



Development of High Power Density Seal-less SOFCs

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Stationary Fuel Cells**

Siemens Tubular Geometry Seal-Less Solid Oxide Fuel Cell

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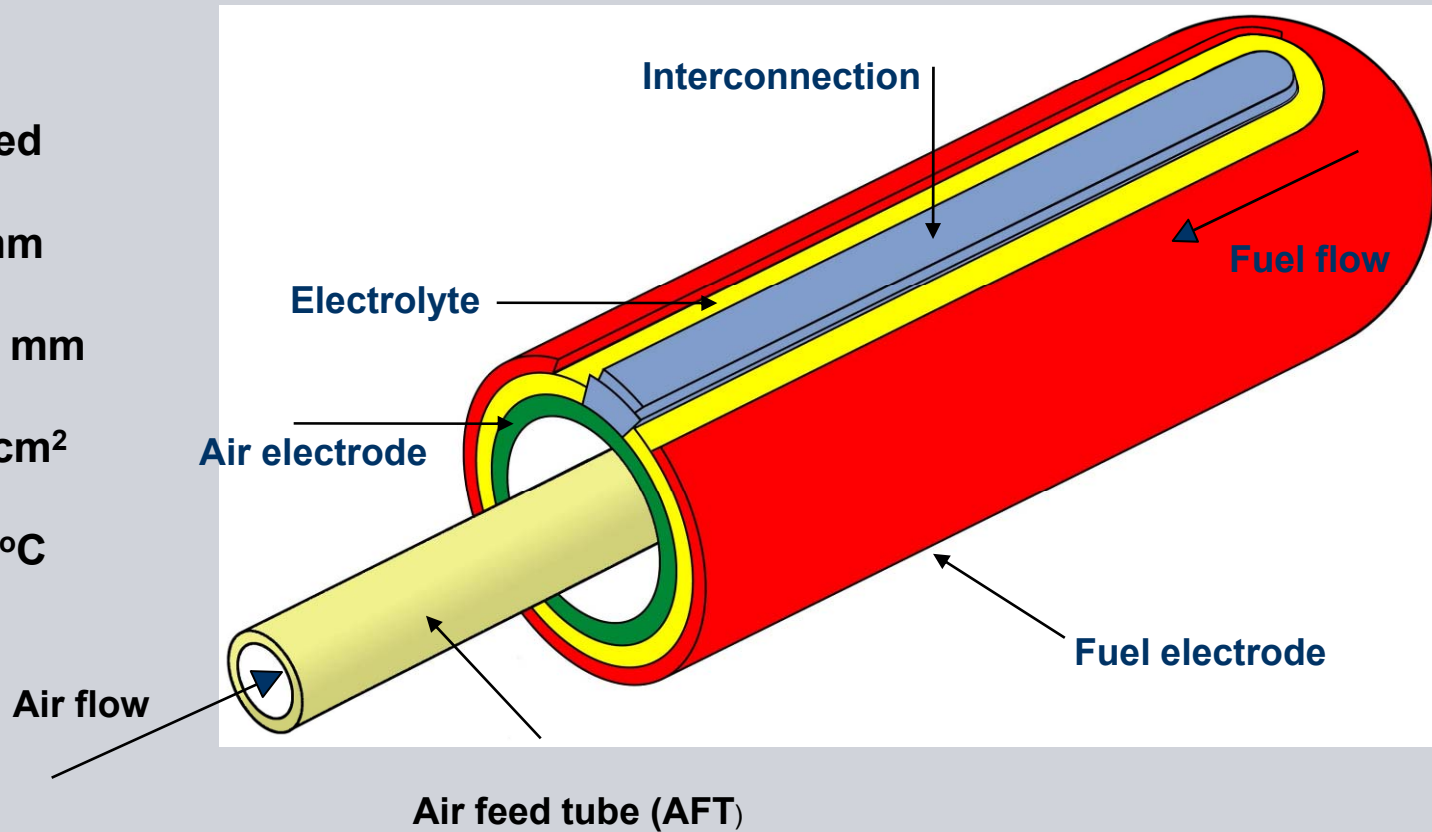
Cathode
Supported

