



**Rolls-Royce**

# **Rolls Royce IP-SOFC Technology Development**

July 15<sup>th</sup>, 2009

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# Summary

- **RRFCS has developed tools to characterize and improve our fuel cell technology**
- **Cell technologies are being developed by RRFCS which can meet performance and cost targets**
- **Scaled tests are demonstrating good performance and durability**

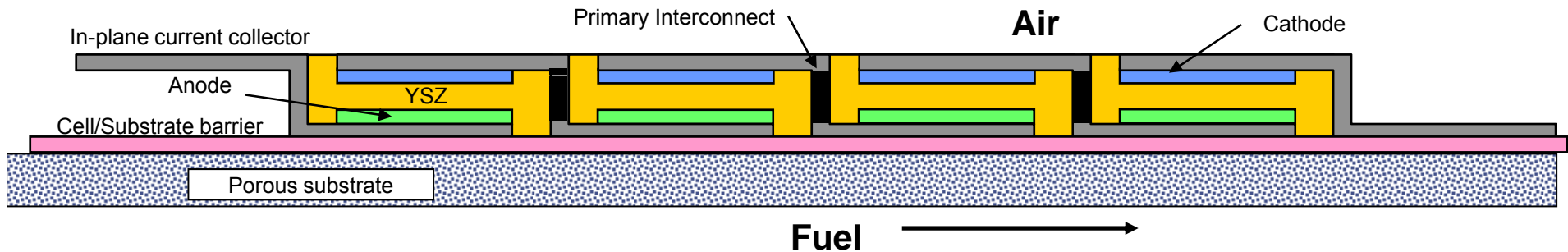
# Rolls Royce IP-SOFC Technology Development

- **Technology and approach**
- **Cell performance testing and modeling**
- **Cell design improvements**
  - **Cell Pitch**
  - **Cell Materials**
  - **Primary Interconnect**
- **Cell performance and degradation**

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# Rolls-Royce integrated planar solid oxide fuel cell tube



## Integrated planar series arrangement

Series connected cell design for high voltage low current

Thin layers of active materials minimise cost

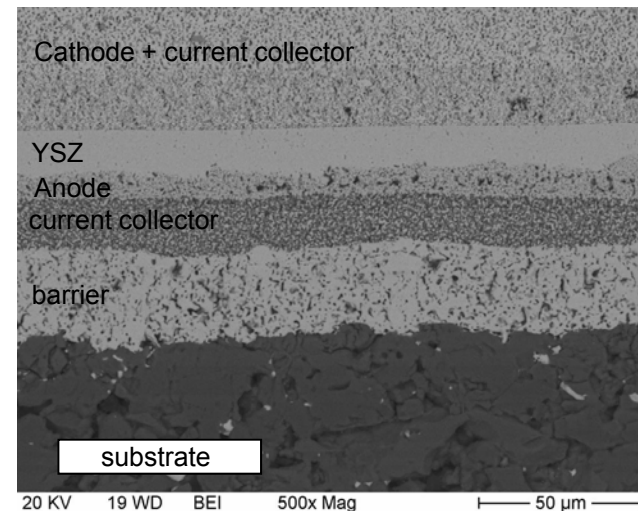
Ceramic support material uses low cost  $\text{MgO} + \text{Al}_2\text{O}_3$  powder + low cost extrusion

## High voltage low current benefits

Easier hence cheaper for power electronics to convert low current DC to AC

High voltage facilitate direct conversion to 480 V AC grid requirement

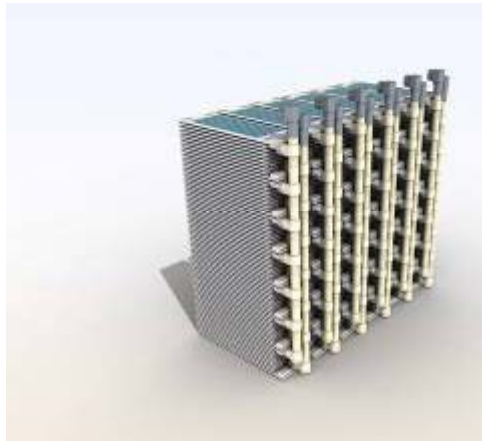
Low currents give low Ohmic  $I^2R$  losses offering greater materials options



