SECA Program Review

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Fossil Power Generation
Stationary Fuel Cells

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Significant Results

- Demonstrated significantly higher power density and higher power per cell relative to cylindrical cells through materials and cell design improvements
- Demonstrated voltage stability of next generation cells - Delta8
- Completed Phase 1 stack test
- Met all Phase 1 milestones
- Developed lower cost and scalable processes for cell manufacturing
- Developed materials and processes to further increase cell power by 50%
- Increased Delta8 cell length to 100 cm from 75 cm – new cell active area 2570 cm^2
- Completed stack design for Phase II stack test
- Initiated assembly of Phase II stack

Siemens Tubular Geometry
Seal-Less Solid Oxide Fuel Cell

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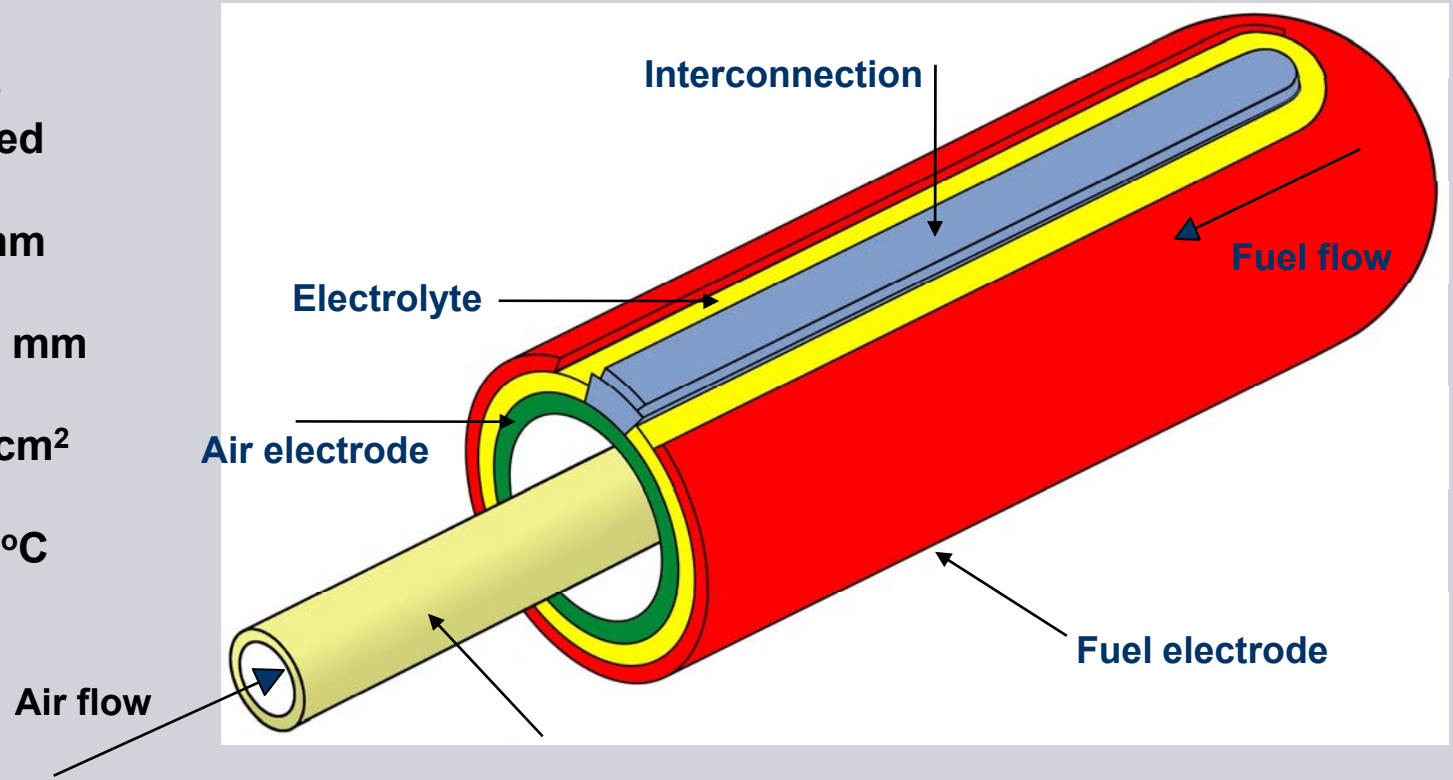
Cathode Supported

D = 22 mm

L = 1500 mm

A = 850 cm^2

T = 1000^{o}C



Air feed tube (AFT)

Siemens Solid Oxide Fuel Cell Materials and Processing

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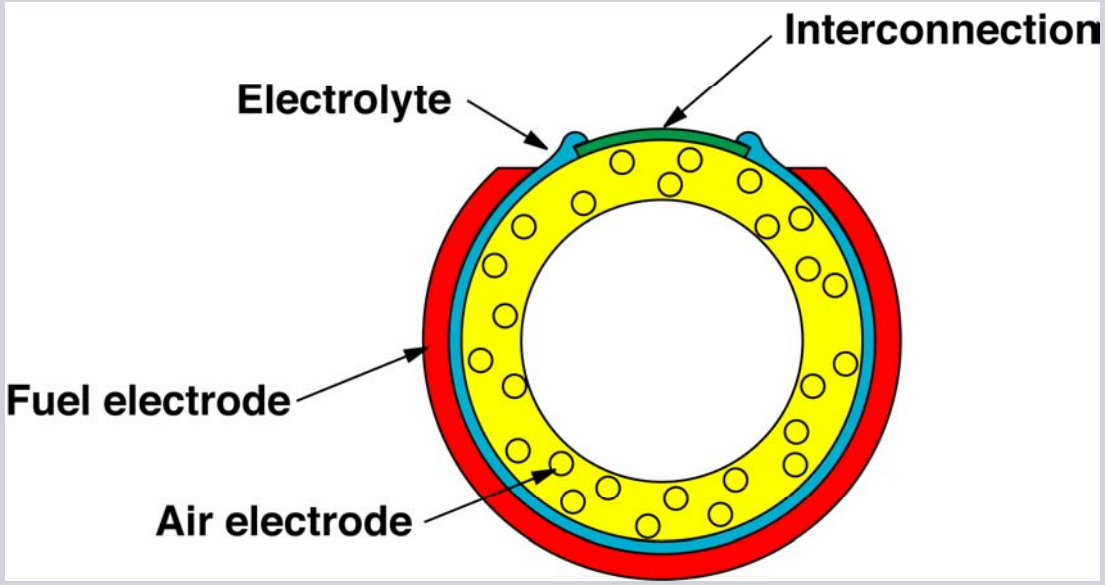
Component	Material	Present Fabrication Process
Air Electrode	Doped $LaMnO_3$	Extrusion-Sintered
Electrolyte	$ZrO_2(Sc_2O_3)$	Atmospheric Plasma Spraying
Interconnection	Doped $LaCrO_3$	Atmospheric Plasma Spraying
Fuel Electrode	Ni-ZrO_2 (Y_2O_3)	Atmospheric Plasma Spraying



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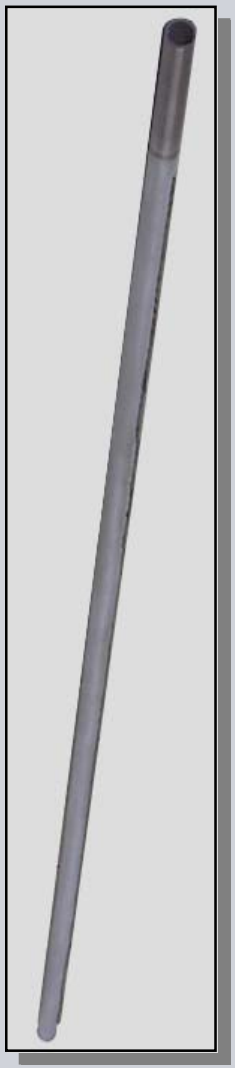
Base-line Cell Performance



Single Cell Performance

- DC Power: 110 W/cell @ 0.70 V
- Fuel: Hydrogen
- Temperature: 1000°C
- Fuel Utilization: 80%

In-System Performance

- Net AC Power: 100 W/cell
- Fuel: Reformed natural gas
- Temperature: 940°C average
- Net electrical efficiency: 46% (atmospheric pressure)