D = 22 mm

L = 1500 mm

A = 850 cm²

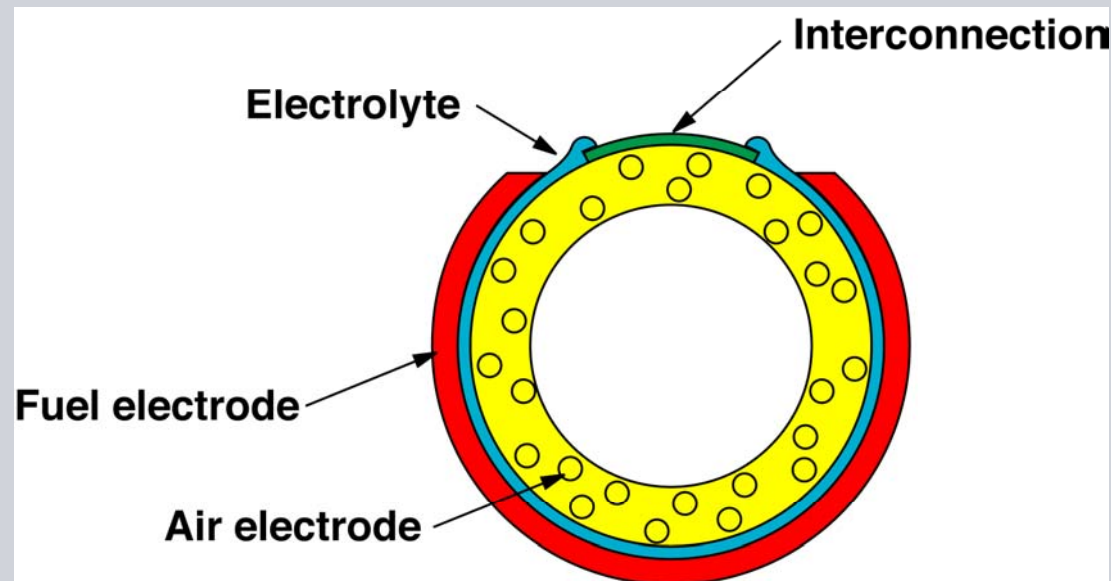
T = 1000°C



Siemens Solid Oxide Fuel Cell Materials and Processing

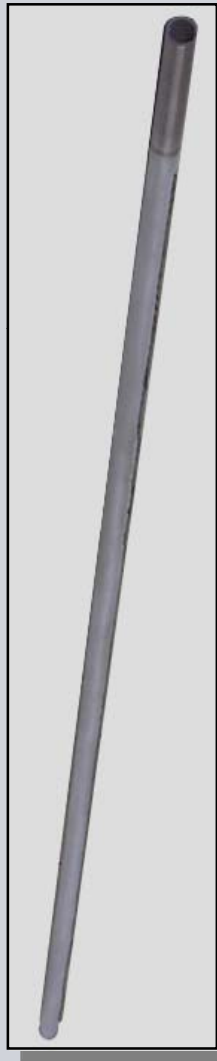
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<u>Component</u>	<u>Material</u>	<u>Present Fabrication Process</u>
Air Electrode	Doped LaMnO_3	Extrusion-Sintered
Electrolyte	$\text{ZrO}_2(\text{Sc}_2\text{O}_3)$	Atmospheric Plasma Spraying
Interconnection	Doped LaCrO_3	Atmospheric Plasma Spraying
Fuel Electrode	$\text{Ni-ZrO}_2 (\text{Y}_2\text{O}_3)$	Atmospheric Plasma Spraying



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Base-line Cell Performance



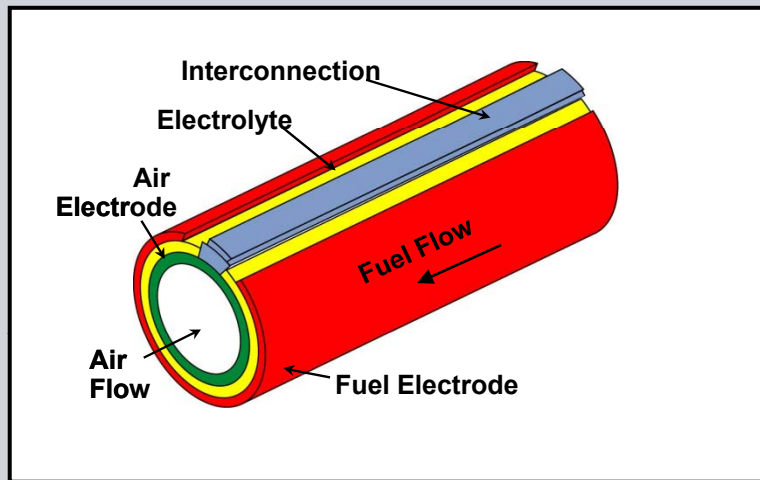
Single Cell Performance

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

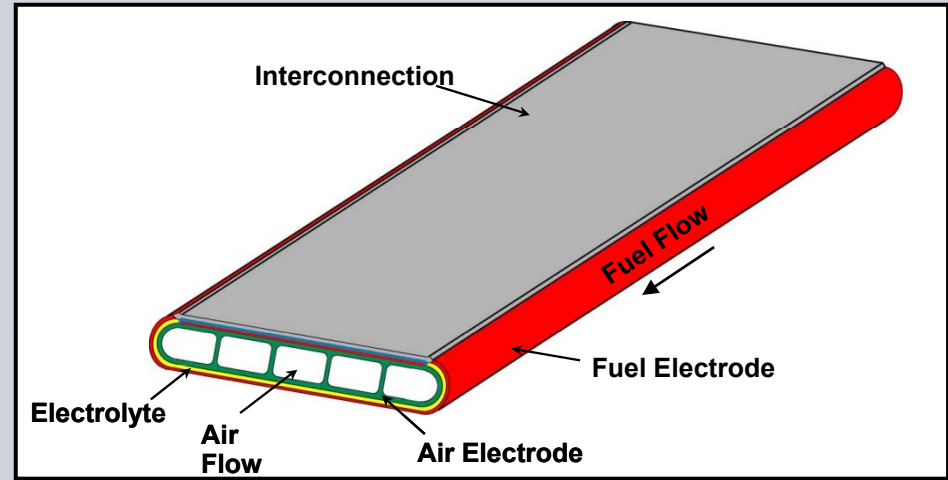
In-System Performance

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

Transition from Tubular to High Power Density (HPD) Cell



Tubular



HPD

Advantages

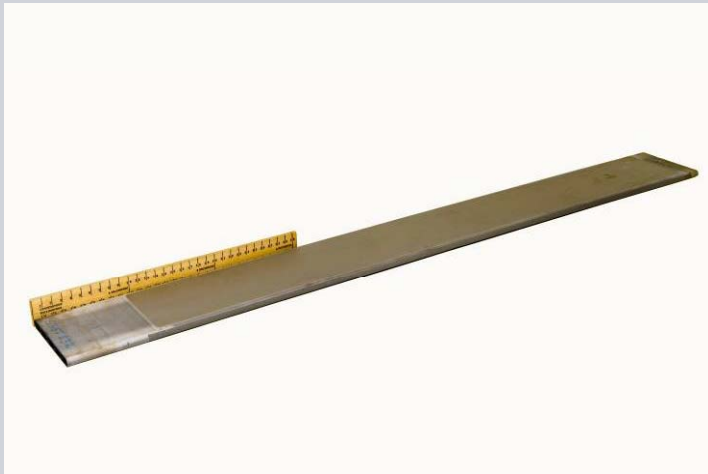
- Closed end enables seal-less design
- Reduction in ohmic resistance
- Increase in cell power density
- More compact stack