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# SECA

- RRFCS is honored to be selected as an industrial team under the SECA program
- 2010 targets
  - Degradation  $<2\%$  / 1000 hours in 5000 hours demo test
  - 15kW stack demonstration
  - System cost target for high volume production  $< \$400/\text{kW}$



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# Achieving the goal

- **High efficiency and low cost targets require focused optimization**
- **Detailed understanding of fuel cell performance drives improvements in cost and efficiency**
- **Cell development for performance improvement**
  - **Cell pitch**
  - **Current collectors**
  - **Electrode overpotential**
  - **Electrolyte**



# SOFC Performance Model Development

Over-potentials (losses)

$$V_{\text{cell}} = E_{\text{Nernst}} - \eta_{\text{ohmic}} - \eta_{\text{act,cathode}} - \eta_{\text{act,anode}} - \eta_{\text{conc,anode}} - \eta_{\text{conc,cathode}}$$

Electronic Resistance      E-Chem Reactions      Mass Diffusion

- Ohmic → based on layer testing, confirmed by EIS
  - Cathode activation
  - Cathode concentration
  - Anode activation
  - Anode concentration
- } based on cathode symmetric cell testing
- } based on cell testing

# Testing Performance Envelope

- **Temperature (700 – 950°C)**
- **Pressure (1 – 6.5 Bar<sub>a</sub>)**
- **Cathode composition**
  - **Oxygen partial pressure (0.08 – 1 Atm)**
  - **CO<sub>2</sub> and H<sub>2</sub>O additions**
- **Fuel composition**
  - **Bundle inlet to bundle outlet**
  - **Fuel dilution to observe anode mass diffusion limitations**

# Testing Capability

- 5 pressurized, 8 atmospheric test stands with system relevant gas compositions
- 10 atmospheric tube/bundle test stands
- 2 pressurized bundle test stands
- 4 block test stands under build/commissioning

