancement - Summary

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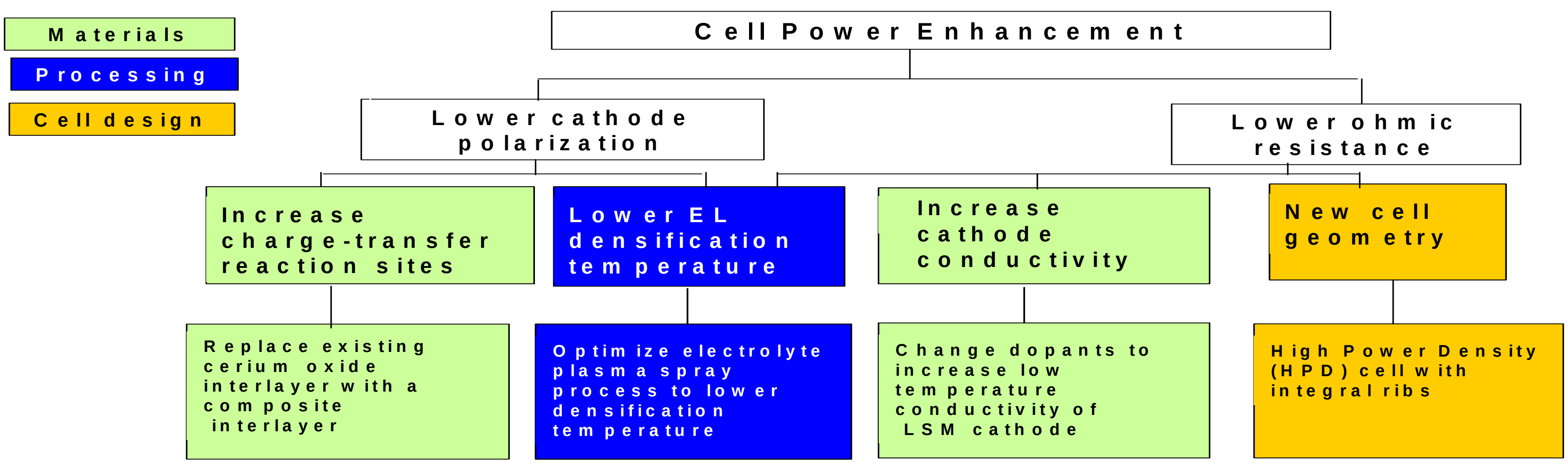
- Significant power increase relative to state-of the-art achieved through advances in materials, processing and cell design
- Further power enhancement expected after integration of individual contributions and optimization/finalization of HPD cell design



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# HPD Cells - Bundling





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# HPD Cell Bundle Configuration

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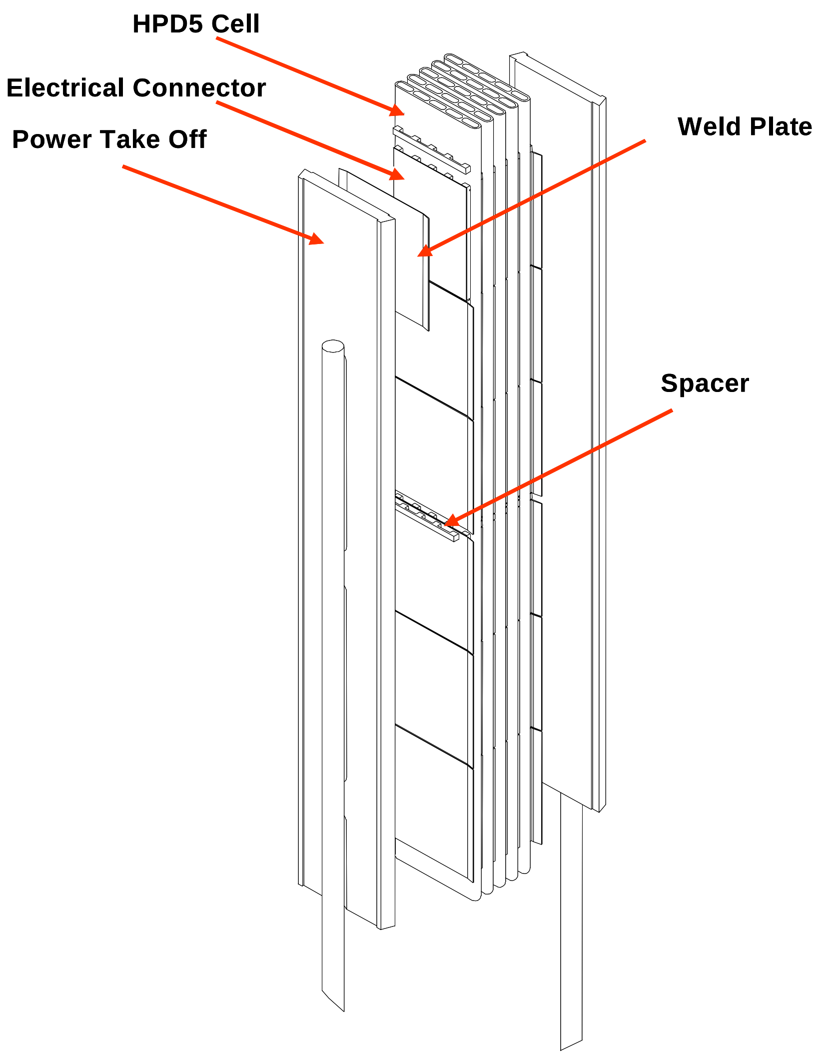