Same cell materials and manufacturing processes – Different design

First Generation HPD Cells

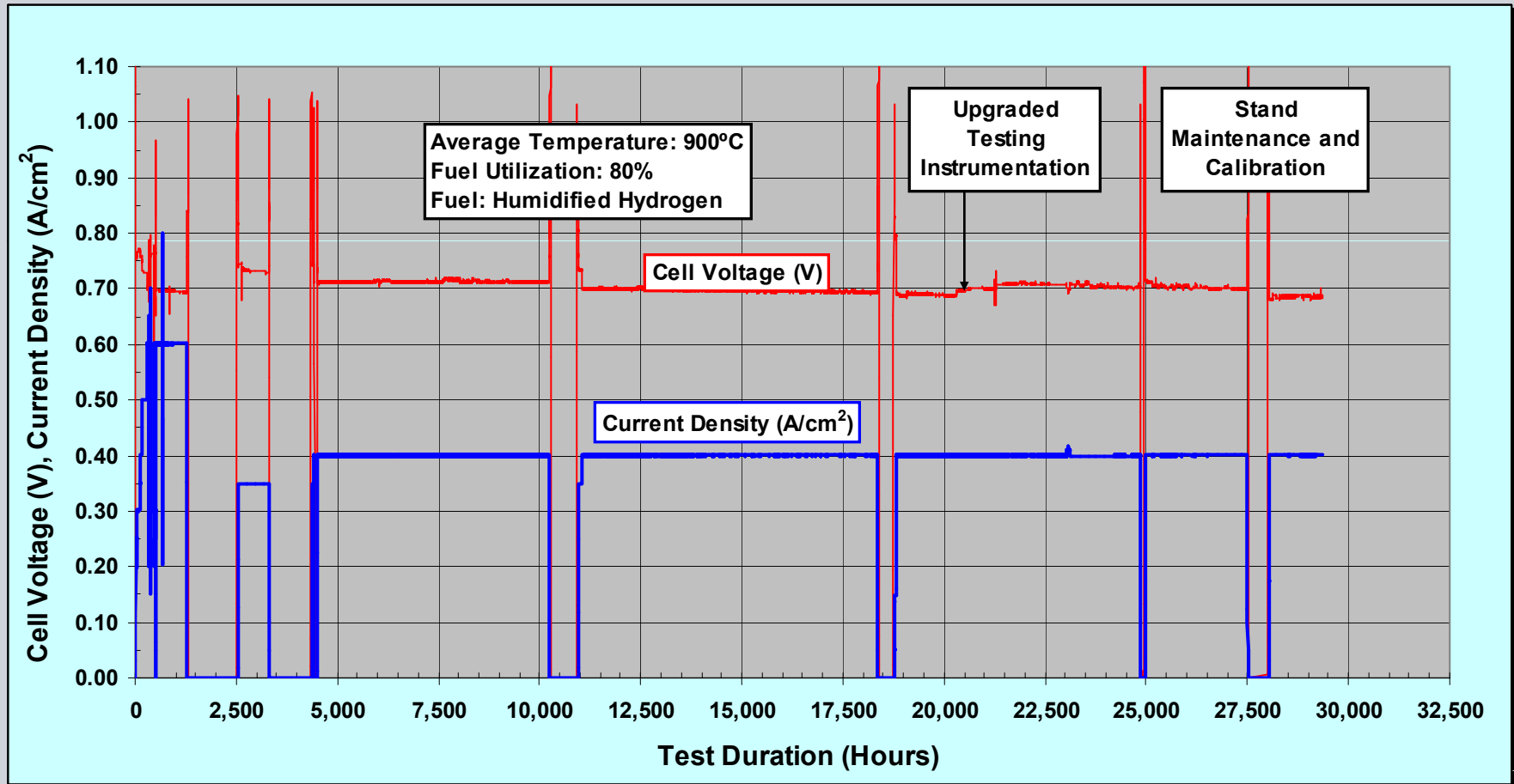
Active Length: 75 cm

Active area: ~900 cm²

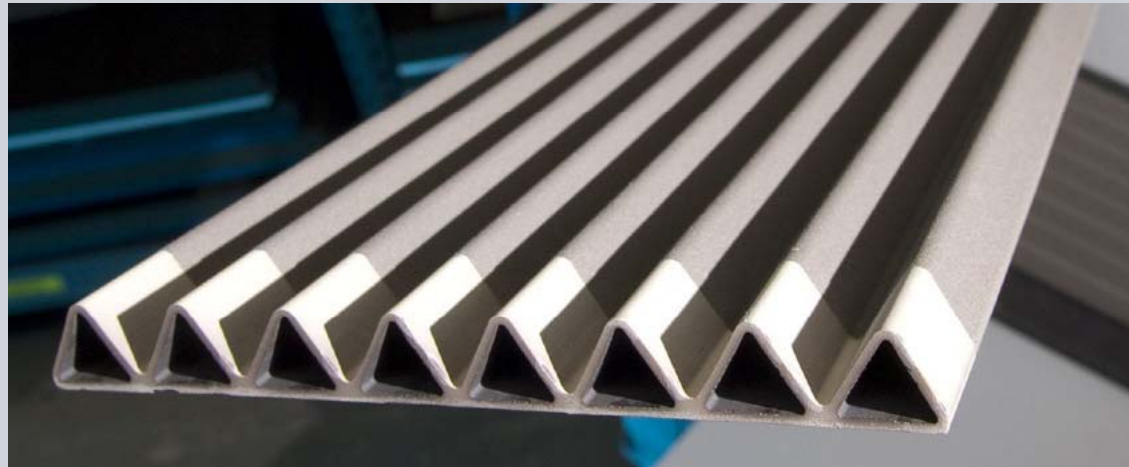


Developed HPD5 (five channels) and demonstrated benefits relative to tubular cells

HPD Voltage Stability



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)**

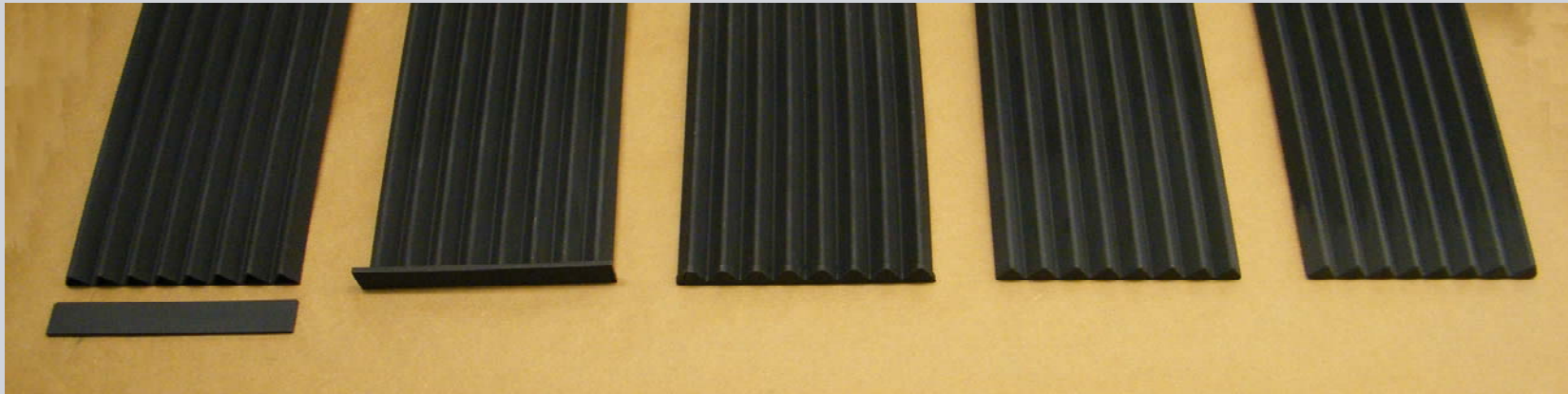
...leading to cost reduction in the cell area

Cell Development . . .