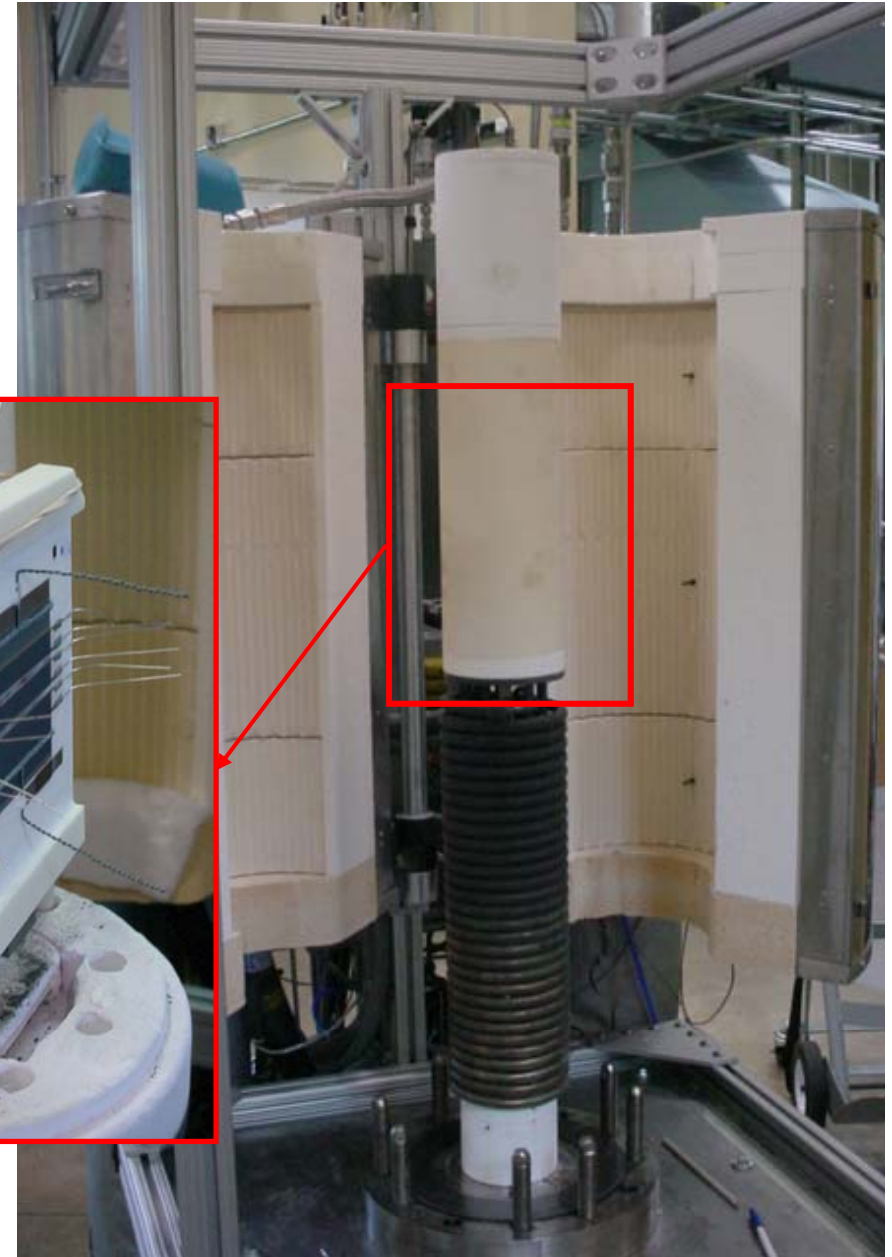


Block Scale Rig  
Located in Derby, UK

5 Pressurized Subscale Rigs  
located in Canton, OH

# Well Controlled Boundary Conditions