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# HPD5 Cell Bundle - 6 Cells

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**Building block for a generator**

**Active cell length:75 cm**

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## Proof-of Concept (POC) System

- Primary objective is to successfully demonstrate the operation of an HPD cell generator
- Secondary objective is to gain experience for end of phase 1 system deliverable – Alpha unit
- 36 HPD5 cells – six bundles of six cells each
- Utilizes air feed tubes
- Design of existing tubular generator modified to accept HPD cells
- Stack: SWPC; BOP: FCT
- Target Start-up: May 2005





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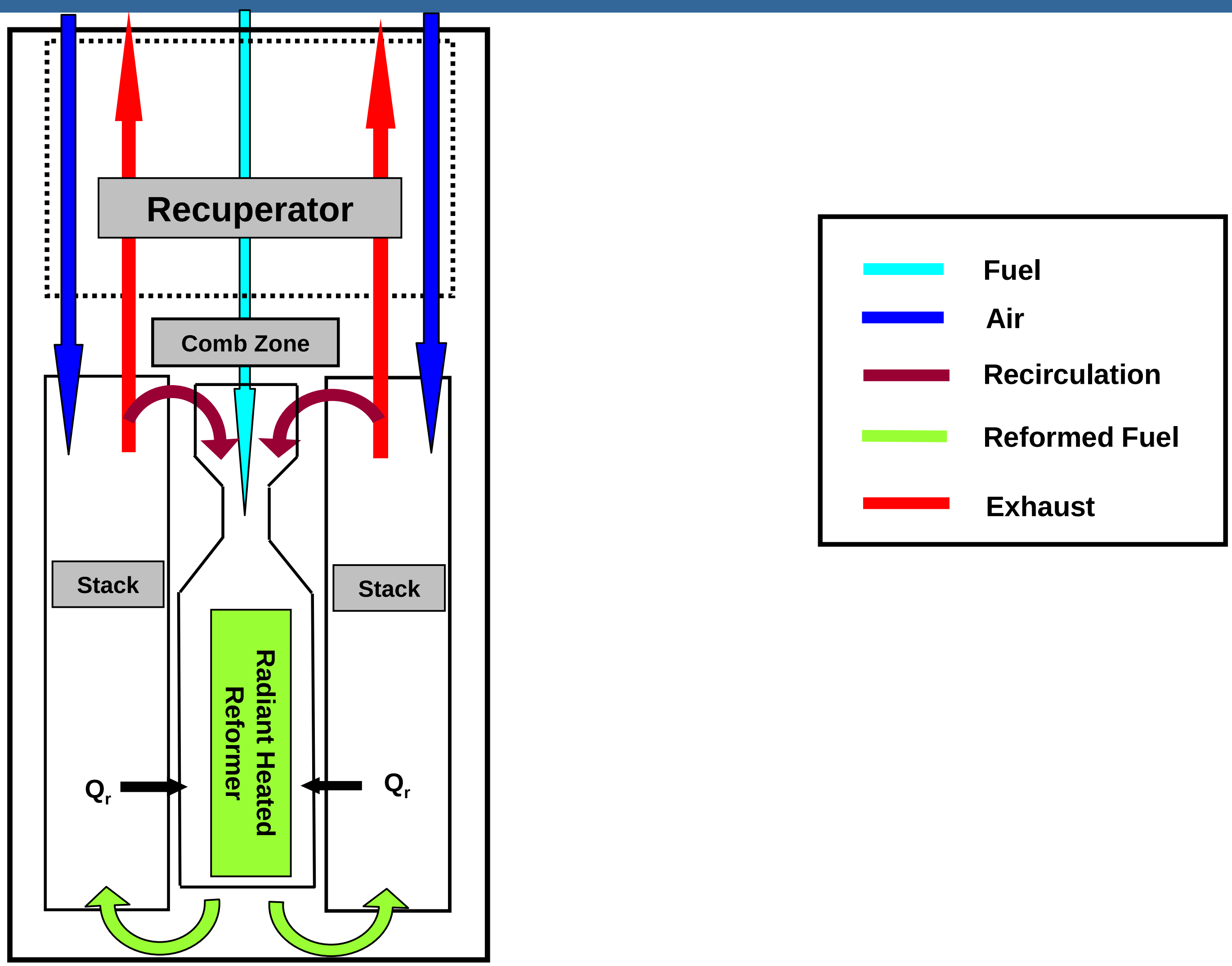
# POC Flow Schematic