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

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

Present Process To Attach Closed End



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

Seamless Closed End



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

Horizontal (One-Step) Sintering of Cathode



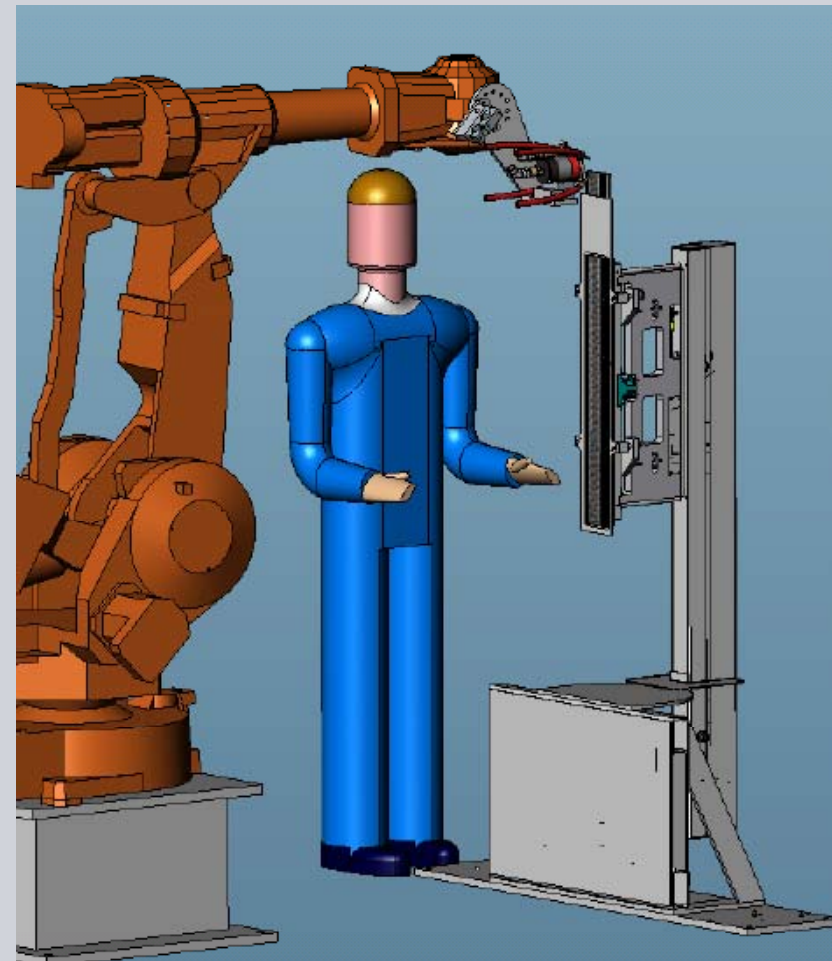
- **Old process**
 - Two- step sintering
 - Horizontal sintering (~ 1200 °C) followed by vertical sintering at ~ 1500 °C
- **New process**
 - Developed non-reactive substrate to sinter cathodes in one step up to ~ 1500 °C

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

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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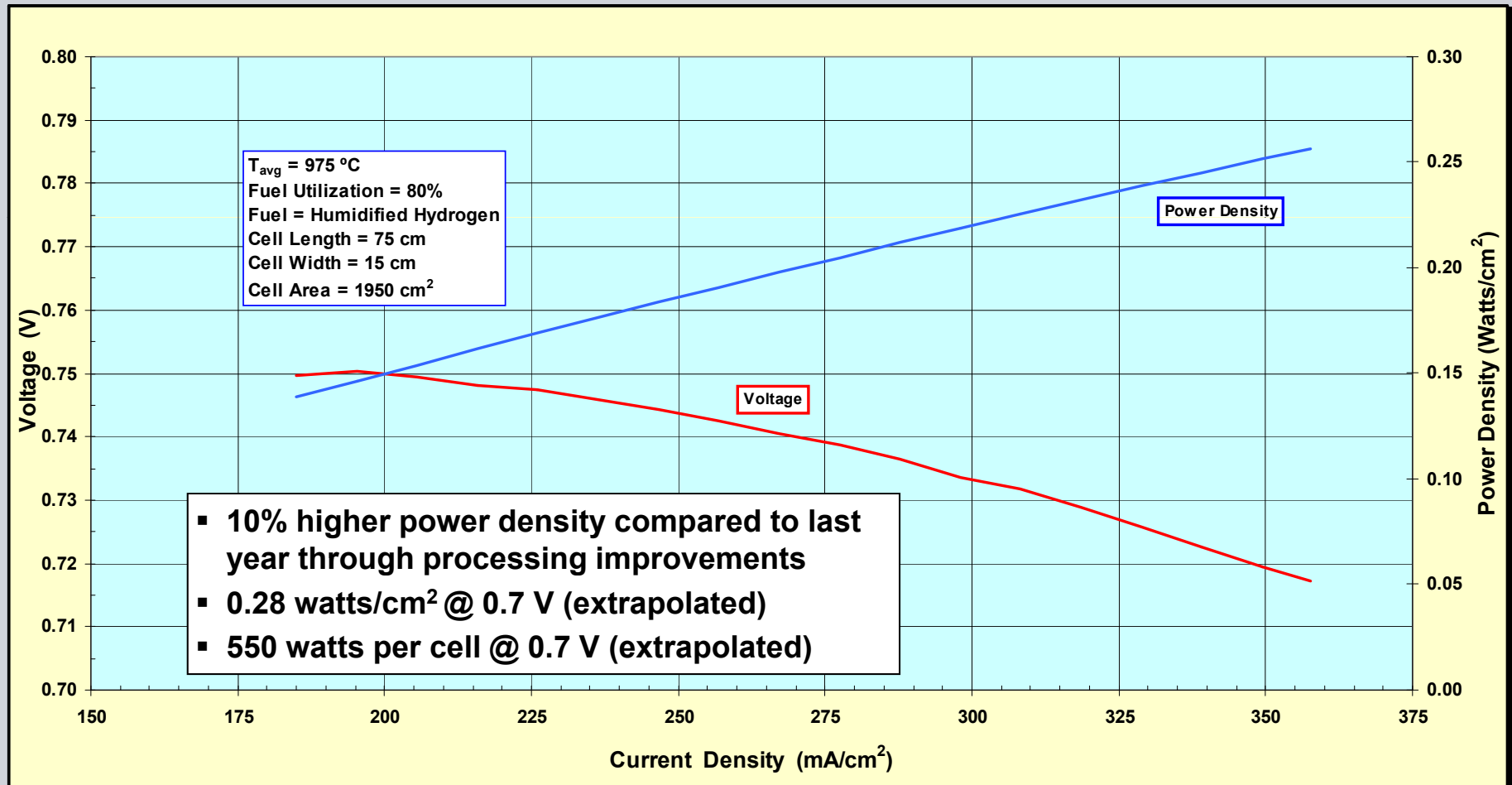
Manufacturing Carousel Design