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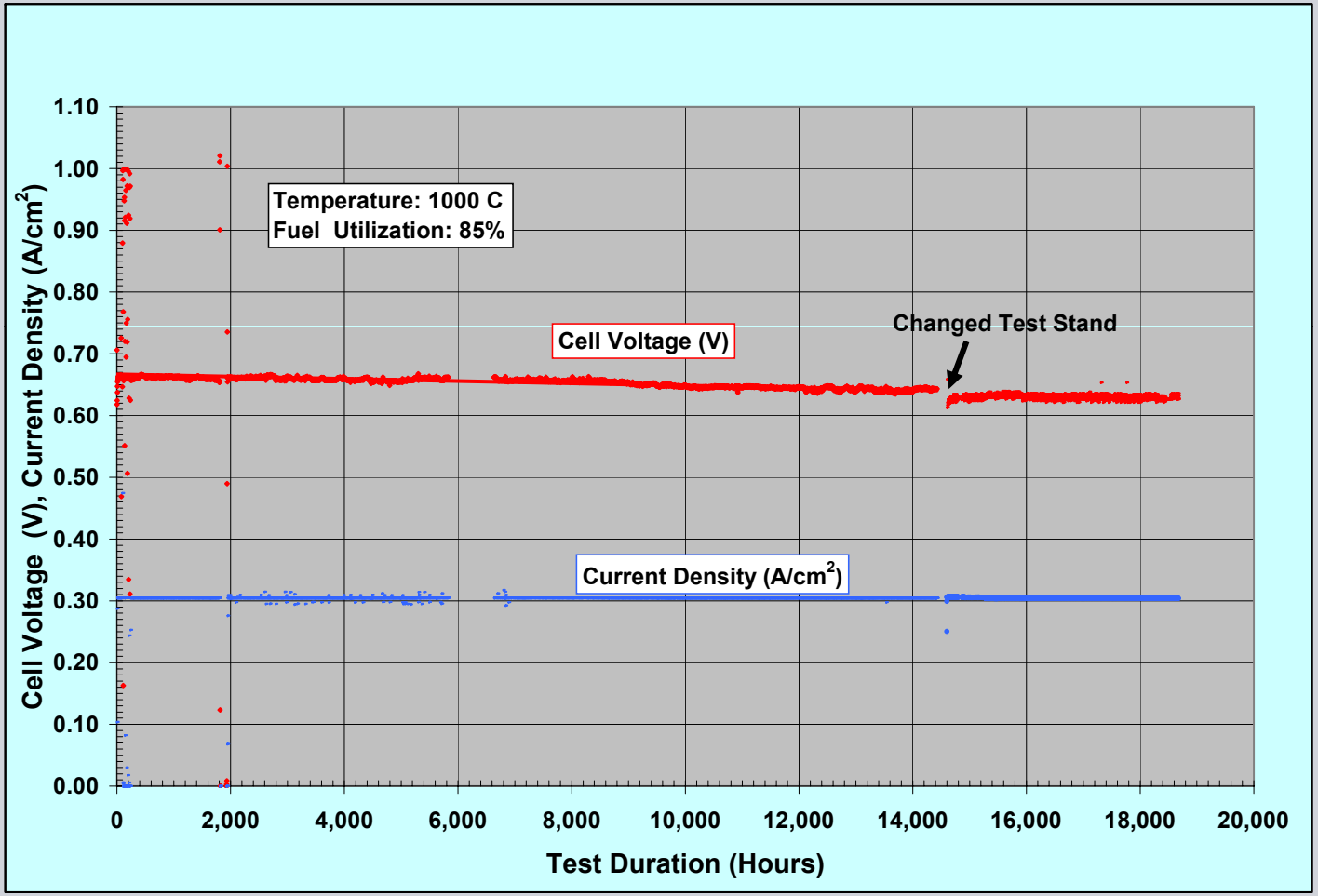
Cell Voltage Stability



~ 0.1% per 1000 hours voltage degradation

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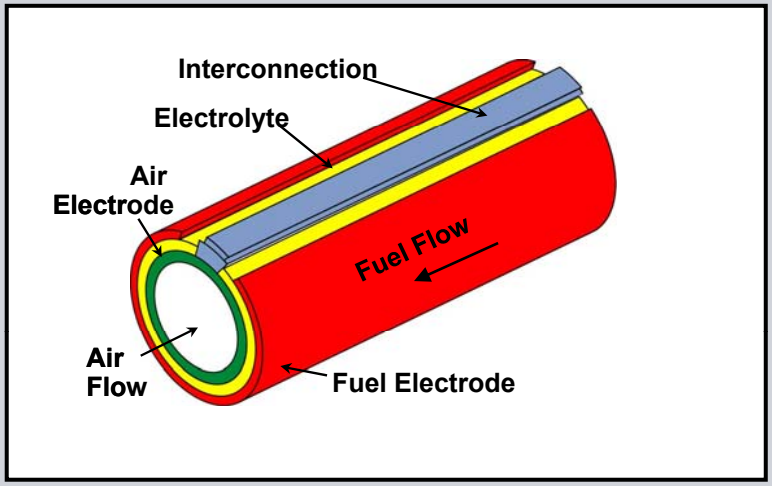
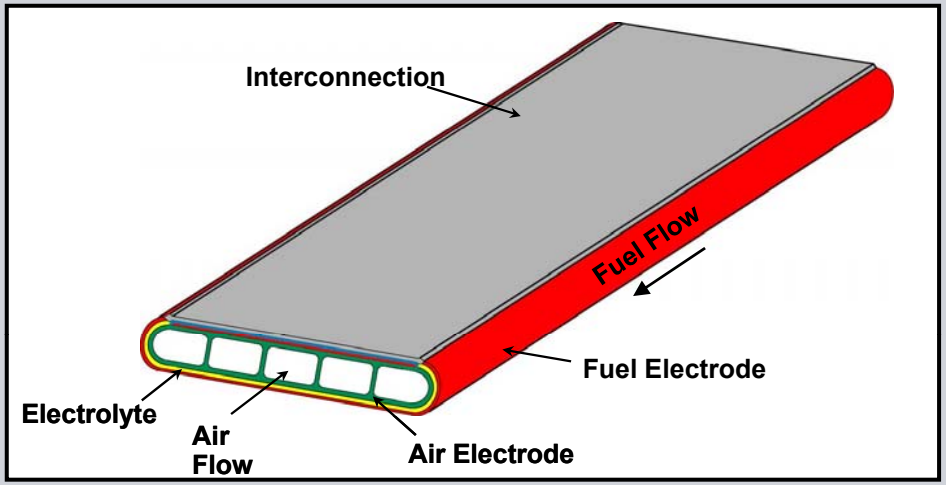
Transition from Tubular to High Power Density (HPD) Cell



Tubular



HPD

Advantages

- Closed end enables seal-less design
- Reduction in ohmic resistance
- Increase in cell power density
- More compact stack

Same cell materials and manufacturing processes – Different design

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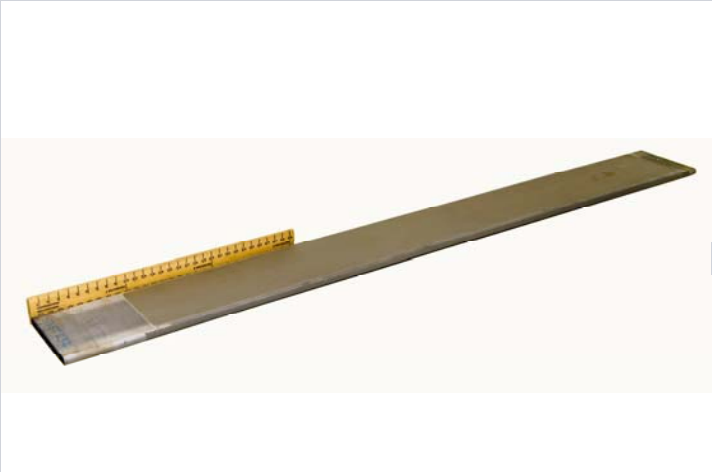
First Generation HPD Cells

Active Length: 75 cm

Active area: ~900 cm^2



Developed HPD5 (five channels) and demonstrated benefits relative to tubular cells

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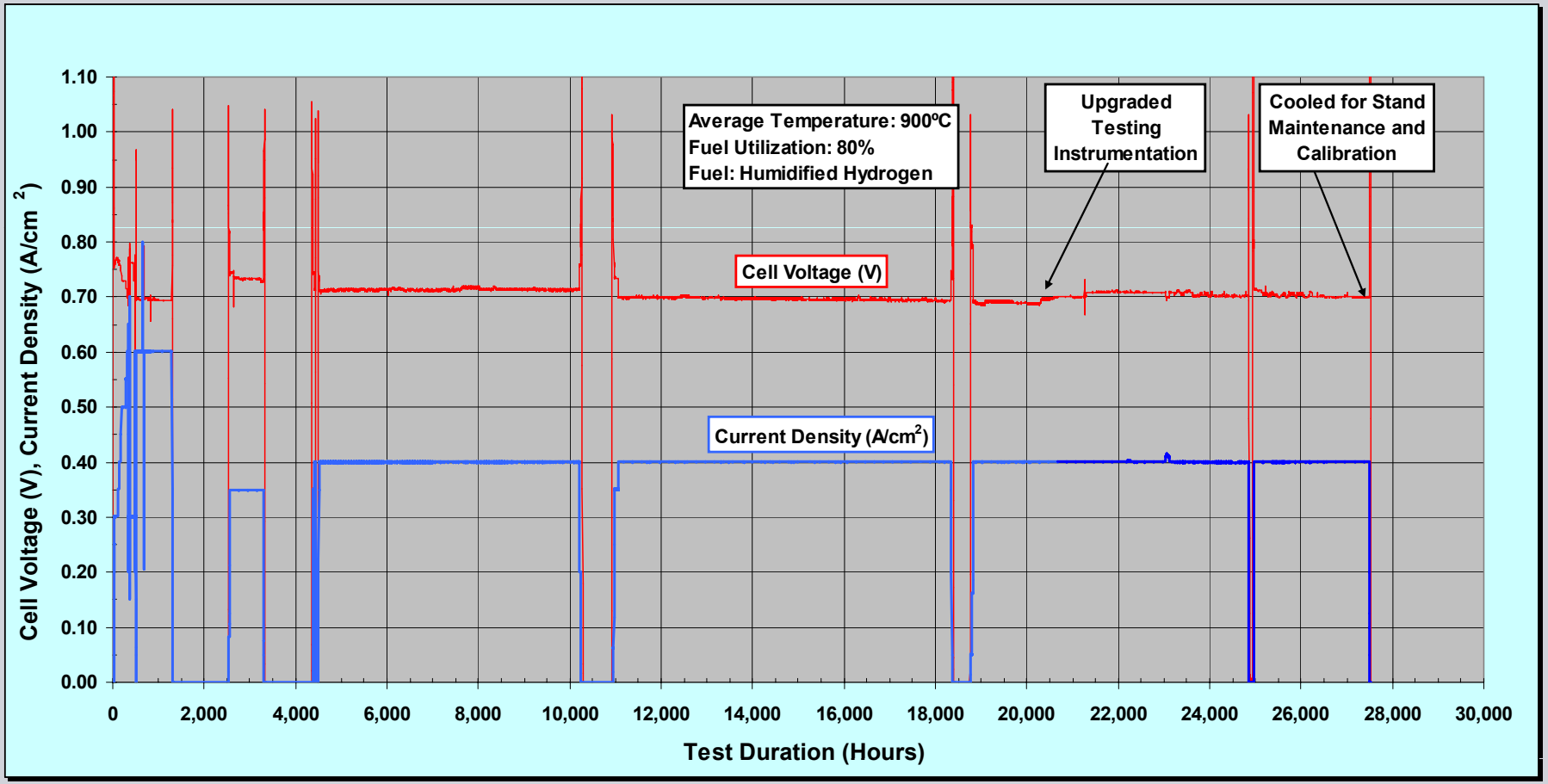
HPD Voltage Stability



