SECA Program Review

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Fossil Power Generation
Stationary Fuel Cells

Significant Results

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- 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
- Fabricated 24-Delta8 cell stack
- Developed modular stack concept to scale to MW systems
- Developed concepts for coal-based >100 MW systems with >50% efficiency, 90% carbon separation and <$600/kW
- Met all Phase 1 milestones to date

Siemens Tubular Geometry
Seal-Less Solid Oxide Fuel Cell

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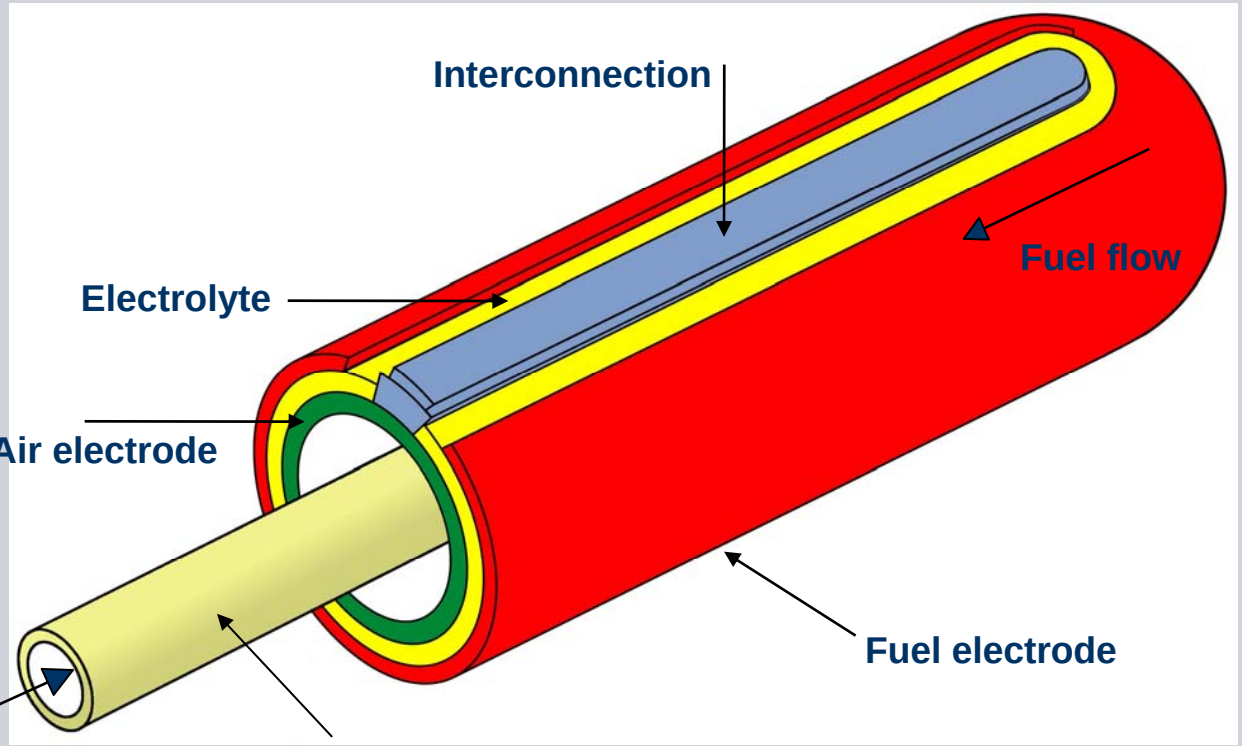
Cathode Supported

D = 22 mm

L = 1500 mm

A = 850 cm^2

T = 1000°C



Air feed tube (AFT)

Siemens Solid Oxide Fuel Cell Materials and Processing

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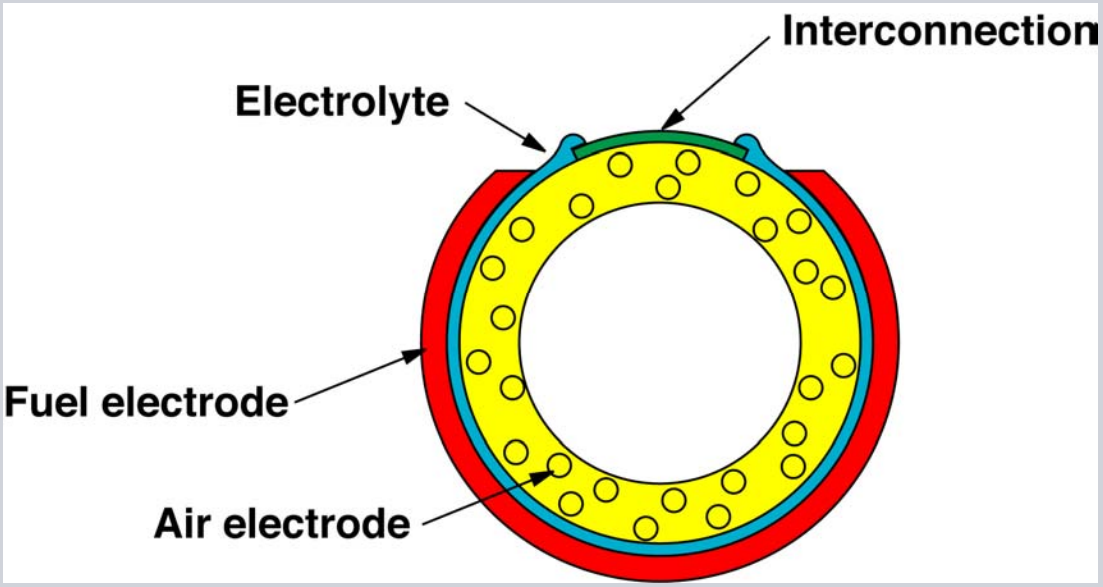
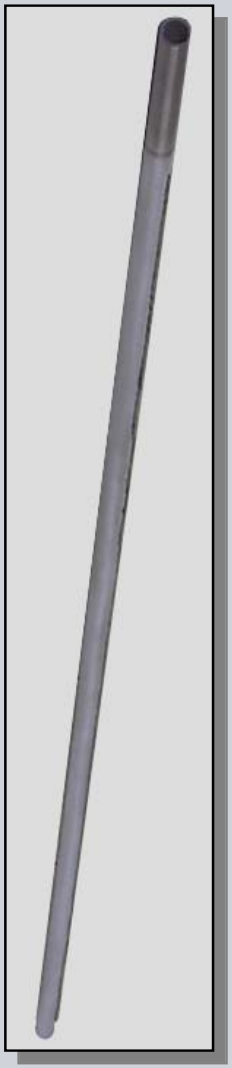
Component	Material	Present Fabrication Process
Air Electrode	Doped $LaMnO_3$	Extrusion-Sintered
Electrolyte	$ZrO_2(Sc_2O_3)$	Atmospheric Plasma Spraying
Interconnection	Doped $LaCrO_3$	Atmospheric Plasma Spraying
Fuel Electrode	Ni-ZrO_2 (Y_2O_3)	Atmospheric Plasma Spraying