- 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

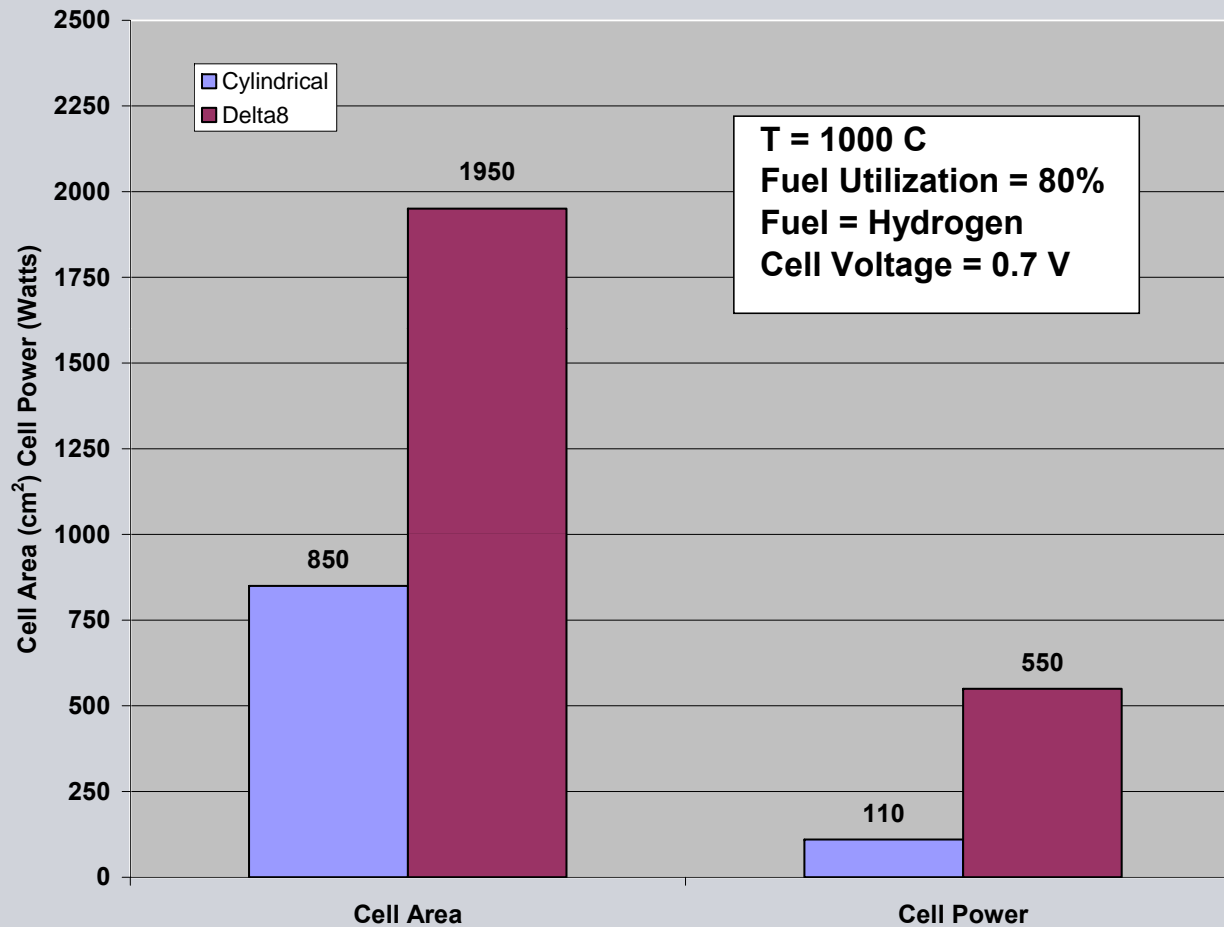


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Delta8 Cell Performance – Voltage vs. Current Density