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# POC Generator Layout

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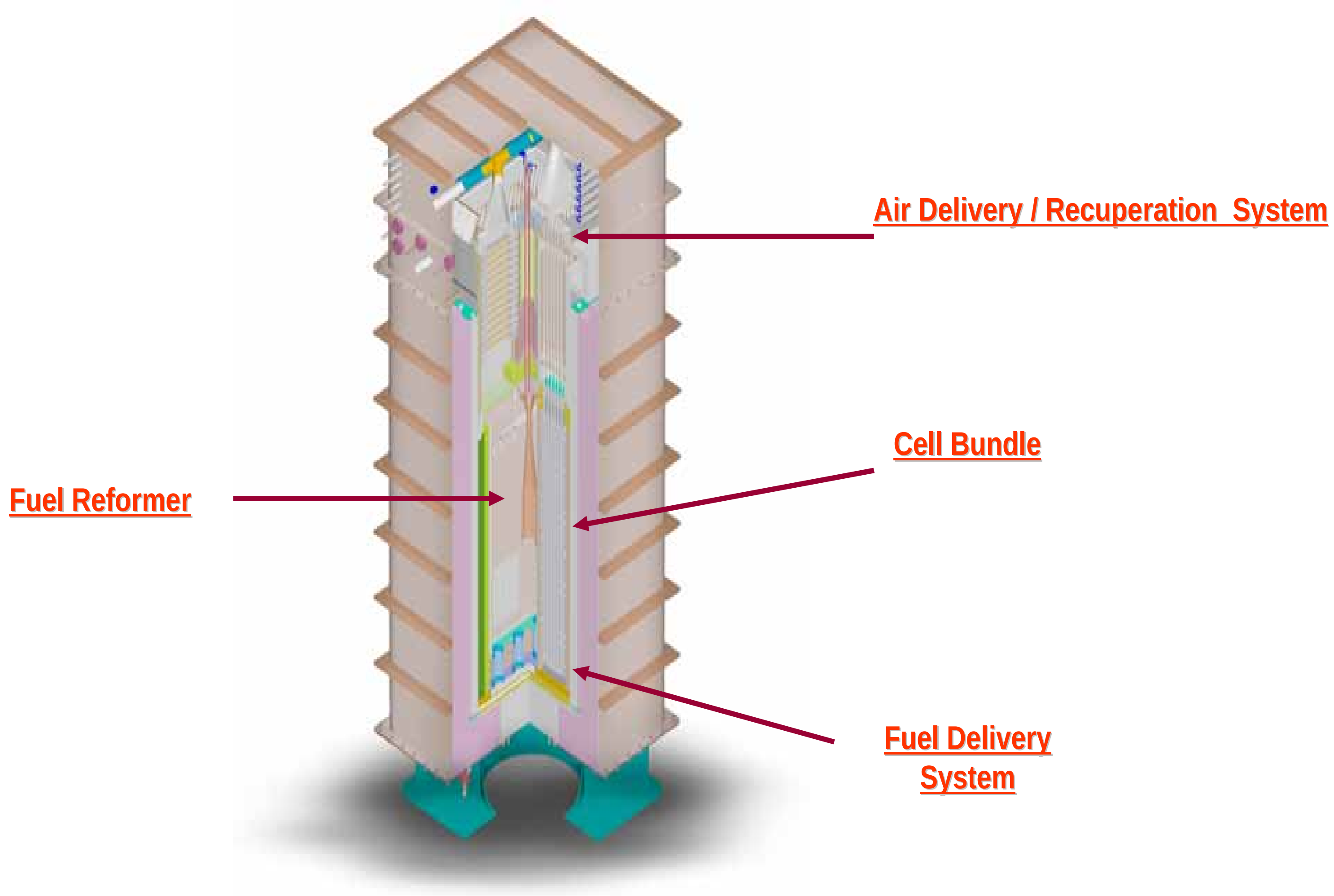