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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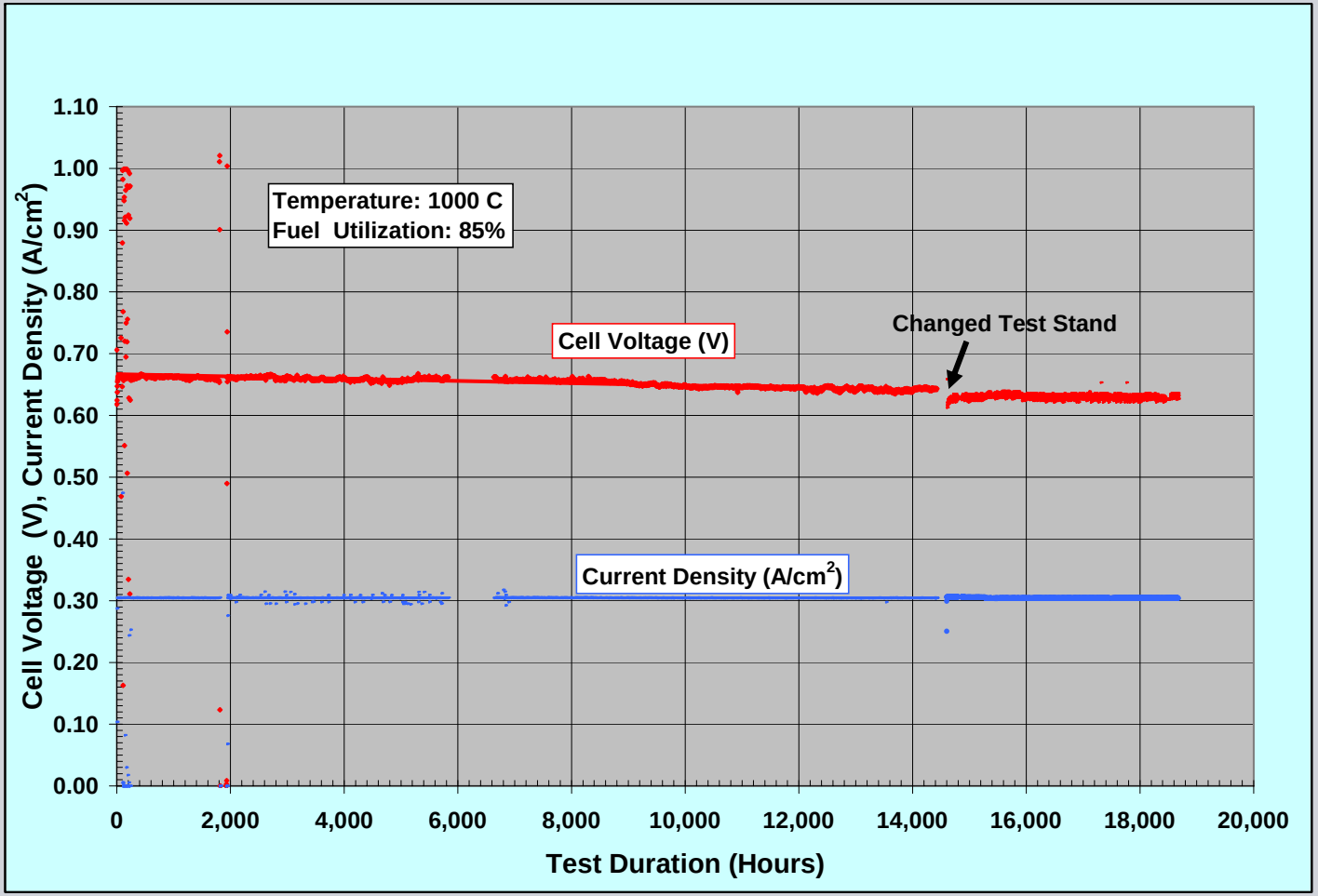
Cell Voltage Stability



~ 0.1% per 1000 hours voltage degradation

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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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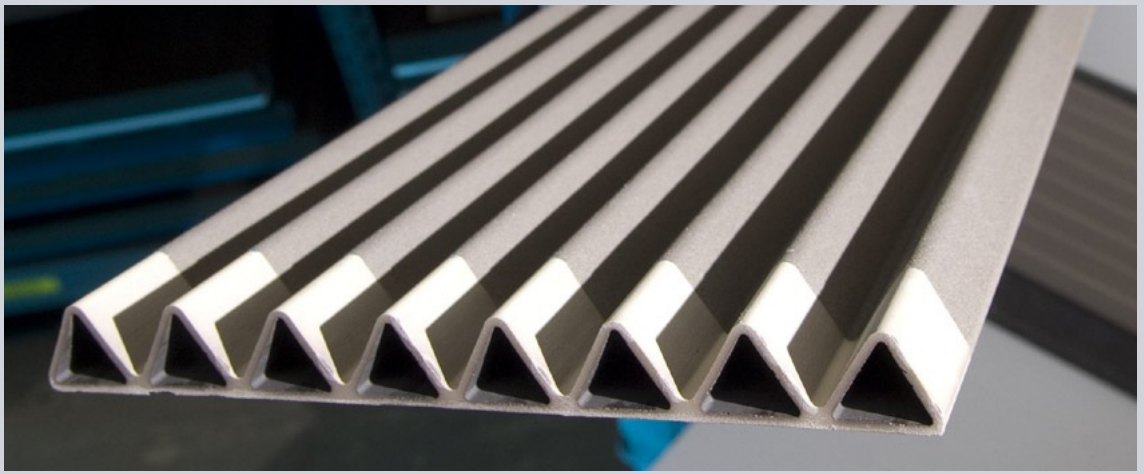
Next Generation Cell Concept – Delta8…



- **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

Air Electrode

Present

L = 75 cm
W = 15 cm
A = 1900 cm^2

Next step (October 2008)

L = 100 cm
W = 15 cm
A = 2600 cm^2

Cell

Delta8 Cell Performance – Voltage vs. Current Density

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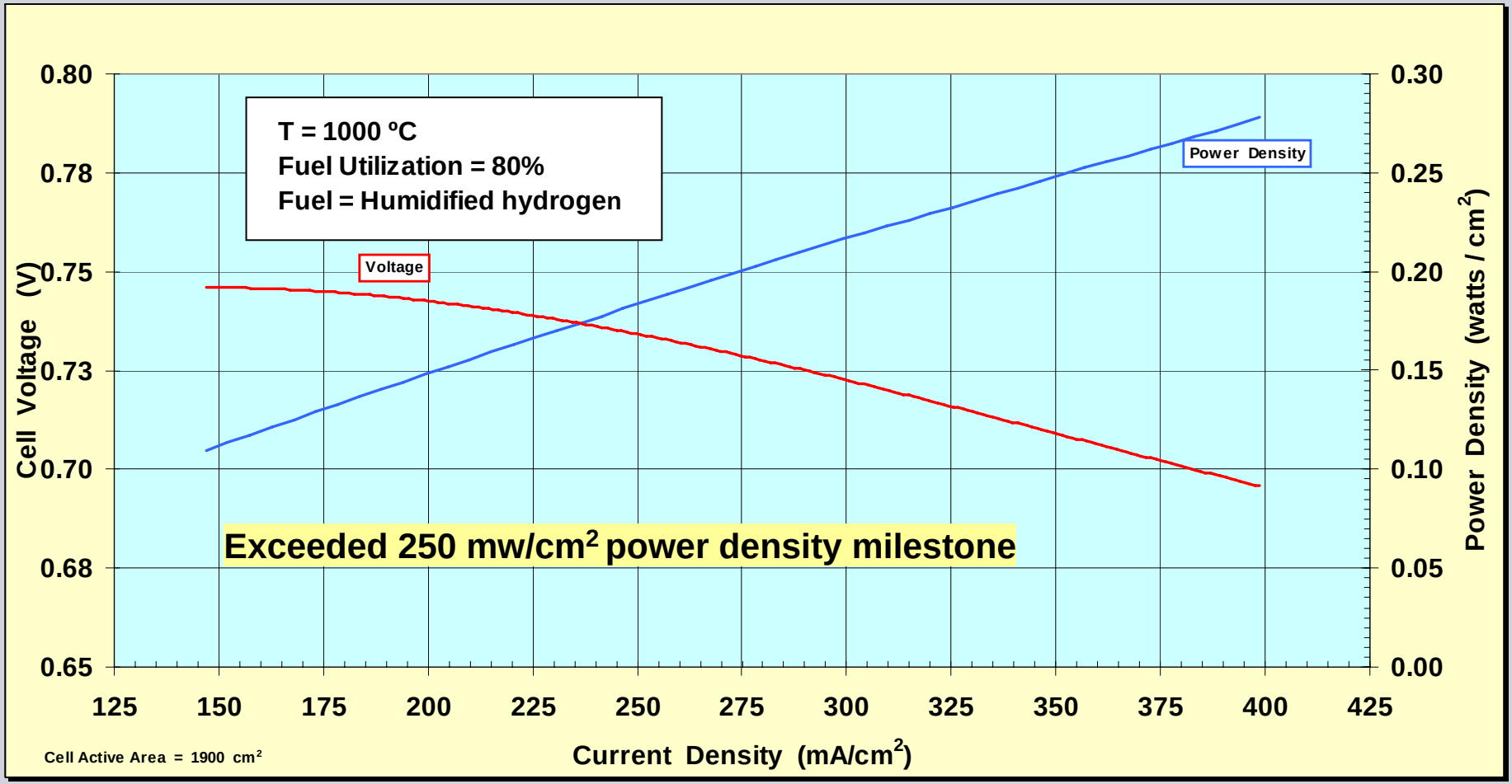