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Accomplishments and Next Steps

- Demonstrated thermal cyclic stability - can withstand multiple thermal cycles
- Demonstrated voltage stability - voltage decline of ~ 0.1% /1000 h
- Cost reduction measures in progress
  - Increase cell power density
  - Lower parts count
  - Reduce assembly cost
  - Simplify balance-of-plant

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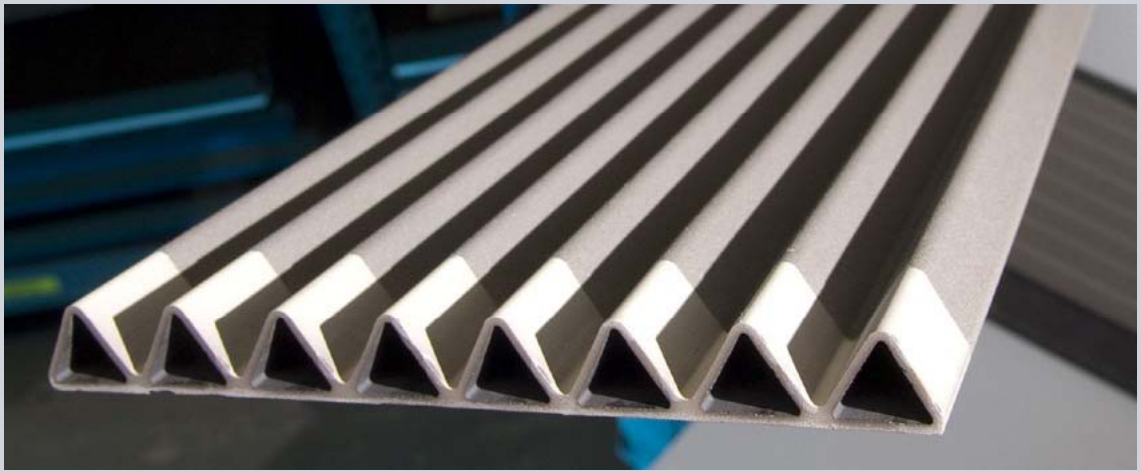
Next Generation Cell Concept – Delta8…



- Closed end - maintains seal-less design
- Shorter current path - reduction in ohmic resistance
- Increase cell power density
- Increase volumetric power density of stack
- Increase cell active area (higher power per cell)

…leading to cost reduction in the cell area

Delta8 Cell Performance – Voltage vs. Current Density

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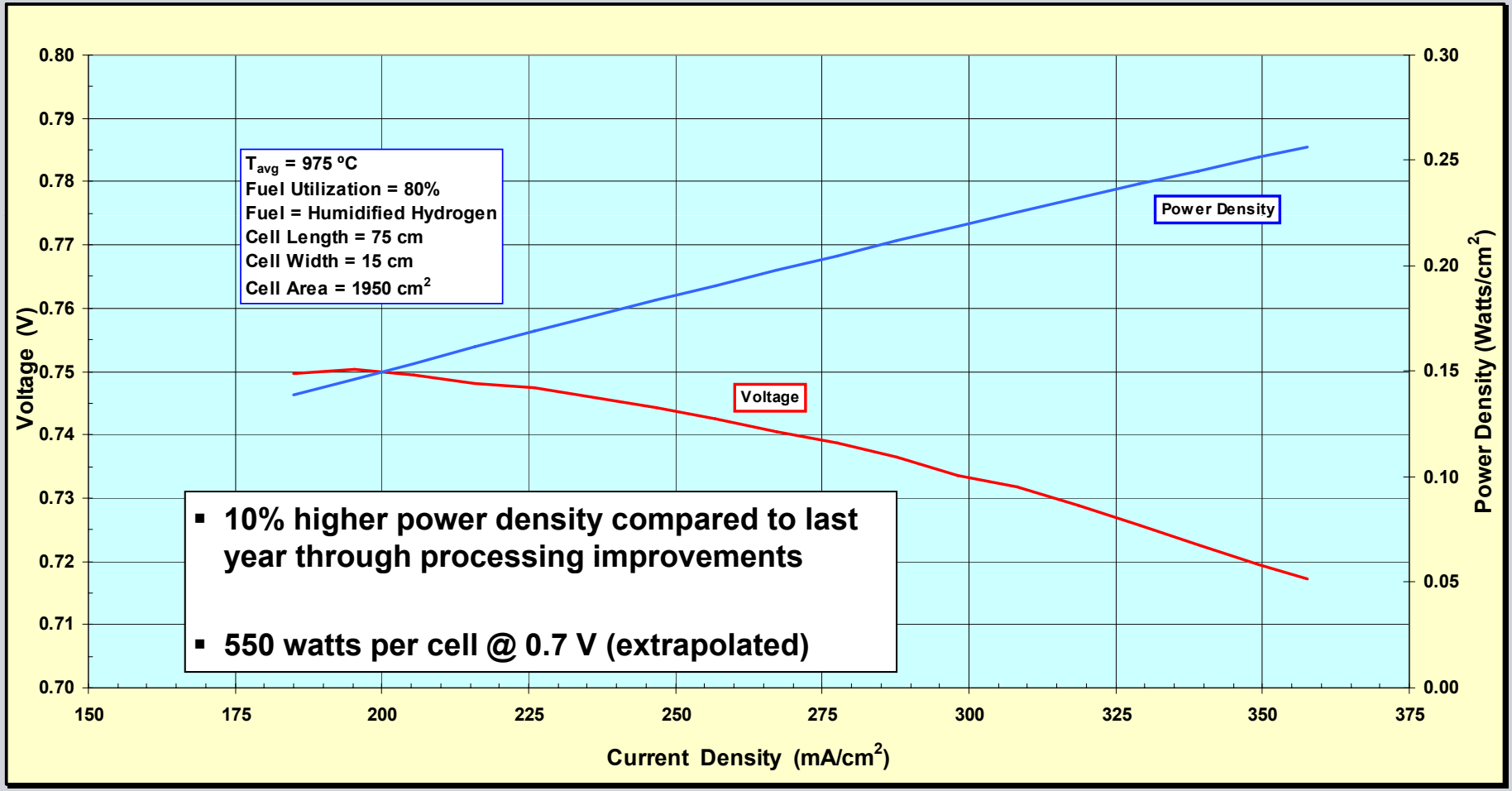

- 10% higher power density compared to last year through processing improvements
- 550 watts per cell @ 0.7 V (extrapolated)

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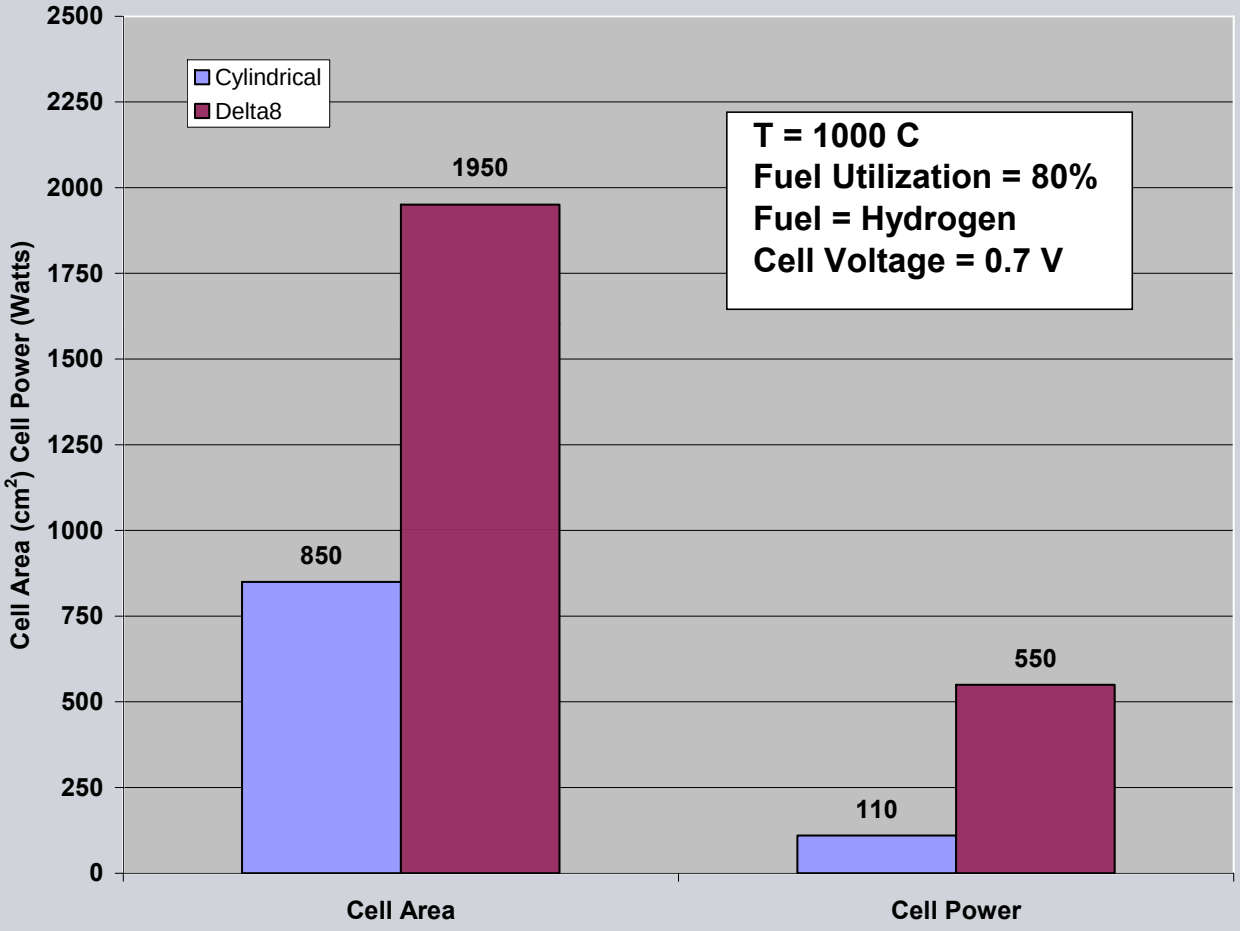
Cell Performance Comparison