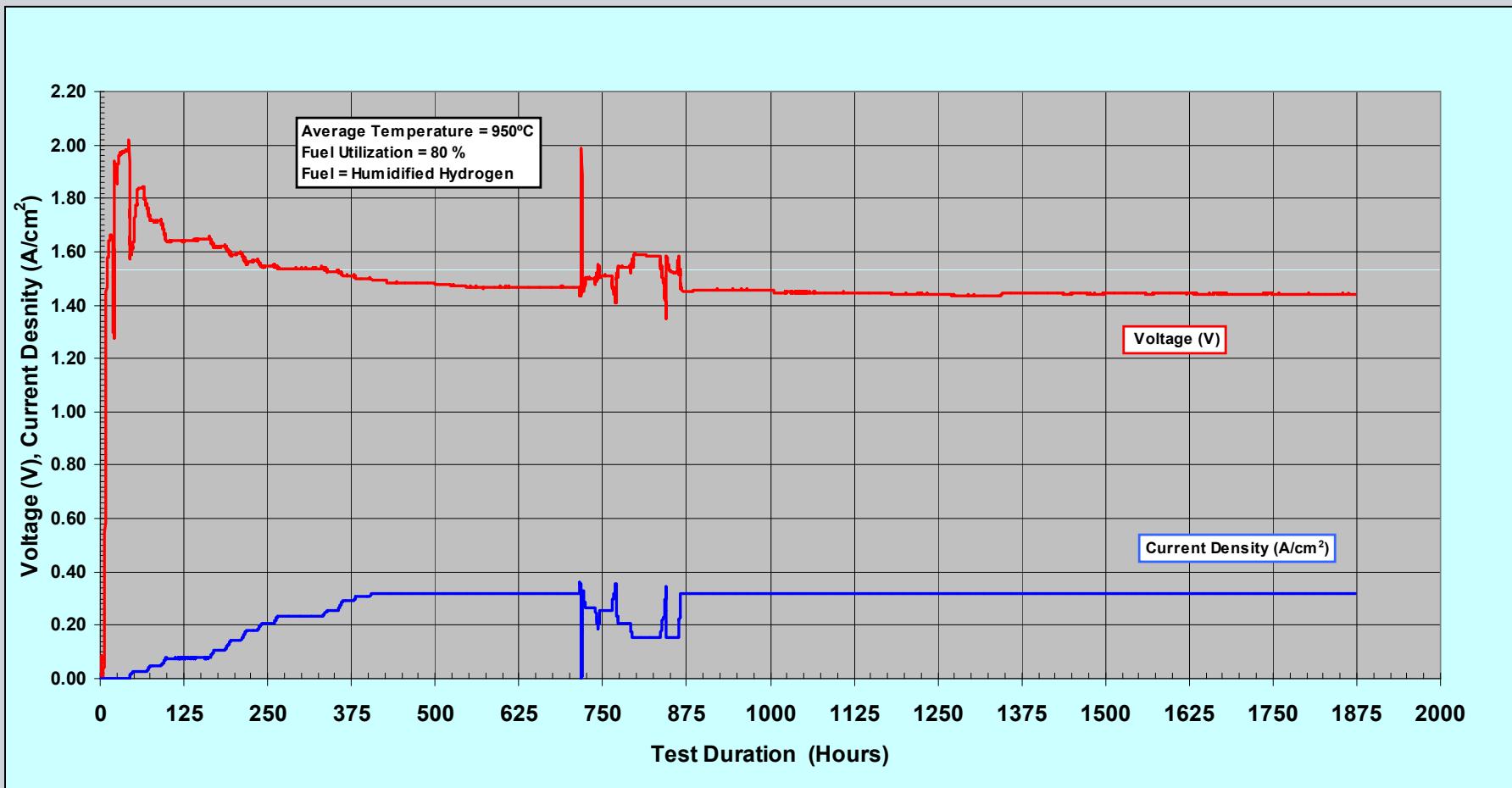


Cell Performance Comparison



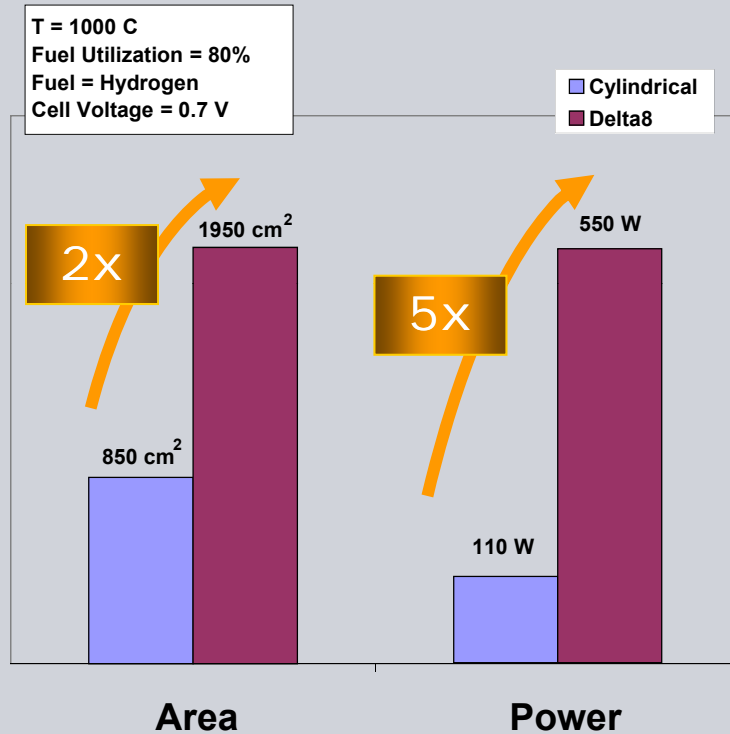
**Delta8 cell area increased by ~ 2X vs. cylindrical cell
 ... cell power increased by ~ 5X**

Delta8 Cell Voltage Stability (2-cell test)

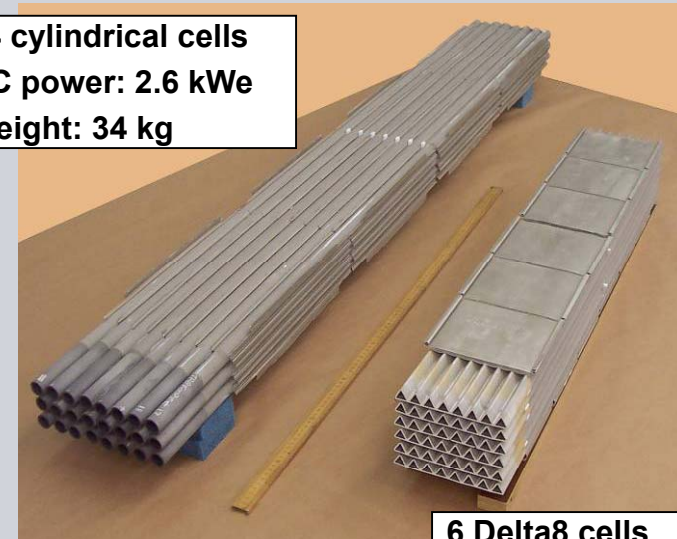


Excellent voltage stability

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%

SECA 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**

Phase I Integrated System



Cell Stack



Complete System

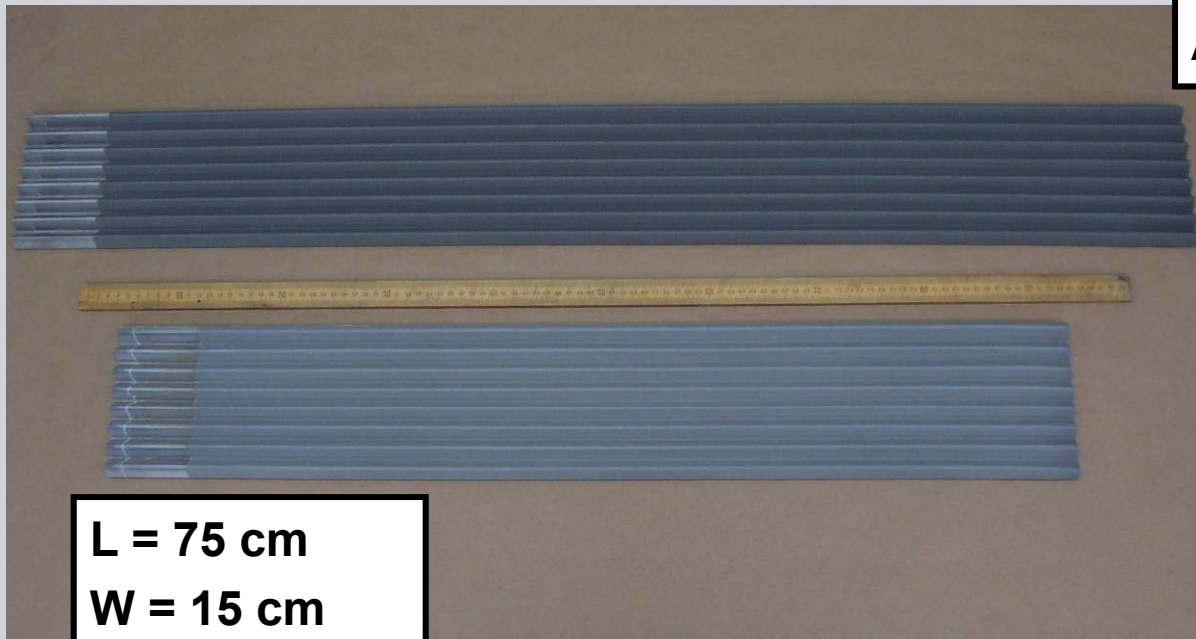
Phase I Stack Test Results

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% CH ₄ , dry basis)	Hydrogen and simulated coal gas
AVAILABILITY	Report availability	Availability factor of 85% at 50% power or greater