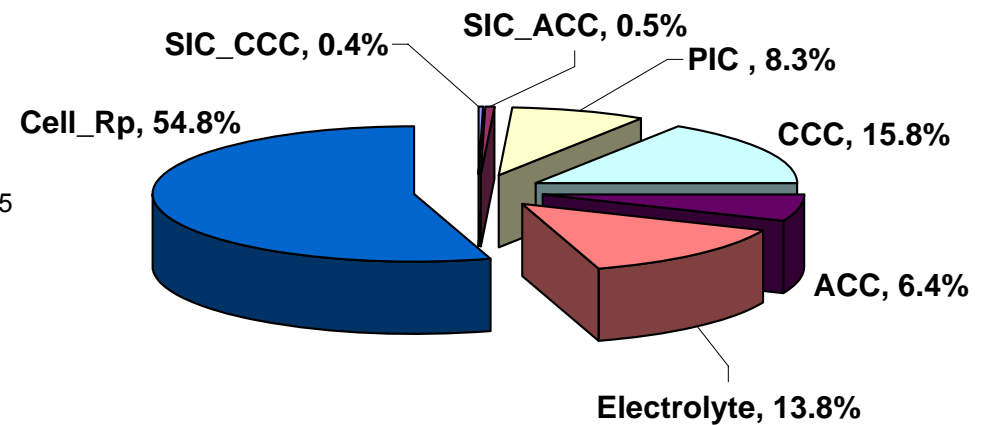
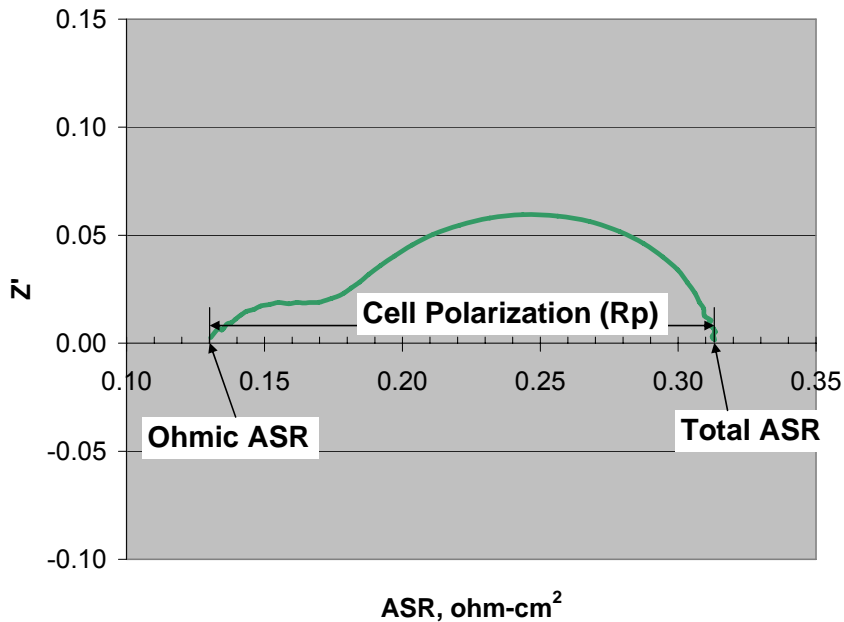
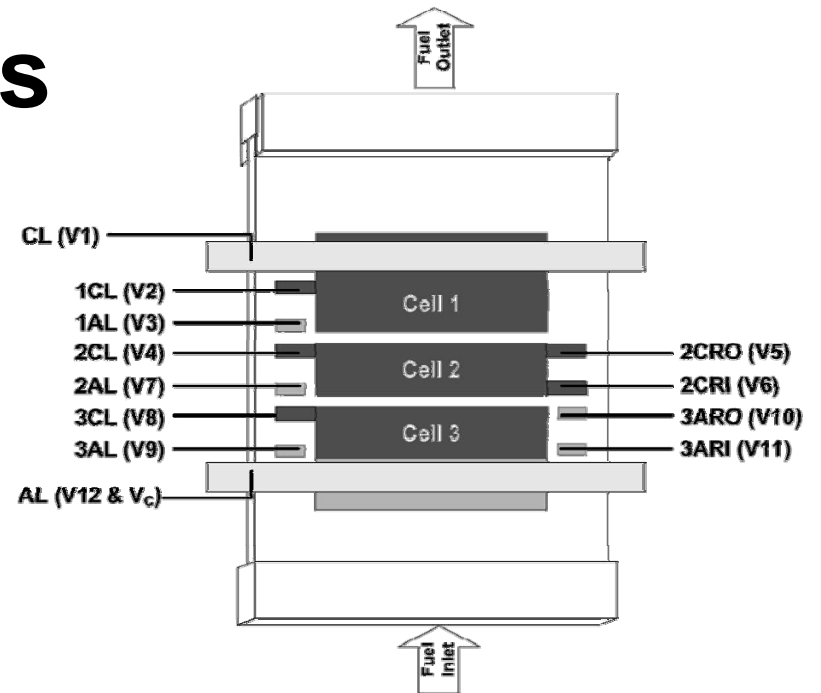
Pressure  
Temperature  
Current/Voltage  
Composition