Delta8 cell area increased by ~ 2X vs. cylindrical cell
… cell power increased by ~ 5X

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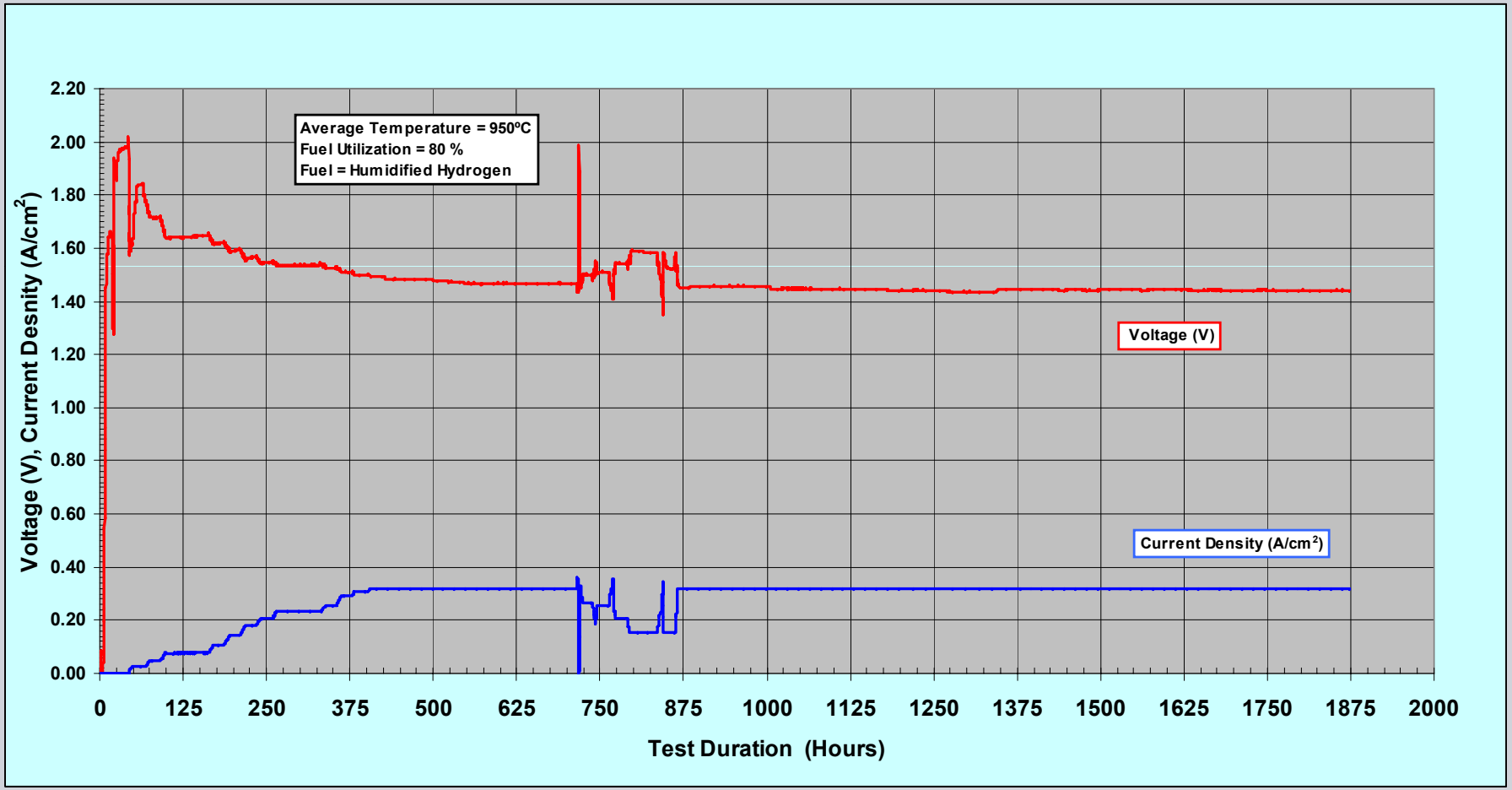
Delta8 Cell Voltage Stability (2-cell test)



Excellent voltage stability

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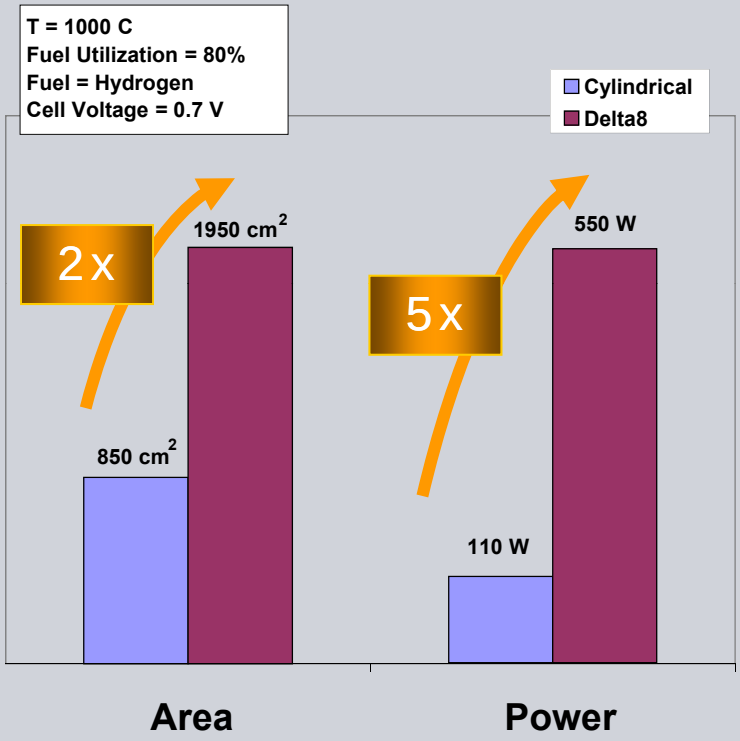
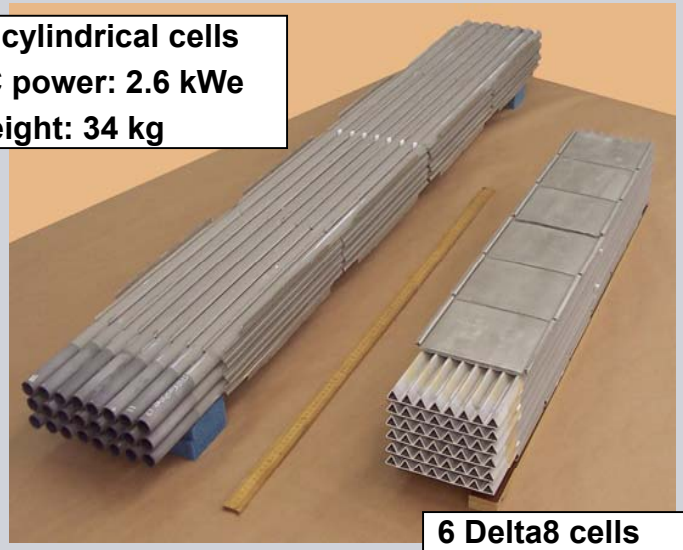
Cell and Bundle Comparison





24 cylindrical cells
DC power: 2.6 kWe
Weight: 34 kg

6 Delta8 cells
DC power: 3.3 kWe
Weight: 20 kg

Reduced weight by 40%, increased power by 25%

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Phase I Stack Test

- 24 Delta8 cells (75 cm long)
- 4 bundles (six cells each)
- Internal recuperator
- Cast ceramic open end holder
- Operation on simulated coal gas
- Thermally self sustaining
- Modified existing balance of plant for stack test