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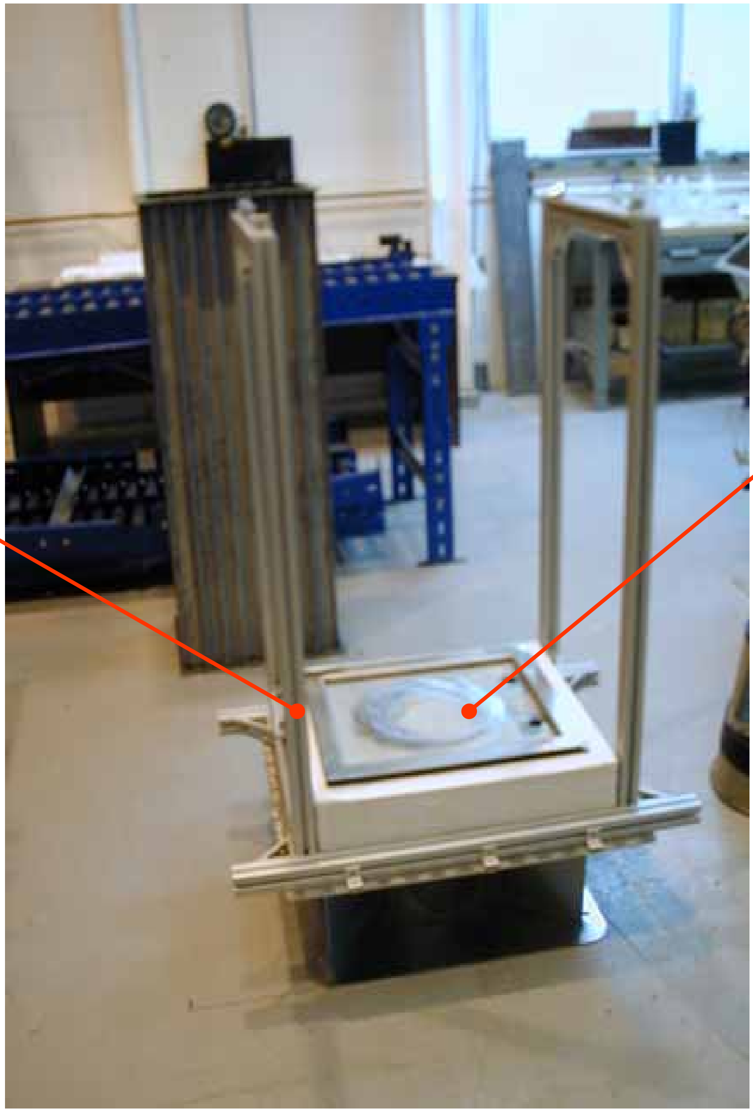
# POC Generator Assembly

SIEMENS Westinghouse



ASSEMBLY FIXTURE

SUPPORT BASE





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# POC Cell Stack

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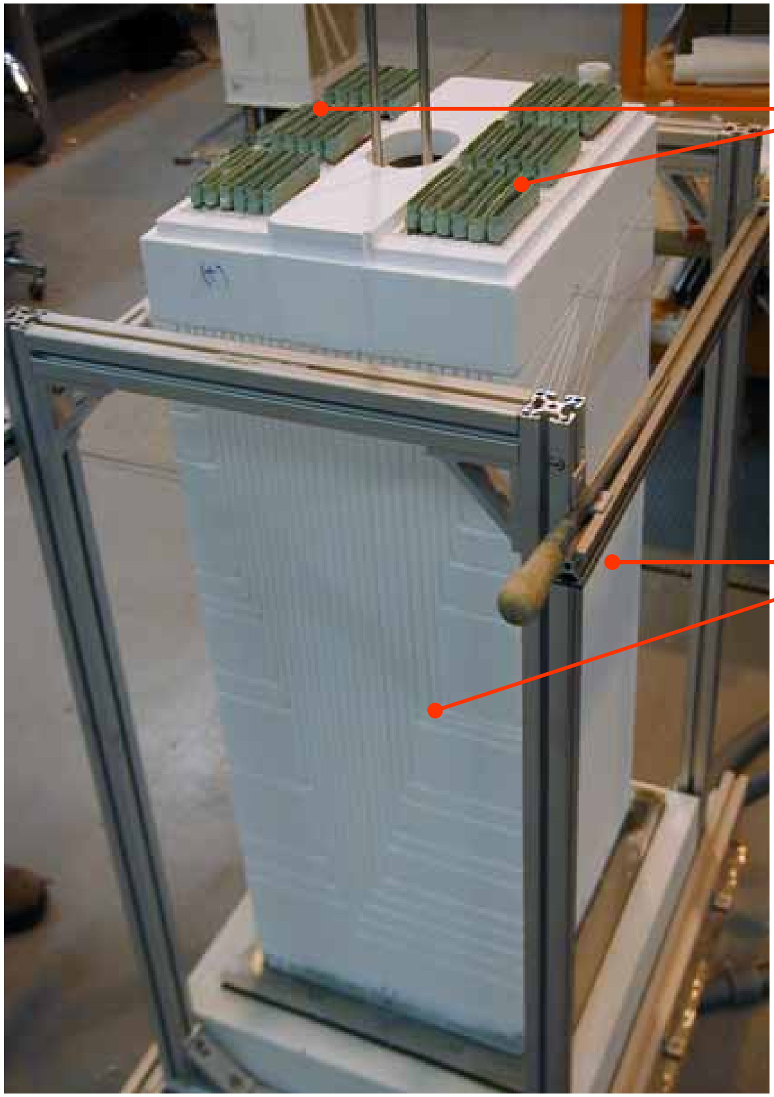

CELL BUNDLES

STACK PERIPHERAL BOARDS

Stationary Fuel Cells

April 2005



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# POC – Generator and Balance of Plant