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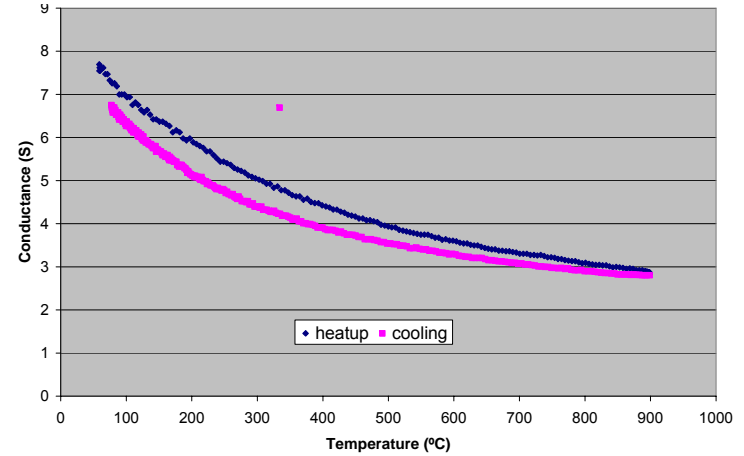
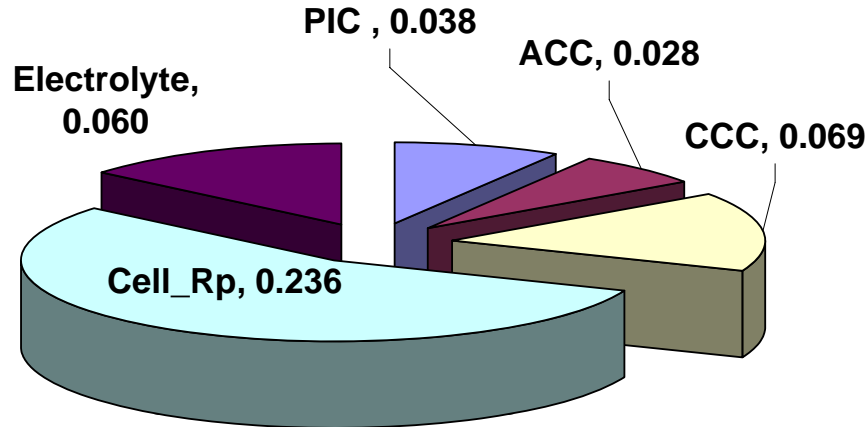
# Detailed Cell Analysis

- Voltage taps to discretize cell losses
- EIS to interrogate e-chem



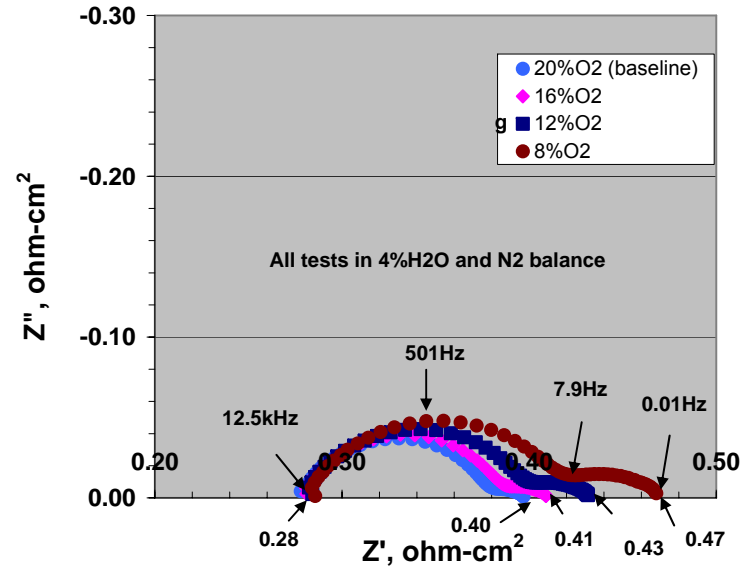
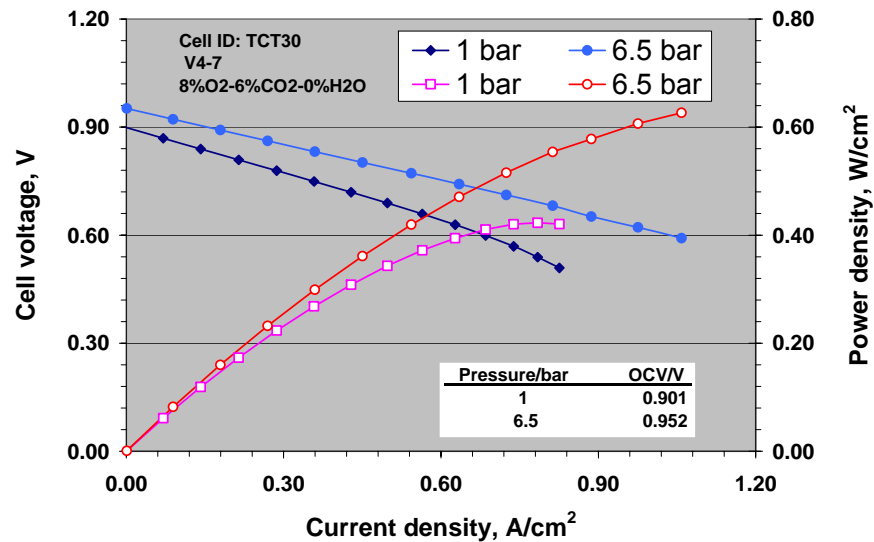
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# Model Development