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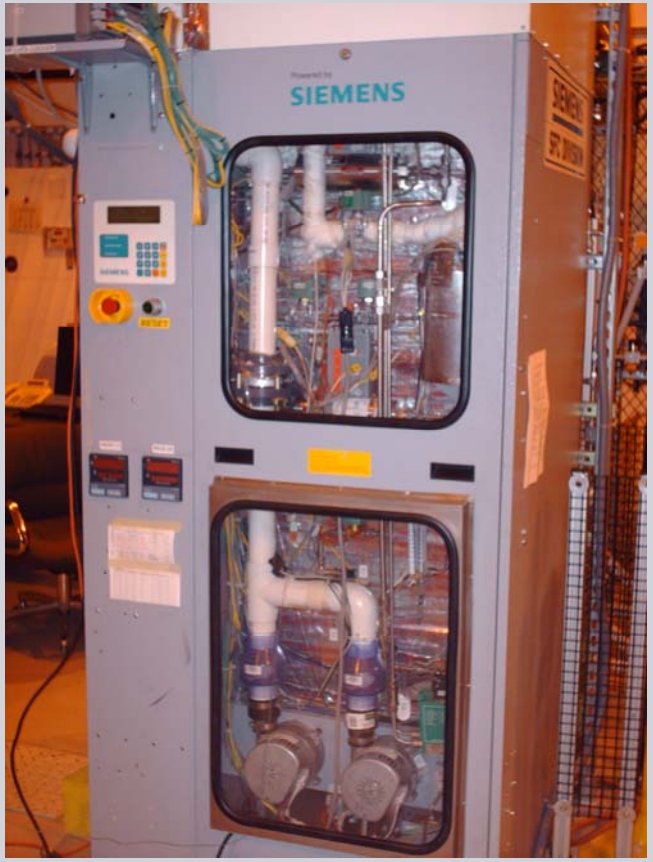
Phase I Integrated System

Cell Stack



Complete System

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Phase I Stack Test Results

Phase I Minimum Requirements		Siemens System Test Results
DELIVERABLE POWER RATING	≥ 10 kW	10 kW
STEADY STATE TEST (Normal Operating Conditions)	5000 hours	5300 hours
	Δ Power < 4.0% degradation/1000 hours	No detectable degradation
TEST SEQUENCE	1) Start-up and conditioning 2) Peak Power Test (after ~300 hours) 3) VJ curve 3) Steady State Test (balance of 5000 hours) 4) Shut-down	In accordance with DOE approved Test Plan
FUEL TYPE	Simulated (subject to DOE concurrence, up to 25% CH4, dry basis)	Hydrogen and simulated coal gas
AVAILABILITY	Report availability	Availability factor of 85% at 50% power or greater

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Cell Development . . .

- Cell Fabrication
  - Seamless closed end
  - One-Step sintering of cathode
  - Mass production concepts for plasma spray
- Cell Power Enhancement

. . . Results in cost reduction, scale-up and manufacturability

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Present Process To Attach Closed End

Closed end cap is attached to the cell in the green stage and the assembly is sintered

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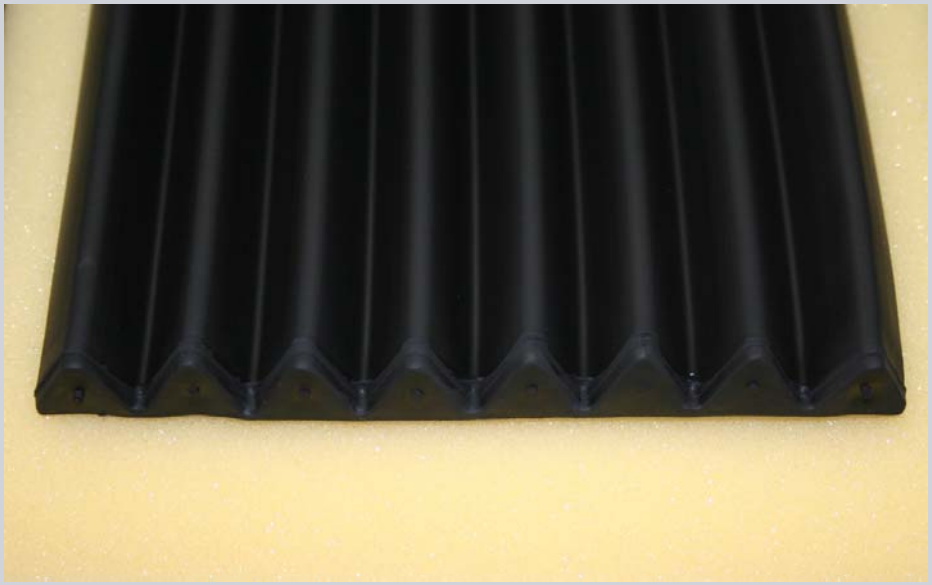
Seamless Closed End



Closed end cap is extruded with the cell … resulting in reduced labor

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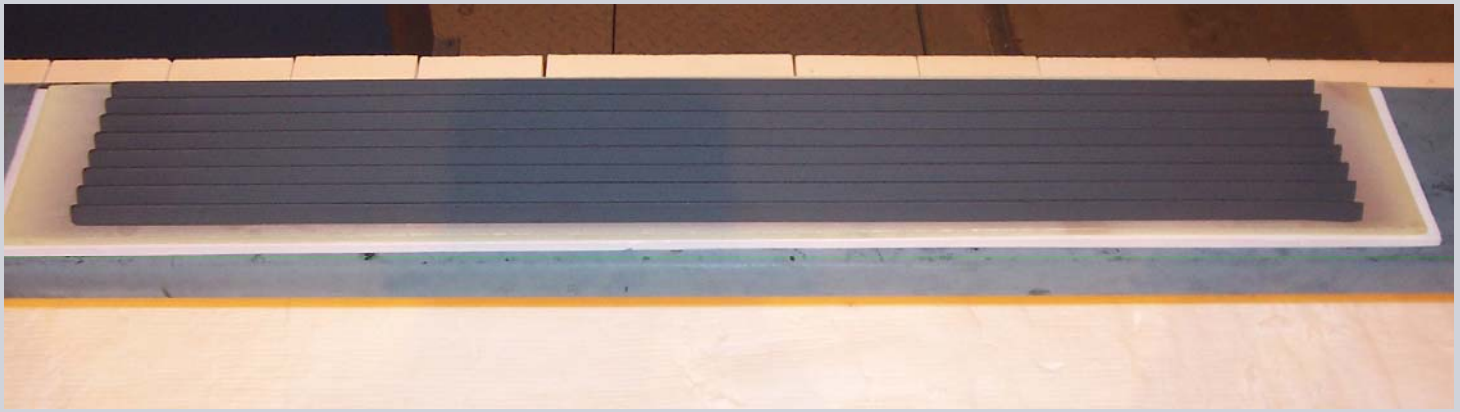
Horizontal (One-Step) Sintering of Cathode



- Old process
  - Two- step sintering
  - Horizontal sintering (~ 1200 ºC) followed by vertical sintering at ~1500 ºC
- New process
  - Developed non-reactive substrate to sinter cathodes in one step up to ~1500 ºC

… resulting in reduced labor, uniform porosity, and uniform dimensions

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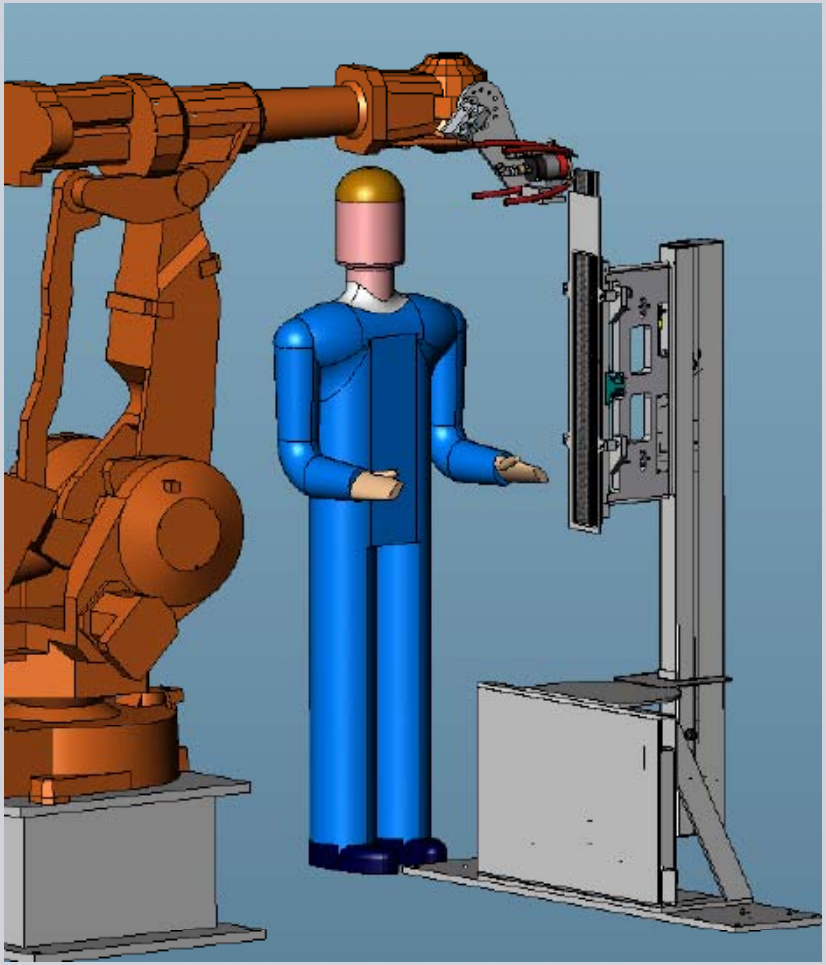
Plasma Spraying

Present Process

- Single part per event
- One gun system
- Each surface is individually coated
- Significant part handling
- Not scale-up friendly