Delta8 Cells – Increased Cell Length and Area

1 M active length cell

**L = 100 cm
W = 15 cm
A = 2570 cm²**



This Year

**L = 75 cm
W = 15 cm
A = 1950 cm²**

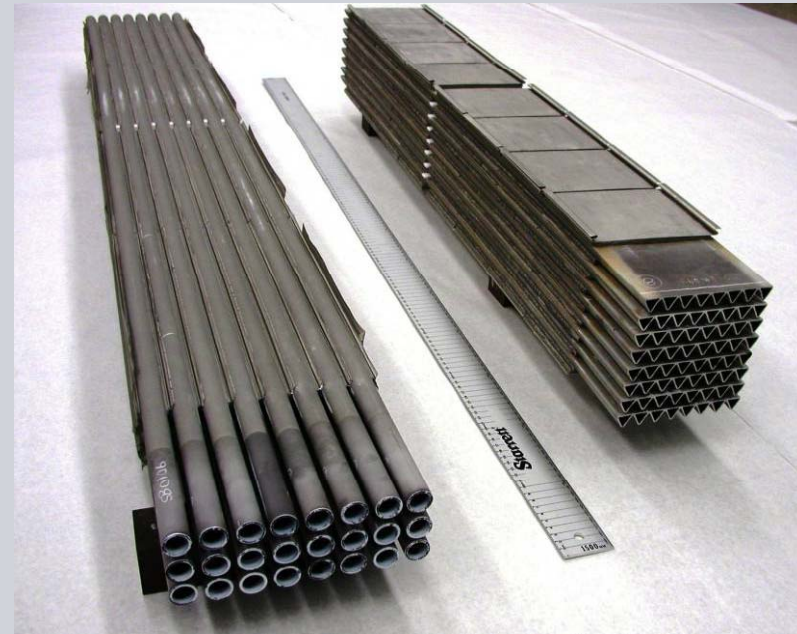
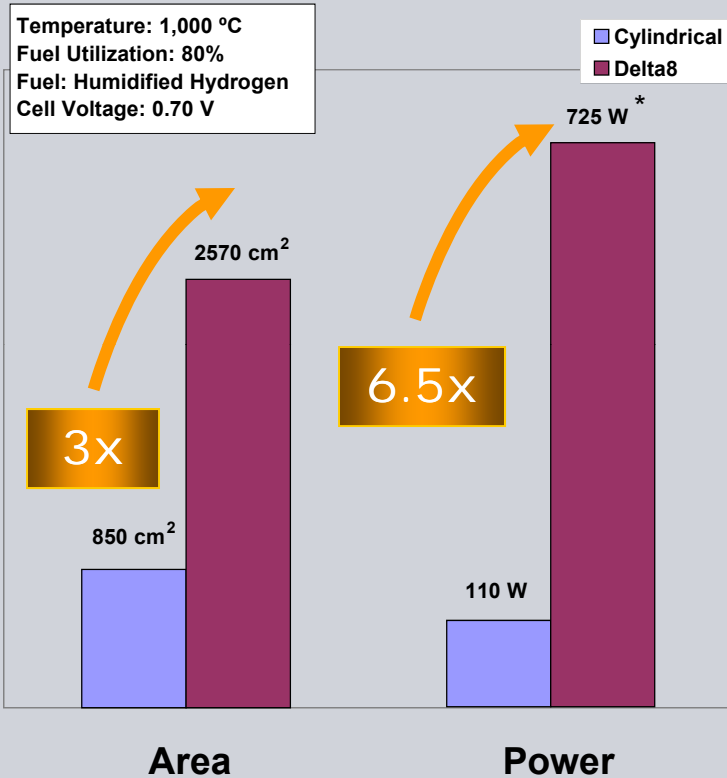
Last Year

1 M active length cell selected for Phase II stack test

1x8 Delta8 Bundle (1 M active length cells)



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

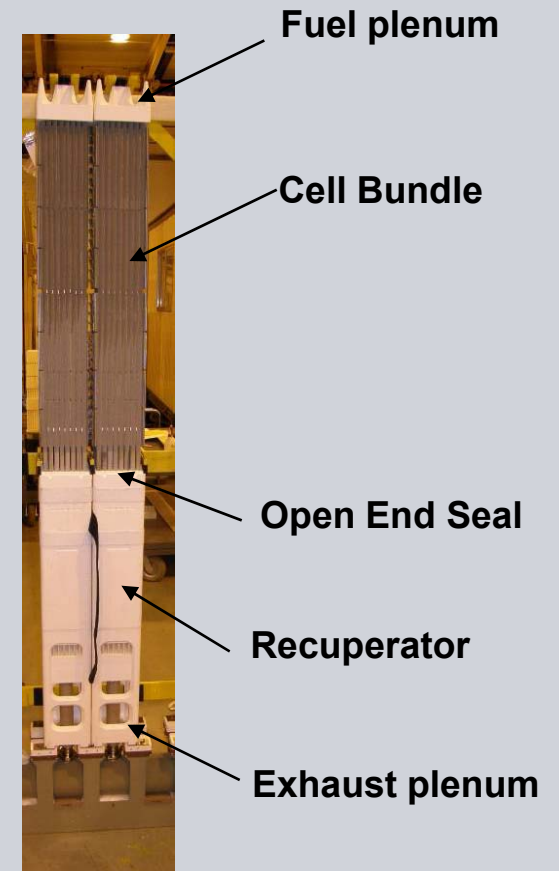
**24 cylindrical cells
 DC power: 2.6 kWe
 Weight: 34 kg**