Delta8 Cell Performance – Voltage vs. Current

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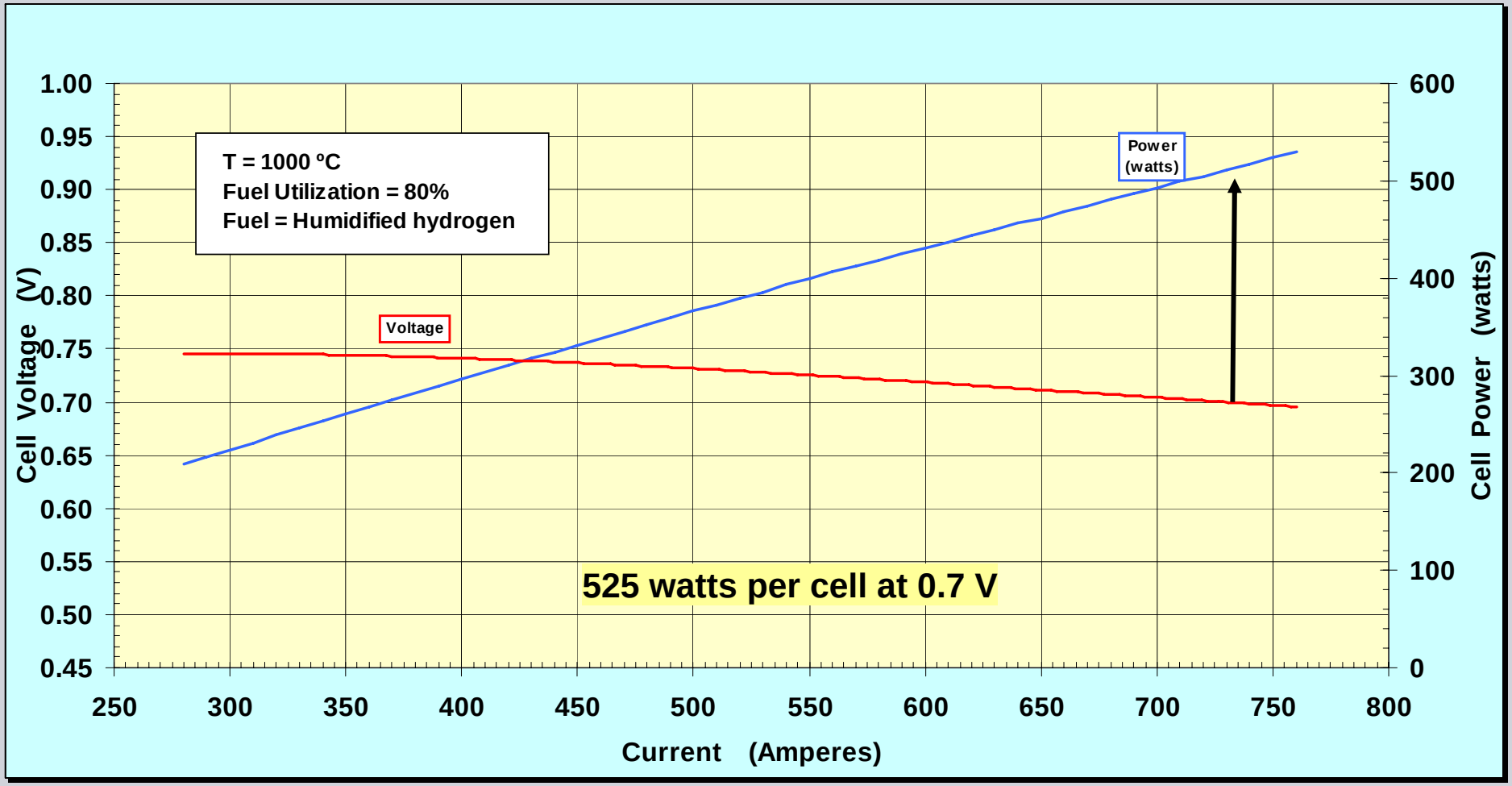