Plasma Spraying
Concept for Mass Production

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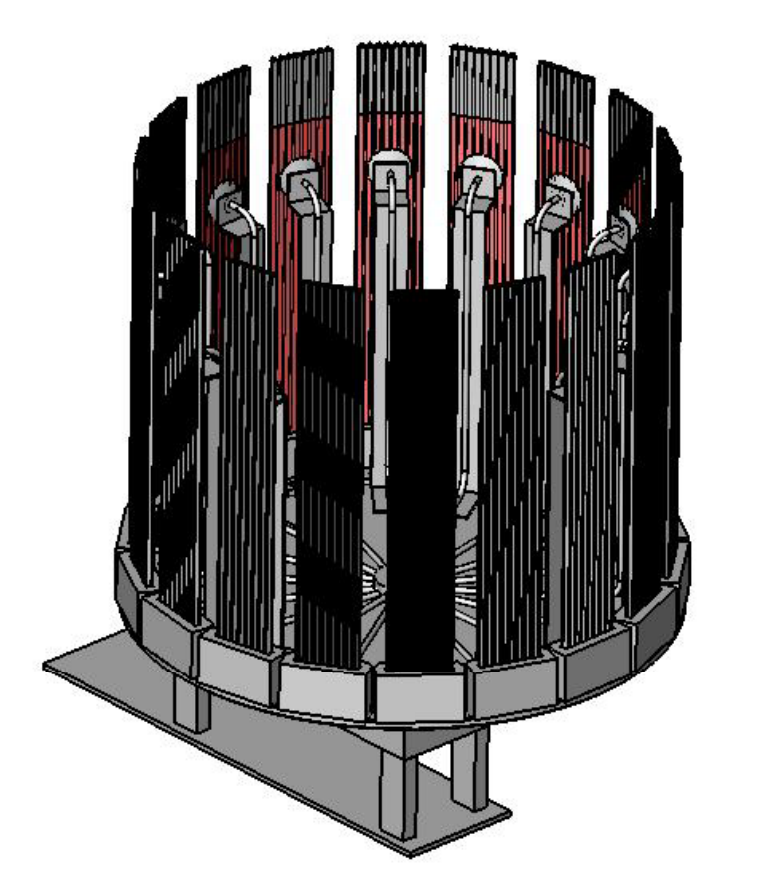
Manufacturing Carousel Design

- Multiple cells processed in one event
- Plasma guns travel vertically while carousel rotates
- Multiple plasma guns
- Robust to dimensional part variation
- All surfaces coated simultaneously
- Significant reduction in spray time



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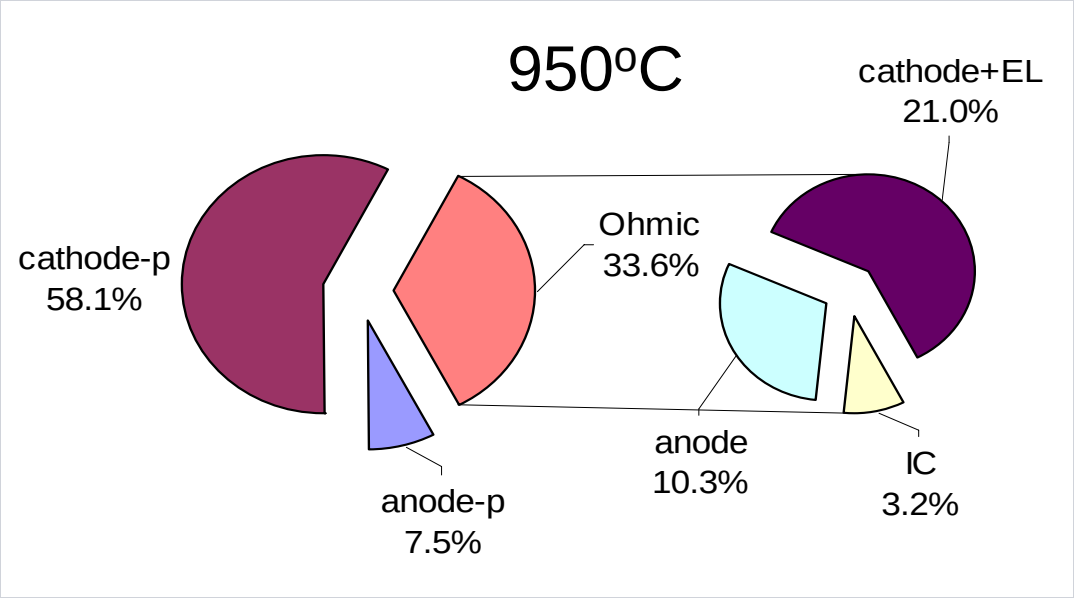
Cell Power Enhancement

The electrical performance of Siemens cathode supported cells is primarily influenced by the cathode–electrolyte interface due to high polarization



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Cell Power Enhancement

- **Lowered electrolyte densification temperature by ~300 ºC through materials and processing improvements**
  - **Maintain active cathode layer porosity**
  - **Prevent formation of insulating phases at the cathode-electrolyte interface**
- **Reduced electrolyte thickness by 50%**

> ➢ **Materials and process development work done on cylindrical cells**
>
> ➢ **Readily transferrable to Delta8 cells**

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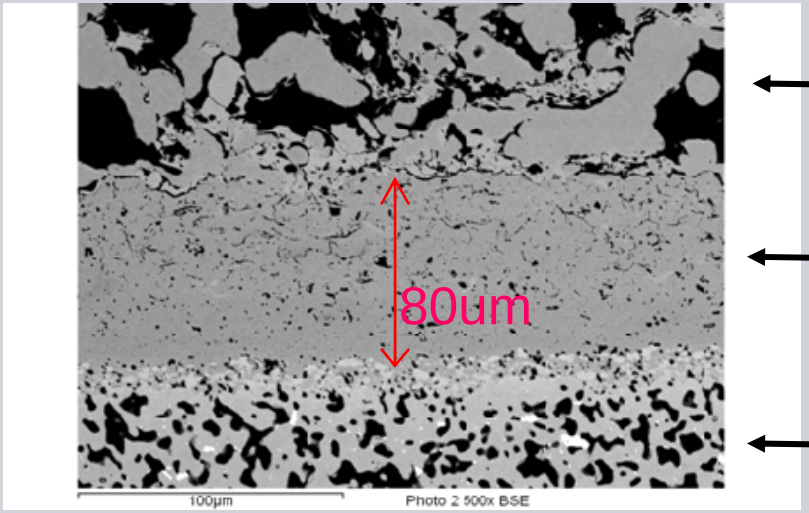
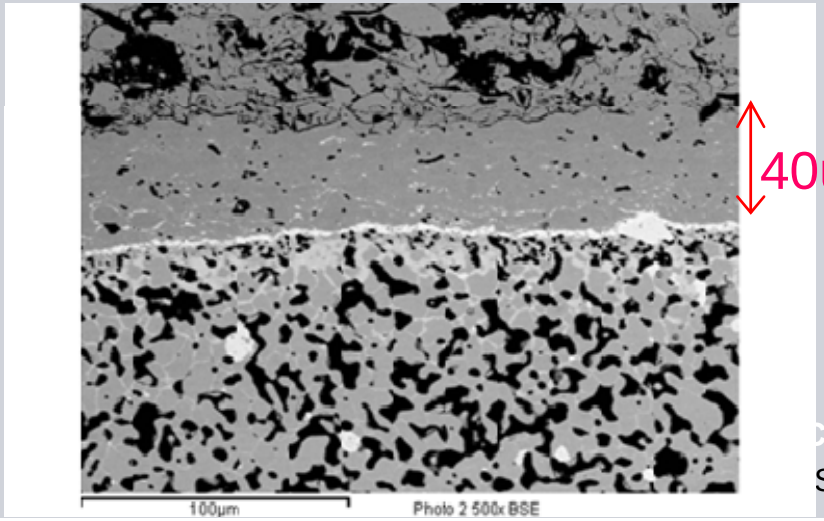
Electrolyte Microstructures