**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

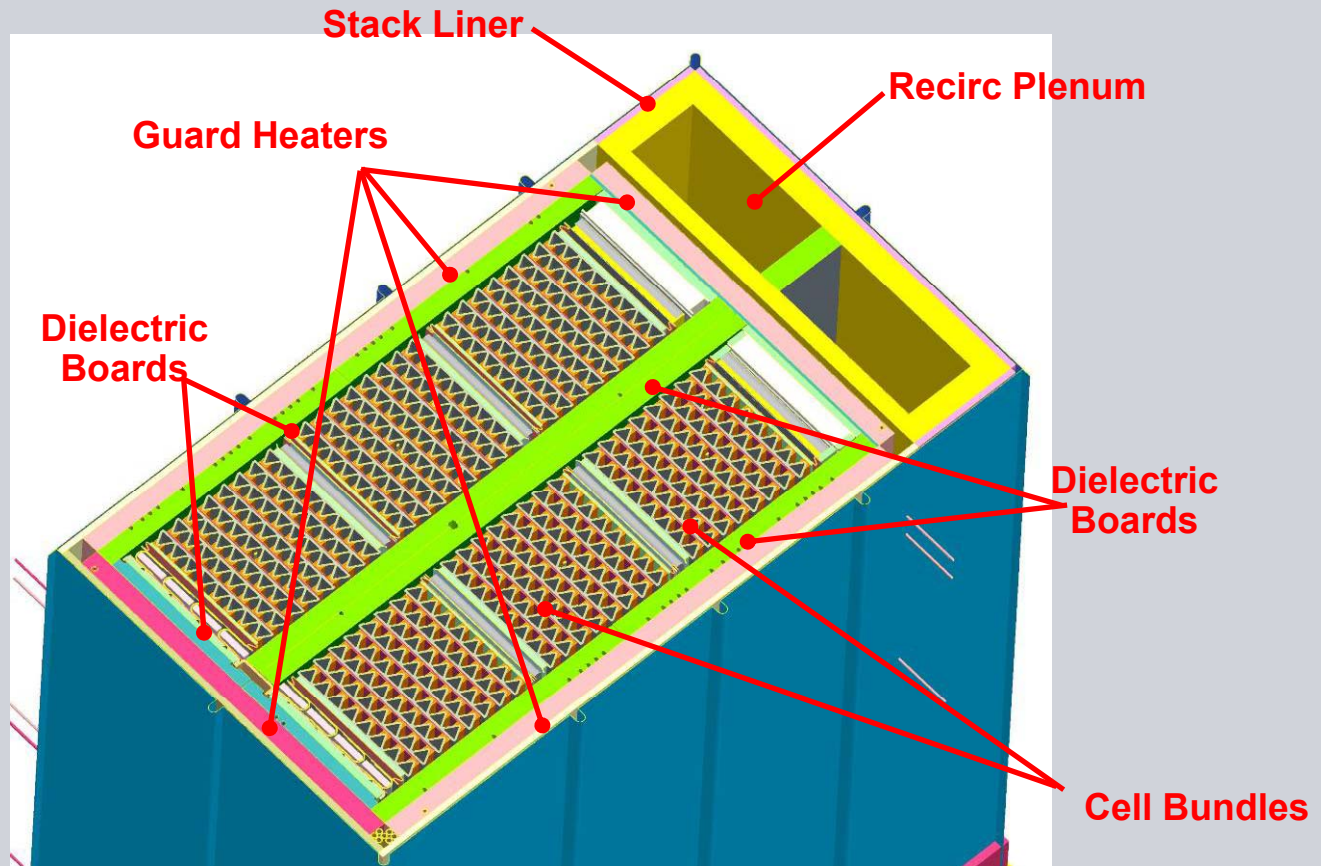
Basic Building Block for Larger Units

- 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



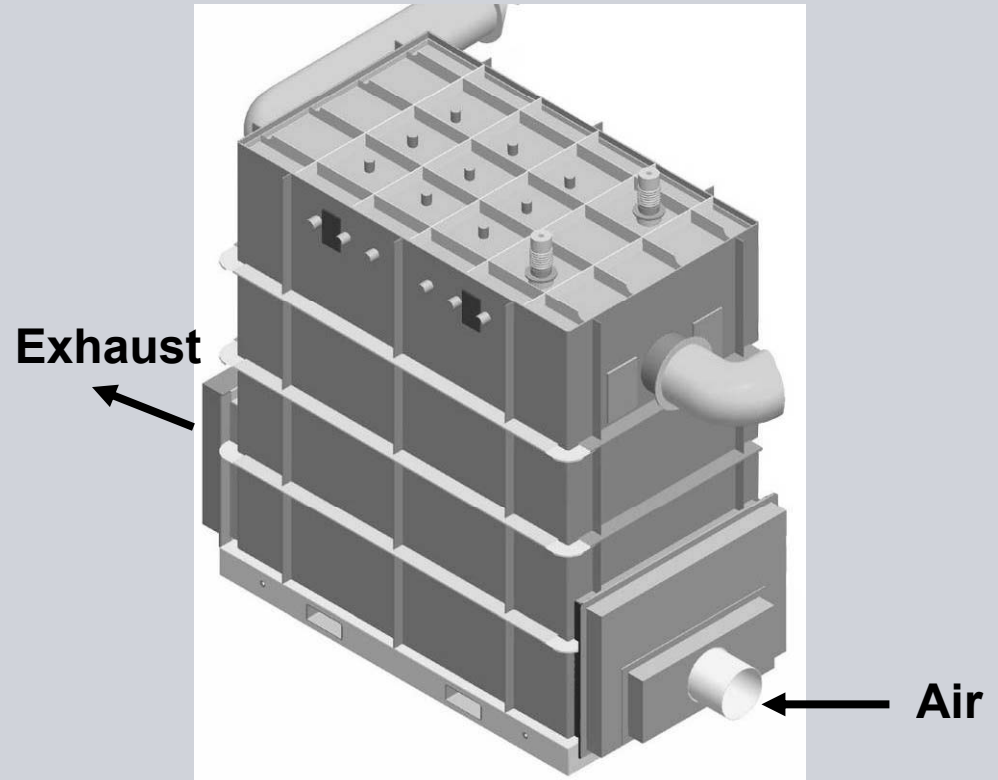
Six basic building blocks will be tested in SECA Phase II stack test

SECA Phase II Stack



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

Summary

- **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**
- **Increased power density (area basis) by more than 2X for Delta8 cells compared to cylindrical cells**
- **Demonstrated voltage stability of both HPD and Delta8 cells**
- **Completed assembly of SECA Phase II stack test**

Acknowledgements

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- **Siemens Stationary Fuel Cells Team**