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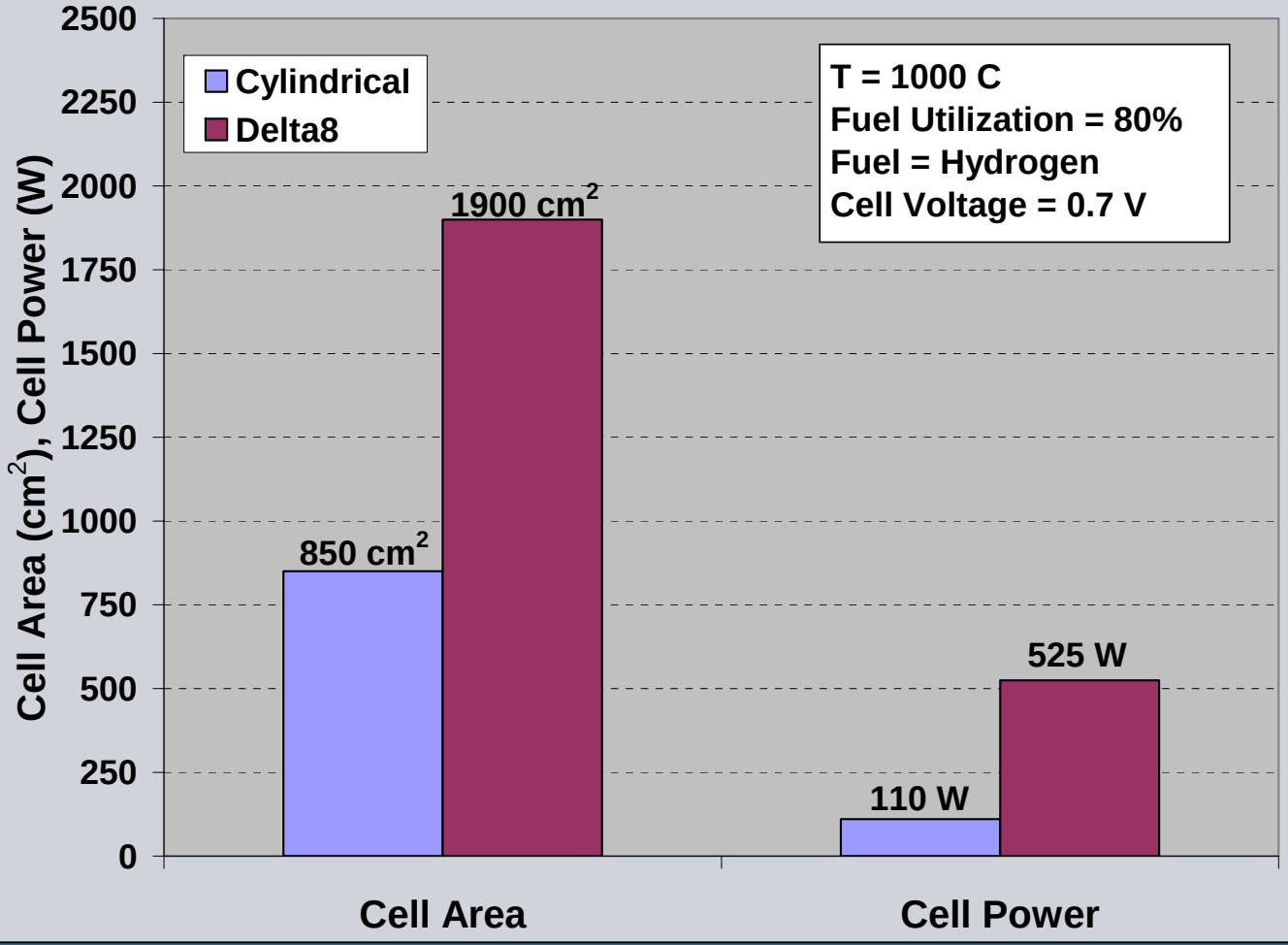
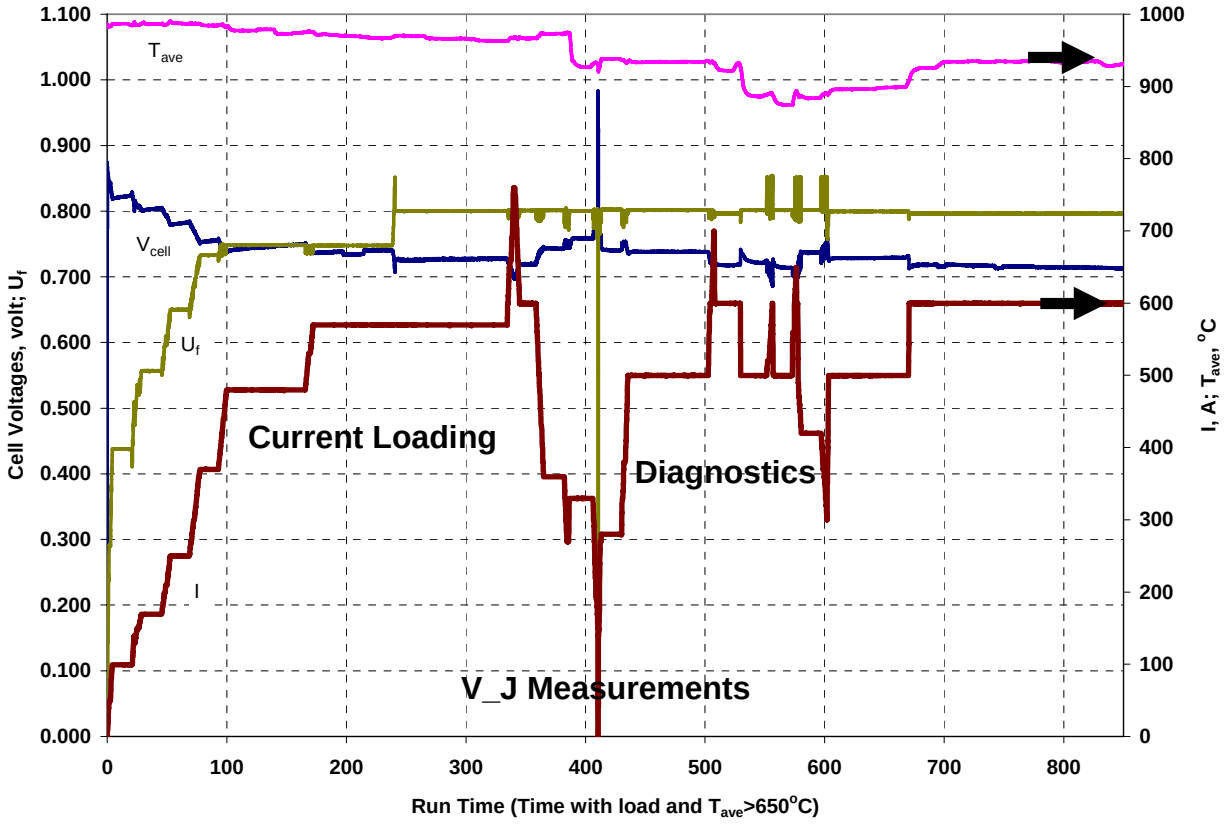
Cell Performance Comparison



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

Delta8 Cell Test Data …….