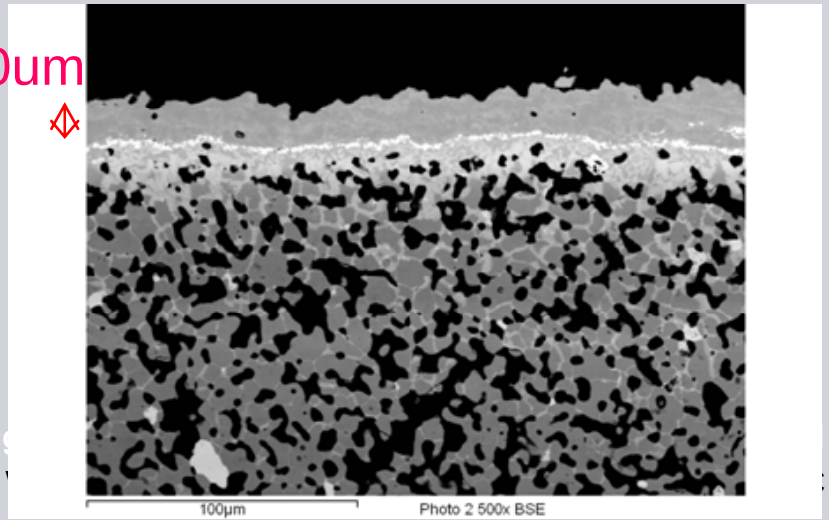
Present electrolyte



½ Thickness electrolyte



¼ Thickness electrolyte



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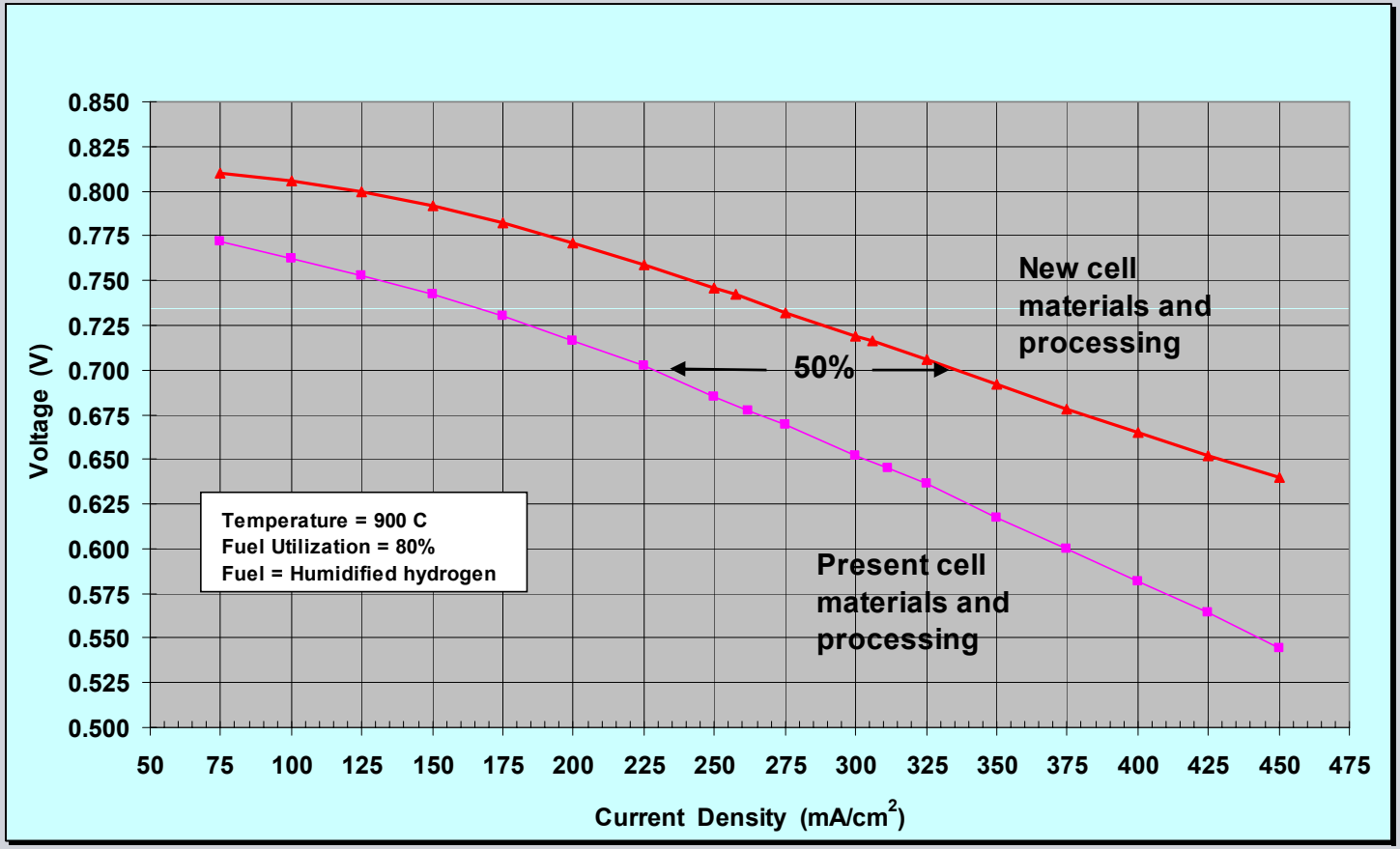
Cell Performance – Cylindrical Cells



50% higher power density at 0.70 V

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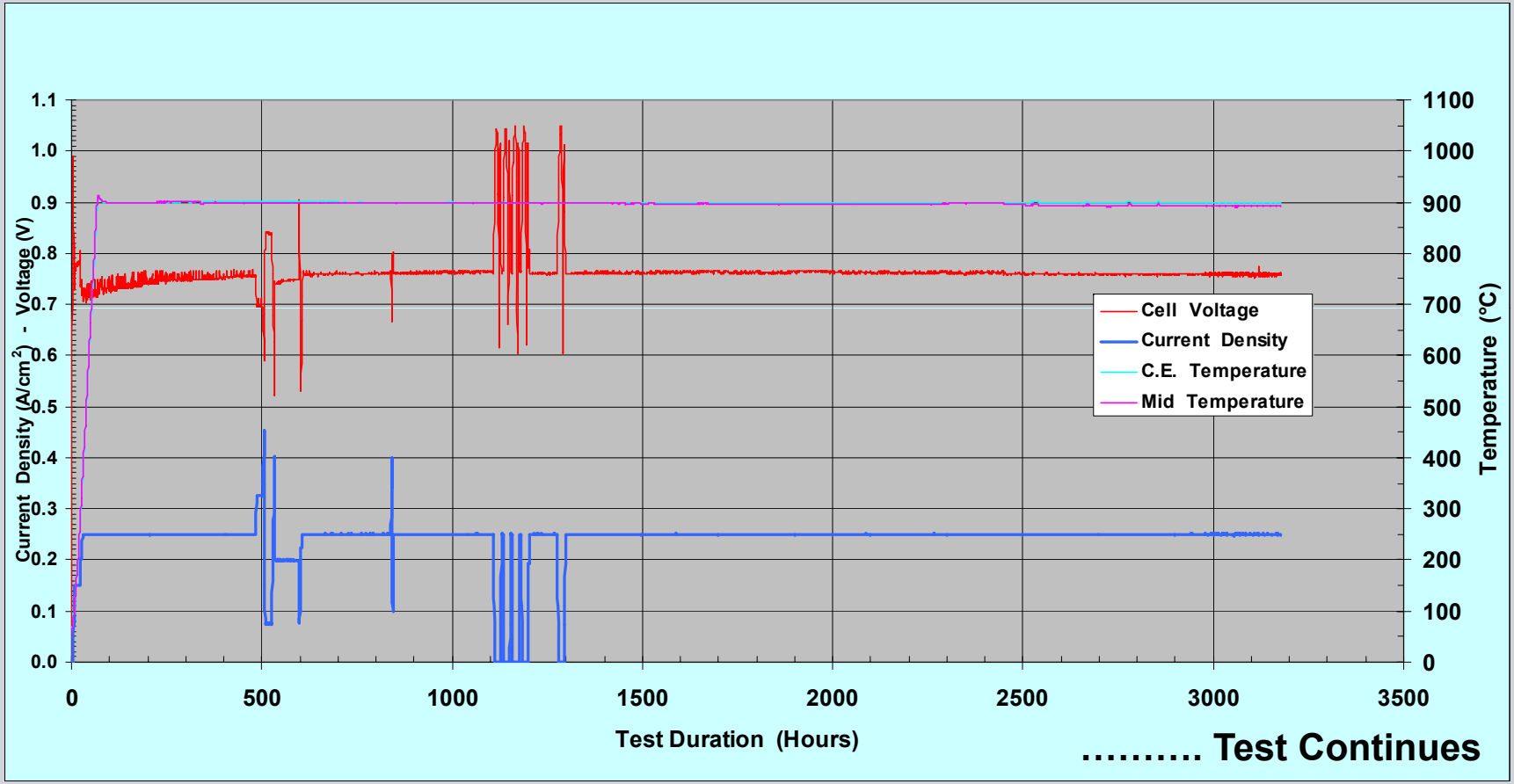
Voltage Stability of Power Enhanced Cylindrical Cell



Excellent Voltage Stability …
Next step: Adapt Process and Materials to Delta8 cells

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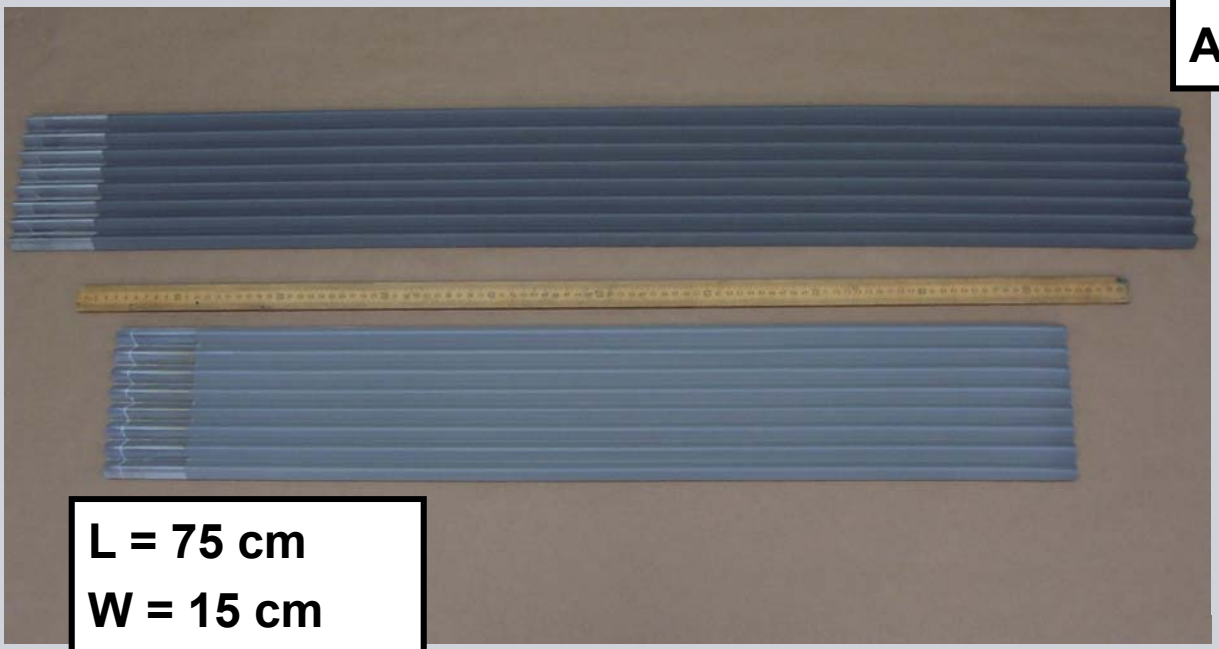
Delta8 Cells – Increased Cell Length and Area

1 M active length cell

L = 100 cm
W = 15 cm
A = 2570 cm^2

This Year



L = 75 cm
W = 15 cm
A = 1950 cm^2

Last Year

1 M active length cell selected for Phase II stack test

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1x8 Delta8 Bundle (1 M active length cells)