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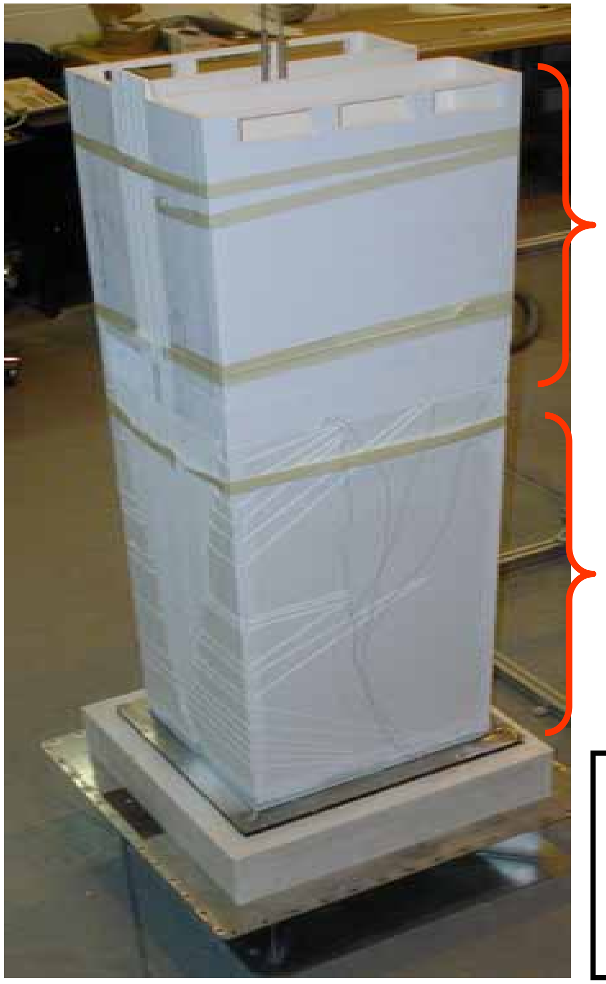
Target Startup May 2005

**Generator**




**Balance of Plant (BOP)**

BOP Developed and manufactured by Fuel Cell Technologies (FCT)



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# Low Temperature Electrolyte



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# Low Temperature ( 800 ºC) Electrolyte - Options

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- Sr- and Mg- doped $LaGaO_3$ (LSGM)
  - APS selected to deposit dense layer
  - Dense layers obtained on 5 cm long sections – Development needed to scale-up to 75 cm long cell
  - Cathode, interconnection, anode and interlayer compositions compatible with LSGM developed
- Scandia stabilized Zirconia (ScSZ)
  - APS selected to deposit dense layer
  - Very similar characteristics as YSZ allows quick adaptation into cell manufacturing
  - Several tubular and HPD cells fabricated



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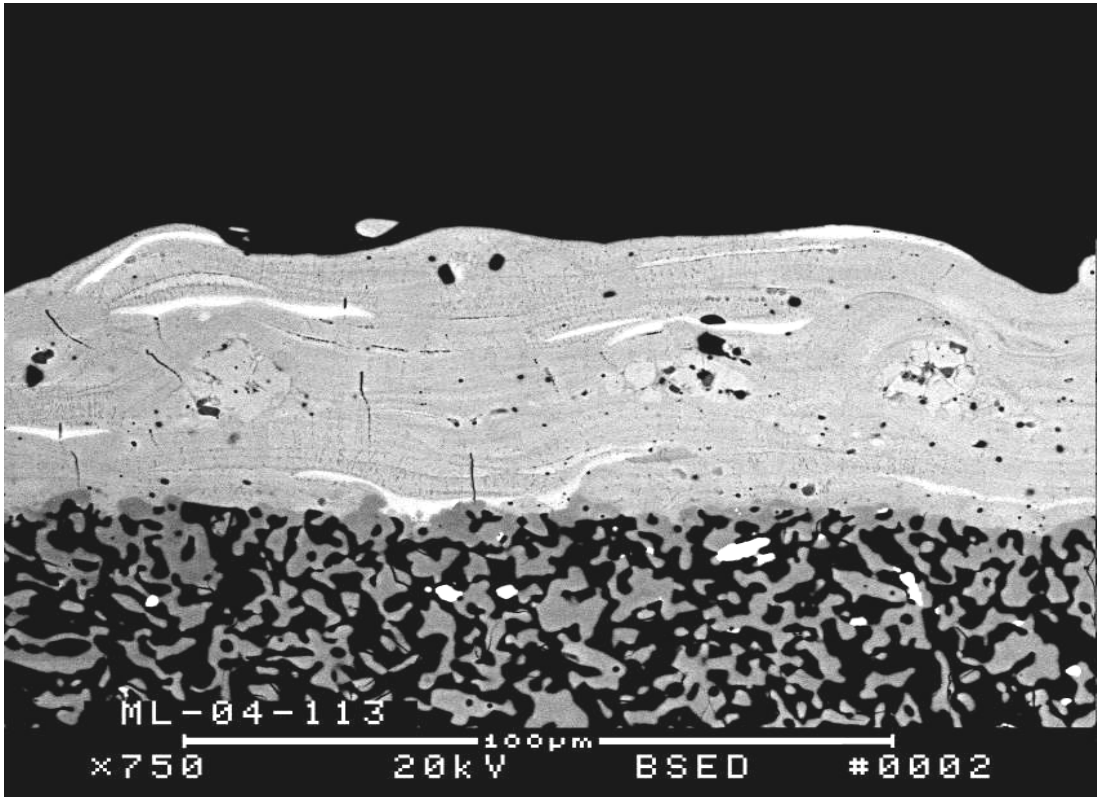
# Plasma Sprayed LSGM - Microstructure