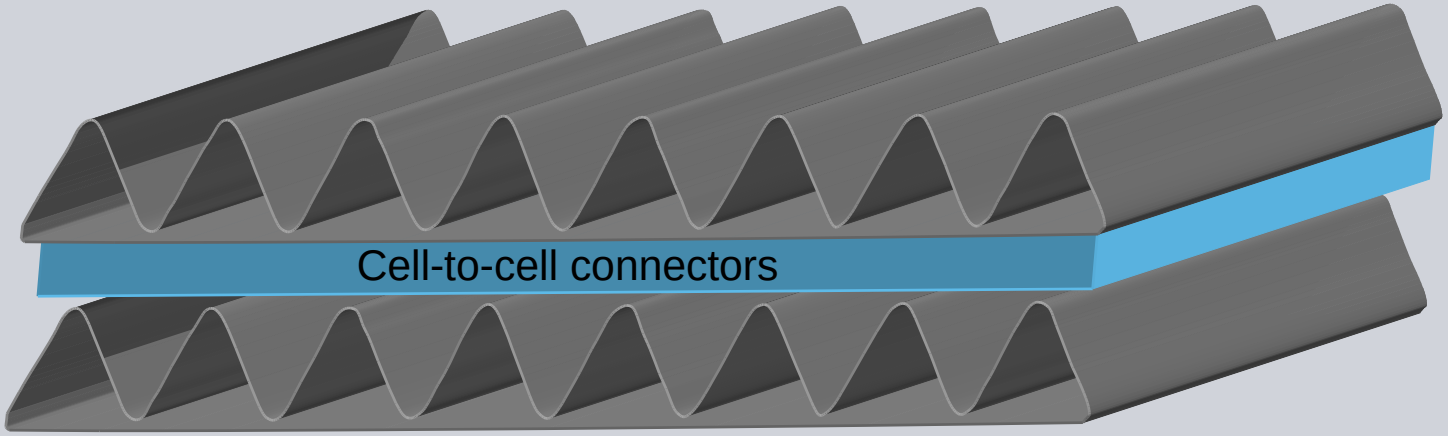


…..Test continues

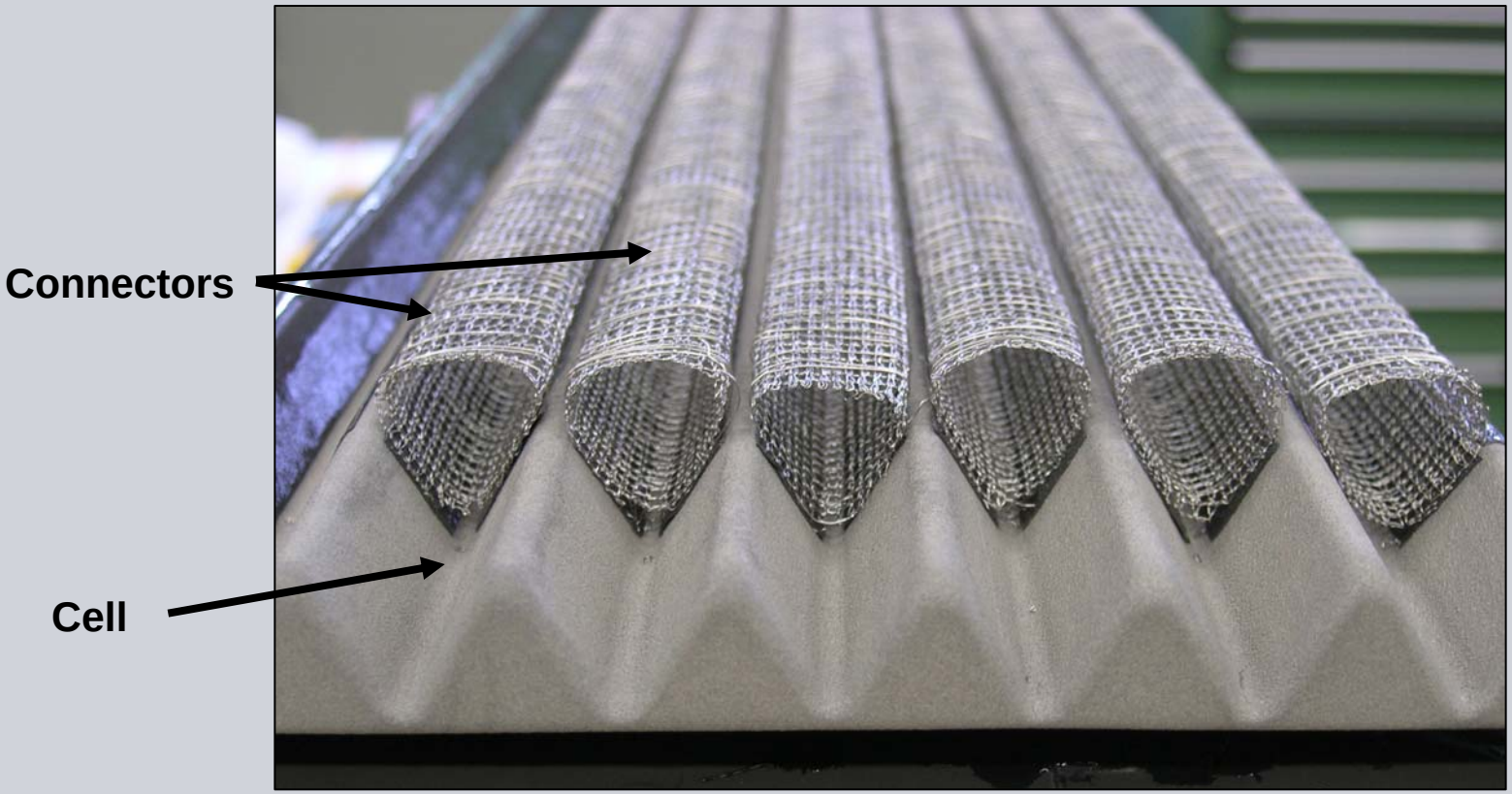
Cell-to-Cell Connectors

Requirements

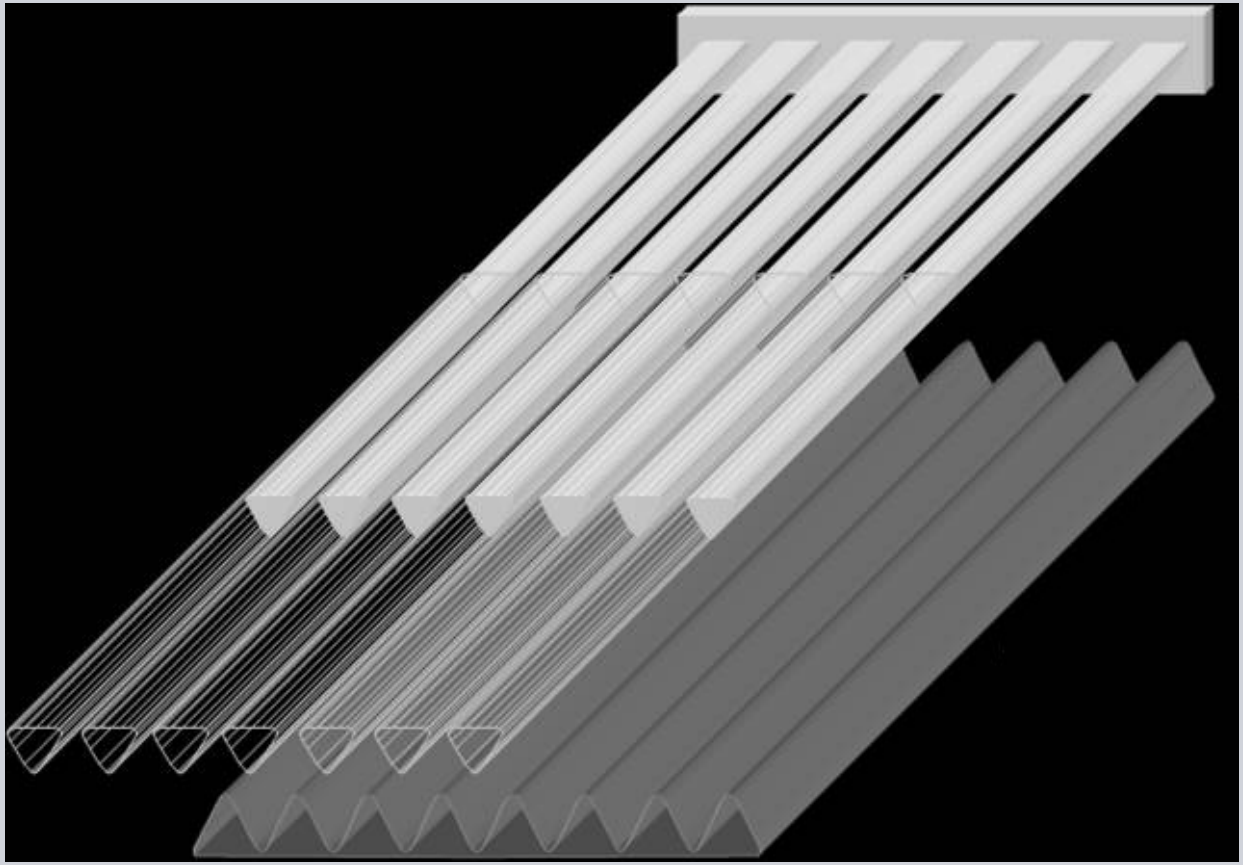
- High conductivity
- Flexibility
- Low cost