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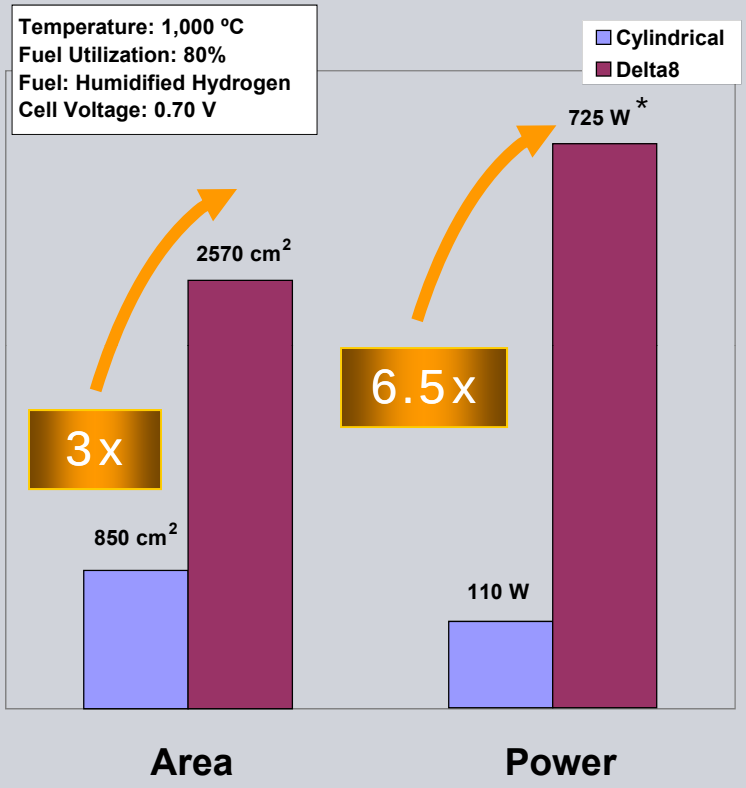
Performance Projection - 1 M Delta8 Cells and Bundles



* Projection based on data for 75 cm active length cells

Delta8 area increased by ~3X vs. cylindrical, however power increased by ~6.5X

24 cylindrical cells
DC power: 2.6 kWe
Weight: 34 kg

8 Delta8 cells
DC power: 5.8 kWe*
Weight: 32 kg

Reduced weight by 5% and increased power by 120%, resulting in lower cost and smaller footprint

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Basic Building Block for Larger Units

- Eight 1 M Delta8 cells
- Fully integrated bundle assembly contains fuel plenum, cell bundle, open end seal, recuperator, exhaust plenum, intake air plenum and electrical connectors
- Cast ceramic components
- Provides fuel, air, exhaust and electrical interfaces for the fuel cells
- Compact recuperator preheats incoming air and eliminates external hot piping

Six basic building blocks will be tested in Phase II stack test

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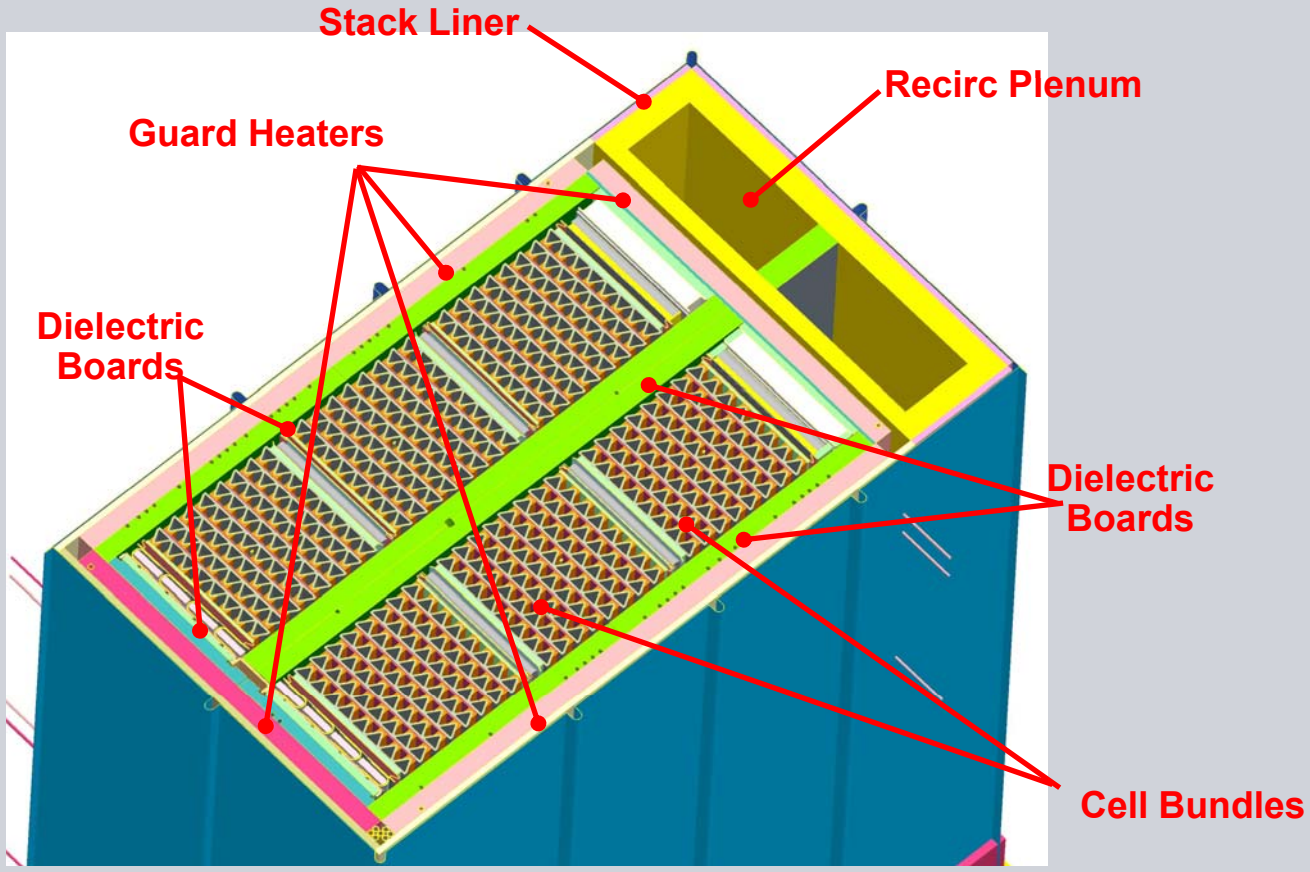
Phase II Stack



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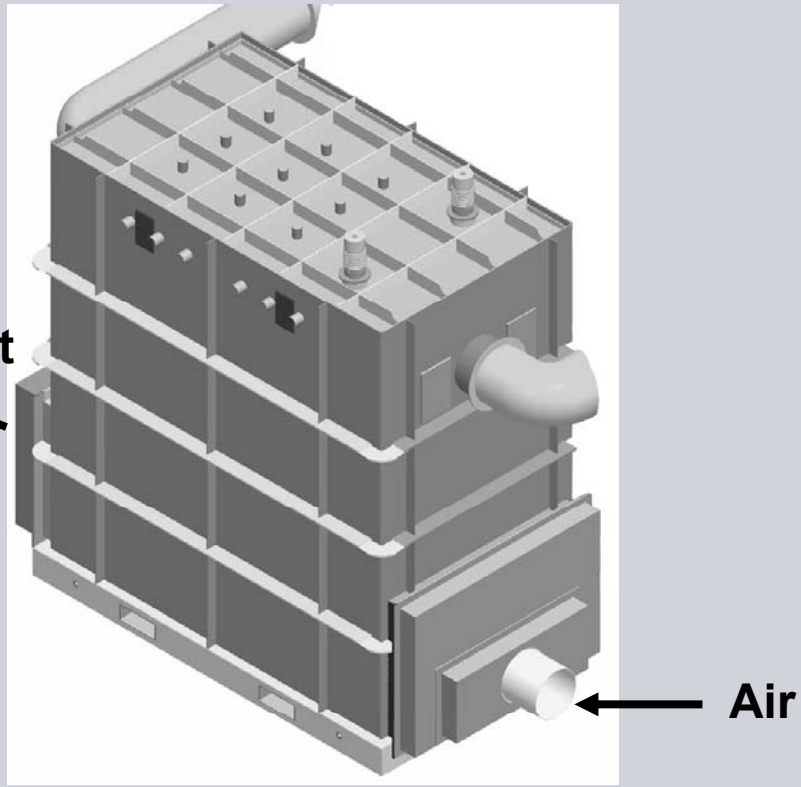
Delta8 Cell Module - Power System Building Block

- 480 Delta8 cells
- Natural gas fuel
- Nominal Power ~ 250 kW (atm. pressure)
- Module Dimensions:
  - Height – 3.4 m
  - Width – 3.7 m
  - Depth – 1.9 m



Larger fuel cell power systems are effectively assembled by aggregating modules

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Summary

- Met all Phase I milestones
- Established Delta8 cell processing parameters and fabricated both 75 cm and 100 cm active length cells and bundles with these cells
- Demonstrated seamless closed end extrusion for Delta8 cells
- Showed significant progress in developing mass production concept of plasma spray process
- Improved power density of Delta8 cells by approximately 10% over first generation cells
- Demonstrated voltage stability of Delta8 cells
- Showed 50% power enhancement in tubular cells by lowering the electrolyte densification temperature and reducing the electrolyte thickness in half – Reduction of electrolyte thickness to ¼ of present value is feasible
- Completed design of Phase II stack test
- Initiated assembly of Phase II stack test

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Acknowledgements

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- Siemens Stationary Fuel Cells Team