LSGM Electrolyte

Cathode





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# Low Temperature Electrolyte - Summary

SIEMENS Westinghouse

- Further development needed to establish feasibility of LSGM electrolyte for HPD cells
- ScSZ electrolyte selected for near-term application



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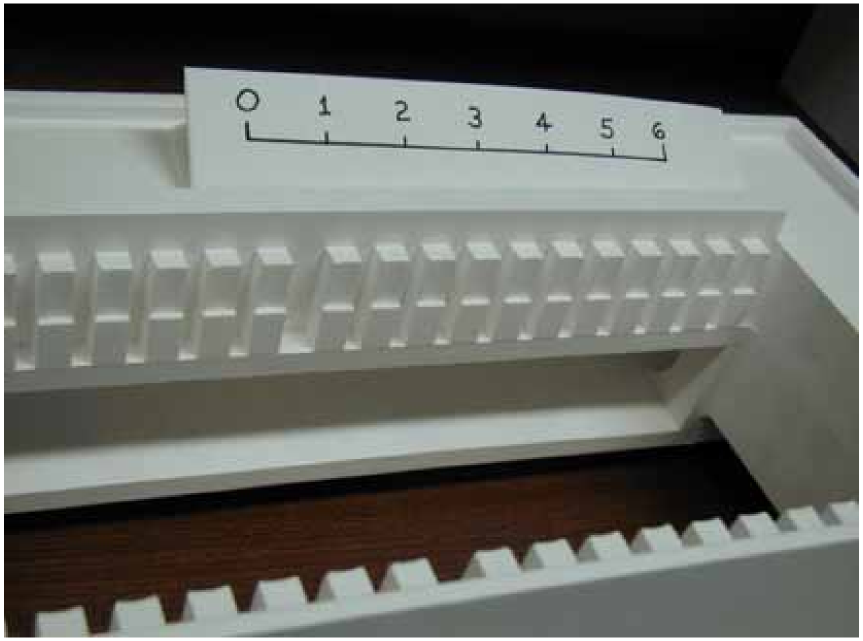
# Low Cost High Volume Manufacturing

SIEMENS Westinghouse

**Feasibility Studies on-going**

- **Net shape forming of stack components (Blasch Ceramics)**
  - **Developed structural ceramics with thermal expansion matched to cell materials for greater reliability**




**Stack Plenum**



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# Low Cost High Volume Manufacturing (Continued)

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**Feasibility Studies on-going**

- **Higher throughput plasma spray processes**
- **Sintering of interconnection, electrolyte and anode**
  - **Higher material utilization**
  - **Reduced manufacturing steps**
  - **Higher throughput**
  - **Lower capital investment**



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# Next Generation HPD Cell – Delta9

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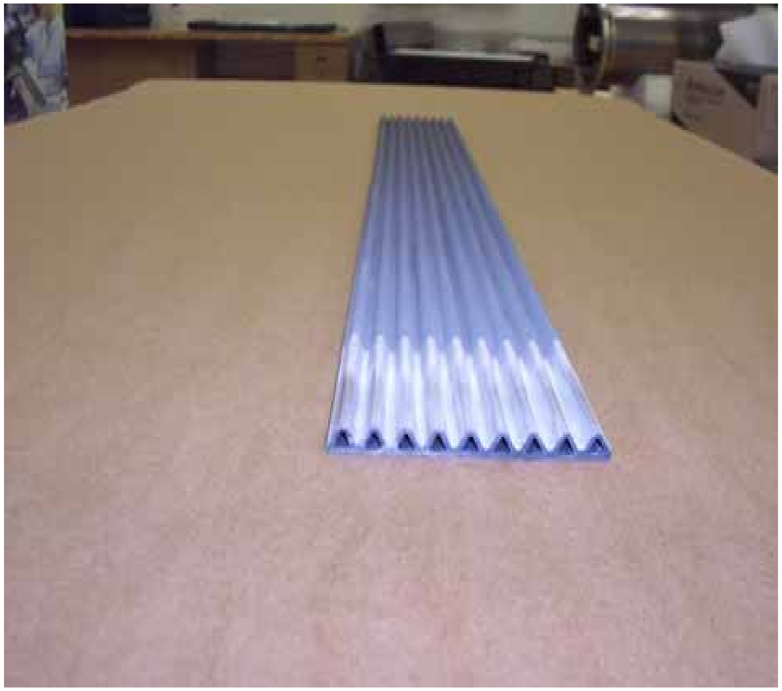
- Surface area increased by 40%, further increasing power density
- Built-in fuel channels
- More compact stack
- Active cell length: 75 cm
- Cell fabrication and testing initiated