Cell-to-Cell Connector Concept



Concept for Connector Application



Simple assembly process

Bundling

Delta8 cells with connectors in place

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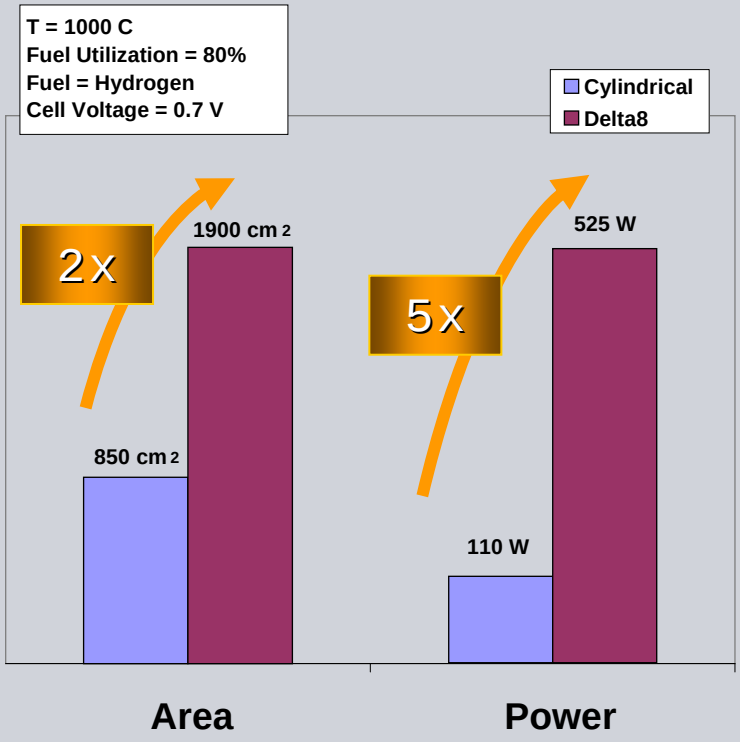
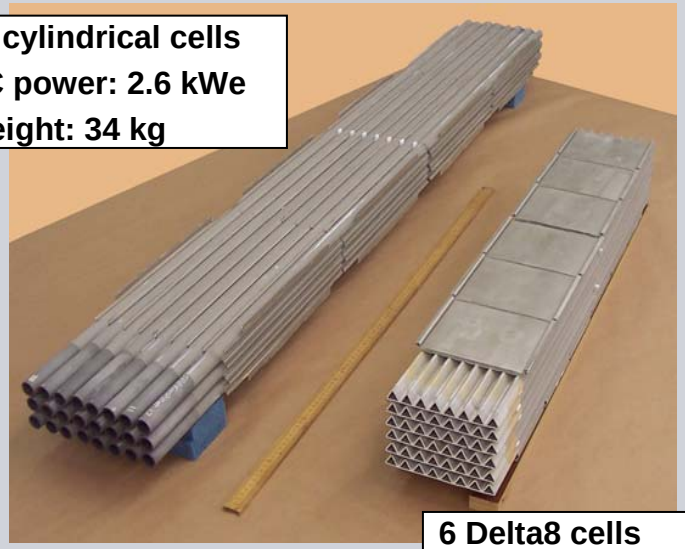
Delta8 Cell Bundle in Preparation

Cell and Bundle Comparison





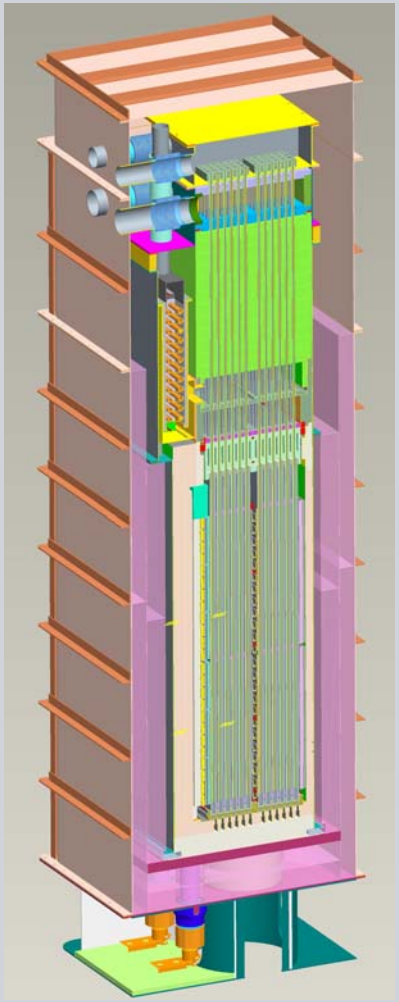
24 cylindrical cells
DC power: 2.6 kWe
Weight: 34 kg

6 Delta8 cells
DC power: 3.2 kWe
Weight: 20 kg

Reduced parts by 75%, reduced weight by 40%, increased power by 25%

Proof-of-Concept Stack Test

- 24 Delta8 cells
- 4 bundles (six cells each)
- Internal recuperator
- Cast ceramic open end holder
- Operation on simulated coal gas
- Thermally self sustaining
- ~14kW rating @ max power
- Modify existing balance of plant for stack test



Stack

Balance-of-Plant

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Cast Ceramic Stack Components

- **Precision cast ceramic open end component**
- **One cast component performs multiple functions**
- **One cast component replaces multiple machined board components**

Proof-of-Concept Stack Build

Bundles in Place

Stack Assembly Complete

Test start:
August 2008

Additional cell and stack design concept verification tests planned

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System Building Block (Module) Development

Objectives

- **Determine the best stack configuration for operation at high current and high fuel utilization**
- **Simplify stack architecture by reducing the number of parts and assembly labor**
- **Incorporate high performance cast ceramic materials**
- **Demonstrate performance and cost analysis that shows a commercial path to $225/kW for the fuel cell stack when incorporated into the baseline IGSOFC plant (>100 MW)**

Validation of Cell, Module & System Components through Analysis

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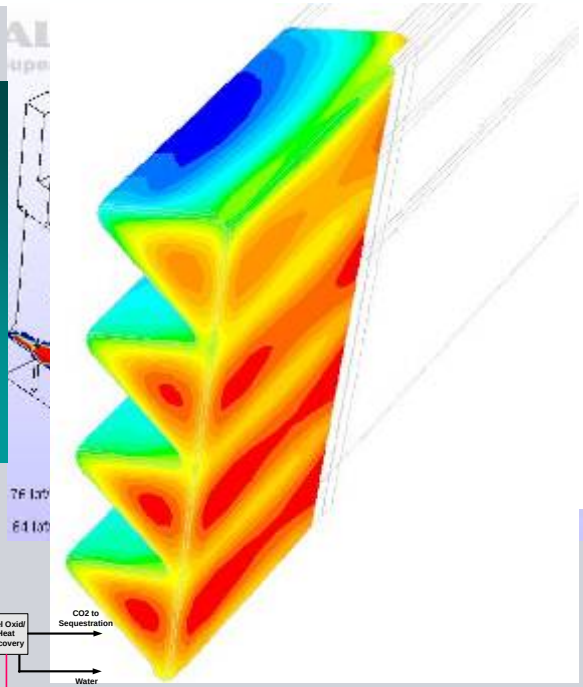
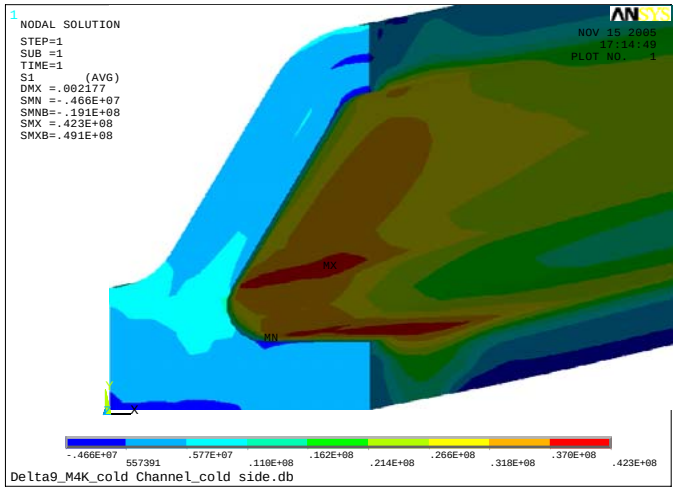
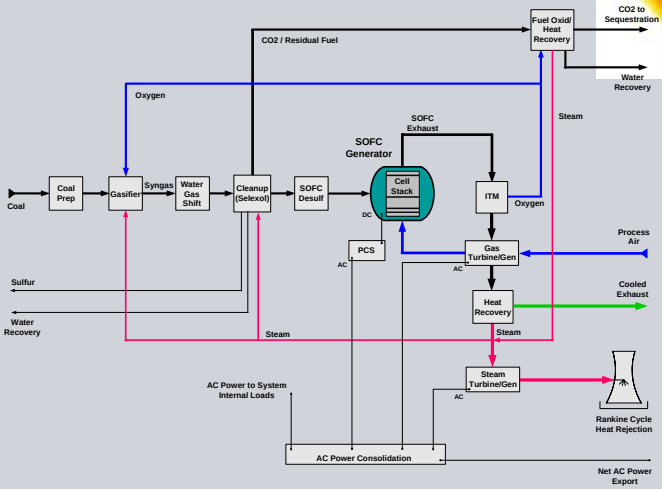
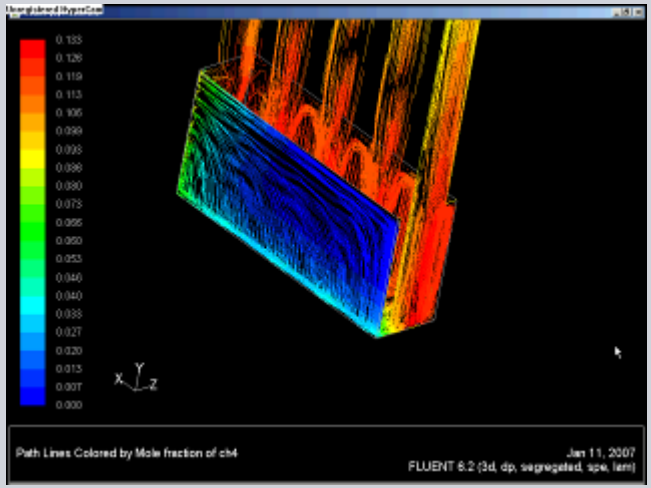
- Stress analysis
- Computational fluid dynamics analysis
- Thermal analysis
- System/Cycle analysis









Delta8 Cell Module - Power System Building Block

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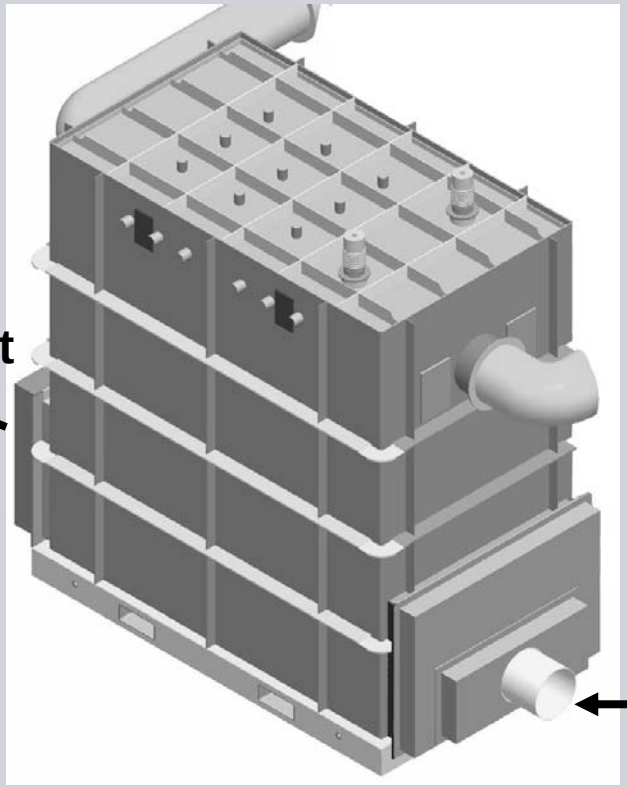
- 480 Delta8 cells
- Natural gas fuel
- Nominal Power ~ 250 kW (atm. pressure)
- Module Dimensions:
  - Height – 3.4 m
  - Width – 3.7 m
  - Depth – 1.9 m



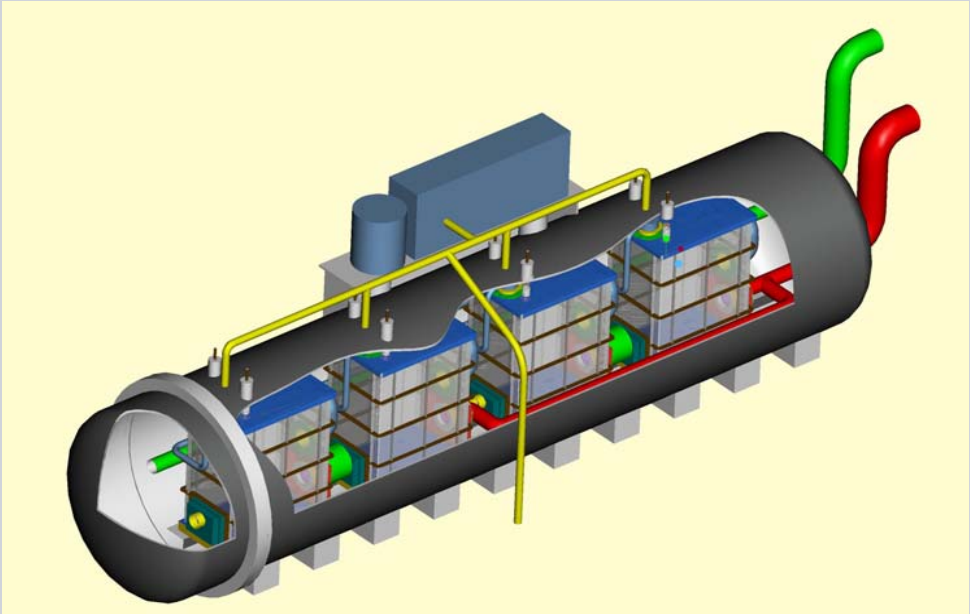
Larger fuel cell power systems are effectively assembled by aggregating modules

Pressurized Cell Module

- 1,920 Delta8 Cells
- Operating Pressure ~ 20 bara
- Coal syngas fuel
- Nominal Power ~ 1.3 MW
- Pressure Vessel Dimensions:

  Length – 17.3 m

  Diameter – 4.1 m



Four Delta8 cell modules integrated into a pressure vessel - - pressure vessel module

Pressurized-SOFC / Gas Turbine / Steam Turbine Power System Cycle Concept for Large Power Generation

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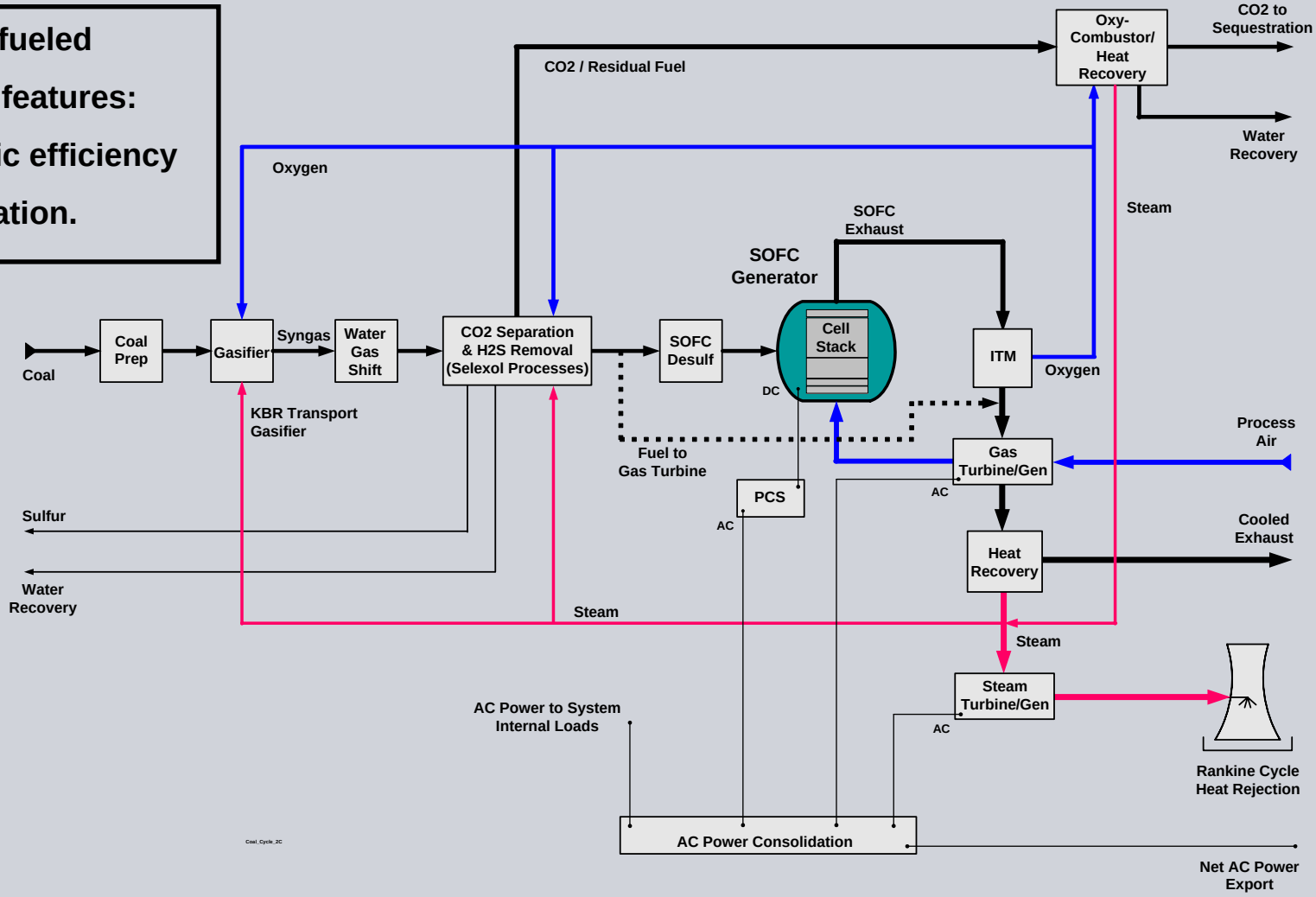
- Coal Syngas fueled
- Performance features:
  - 50% Electric efficiency
  - CO2 separation.



Pressurized-SOFC / Gas Turbine / Steam Turbine Power System Component Arrangement Concept

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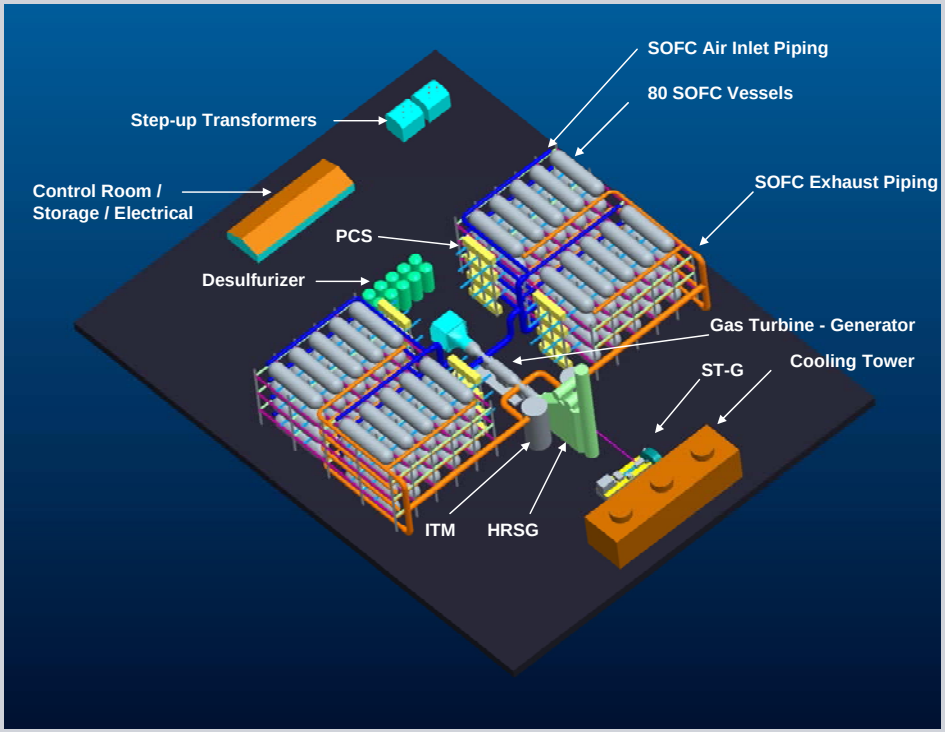
- Eighty Delta8 pressure vessel modules
- Pressurized SOFC process air supplied by gas turbine
- Coal gasification basis – KBR transport gasifier (located on adjacent plot)
- Syngas cleanup & CO_2 separation by pre-SOFC Selexol process
- Gasifier oxygen by ITM oxygen technology
- Electric power capacity ~130 MW Net AC (SOFC + GT + ST – parasitic loads)
- Efficiency: 50% (Net AC / Coal HHV)
- Peak power capability ~170 MW
- CO_2 separation: 90%
- Footprint ~100m x ~100m



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Summary

- Delta8 cells have demonstrated significantly higher power density and power per cell over cylindrical cells
- Assembly of proof-of-concept stack with Delta8 cells completed
- A modular stack concept has been developed that scales to MW-class systems
- Large cell active area and cast ceramic stack components help in lowering parts count
- A system concept for coal based > 100 MW systems with high efficiency has been defined

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Acknowledgements

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