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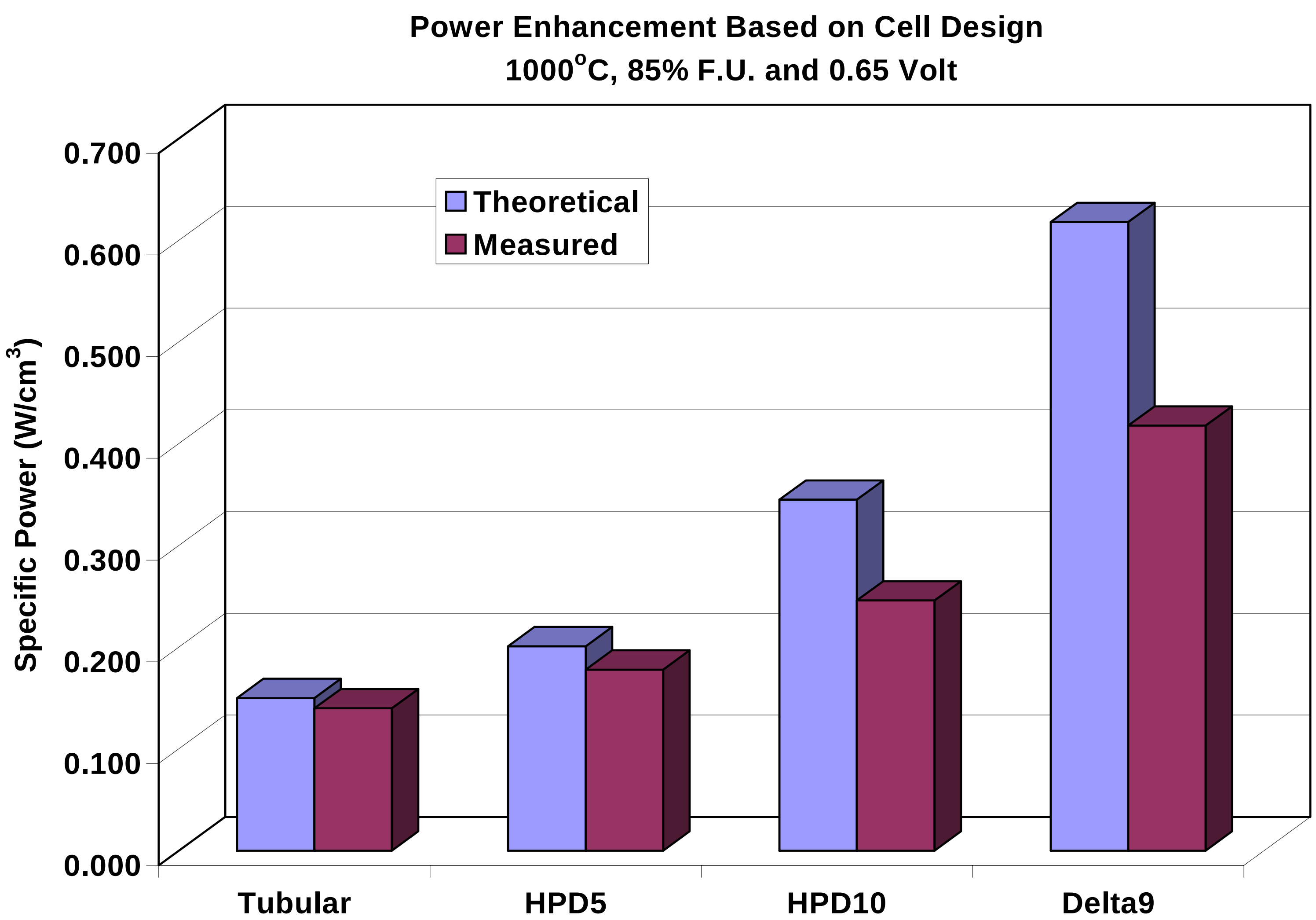
# Volumetric Power Density Comparison





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# Volumetric Power Density Comparison

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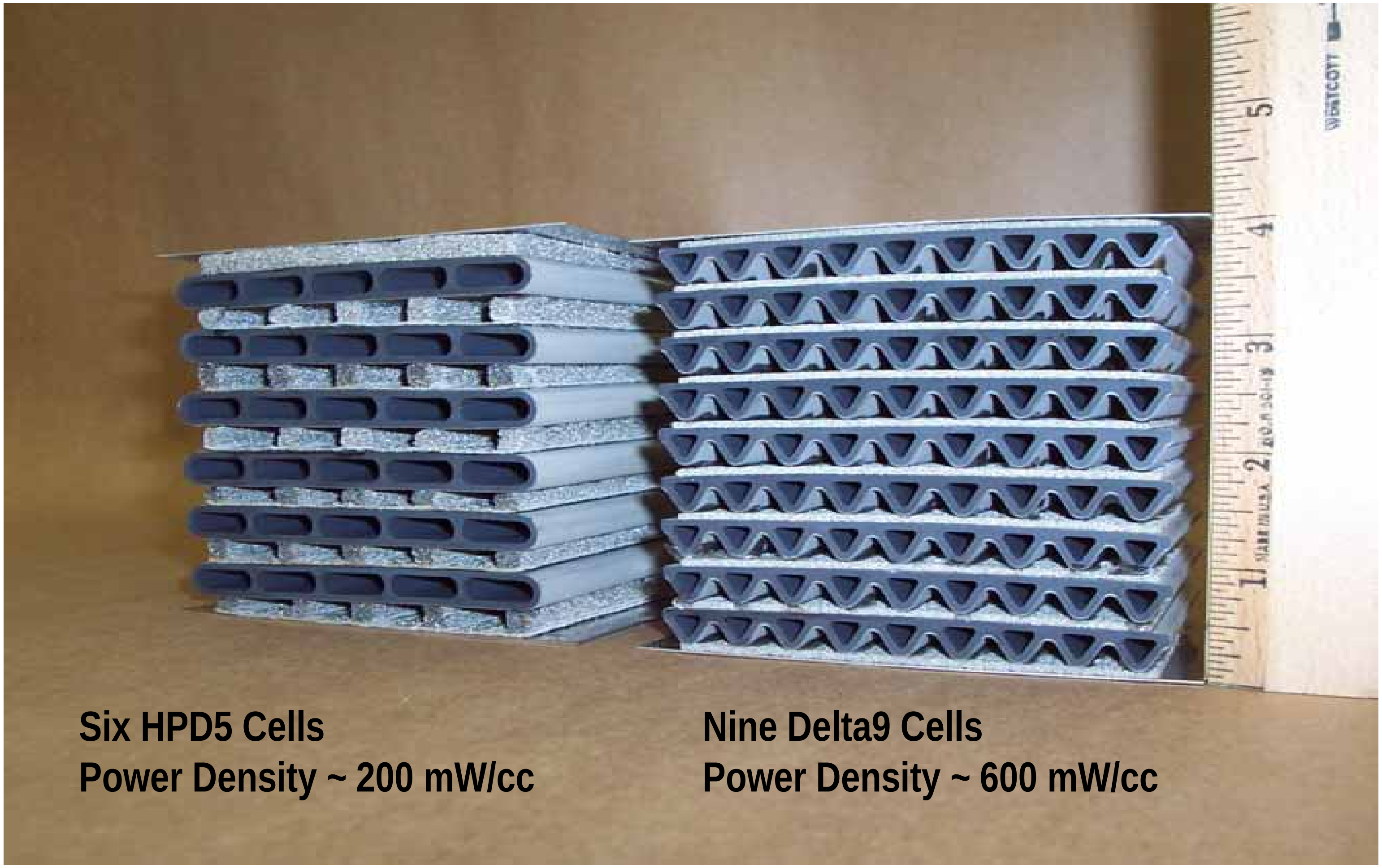
Westinghouse



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# End of Phase 1 (Aug 2006) System - Alpha Unit

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- Operating Temperature: 900°C
- Reduce component count from POC
- Reduce/eliminate air feed tubes
- Reduce cost relative to POC and show path to $800/kW
- Reduce cost of module components
- Demonstrate advanced cell technologies
- 5 kWe Power output
- Electrical efficiency: 40%
- 0.1%/1000 hrs degradation
- Test duration >1500 hours
- Attended start-up, unattended operation



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# Summary

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- Contract started in September 2002
- Fabricated HPD cells and demonstrated significant higher power density over tubular cells – Met program milestones for power enhancement and voltage stability
- Additional power enhancement expected after materials and processing advancements are incorporated into HPD cells
- POC assembly completed
- Next generation HPD cells under development
- Alternate low temperature (800 ºC) electrolytes under evaluation
- Low cost, high volume manufacturing development in progress



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# Future Work (Phase 1)

SIEMENS Westinghouse

- Integrate individual cell power enhancement results in HPD cells
- Test POC system
- Continue evaluation of LSGM and ScSZ as 800 ºC operating temperature electrolytes
- Continue optimization of HPD cell design and HPD cell fabrication
- Incorporate POC system lessons learned and cost reduction developments in alpha unit scheduled at the end of phase 1 (August 2006)
- Pilot production of SECA alpha units scheduled for second half of 2006 for field demonstrations





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