## Layer Conductivity Tests

## Pressurized Cell Testing



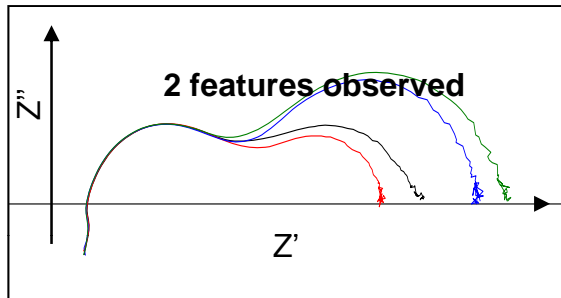
## Cathode Button Cell Tests

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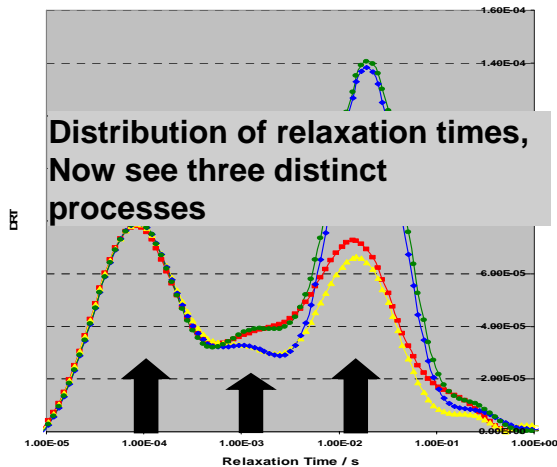


# De-convolution of cell performance and degradation contributions

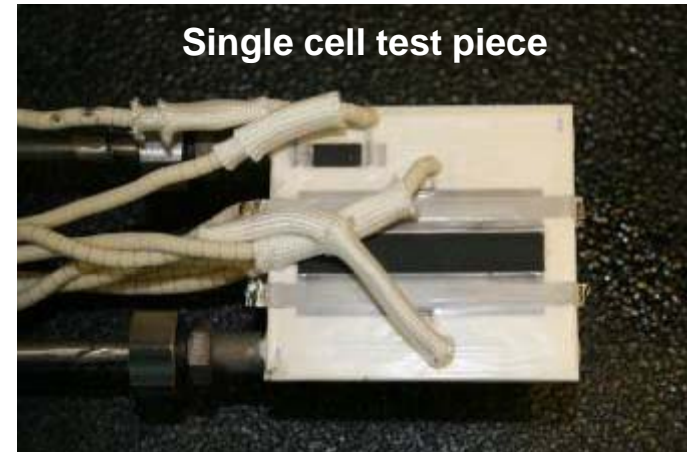
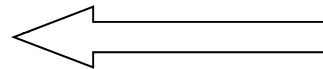
Impossible to de-convolute - only Ohmic and non-ohmic losses



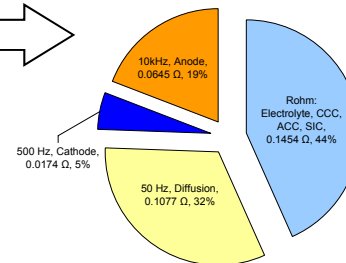
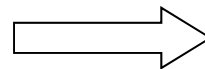
FFT Analysis



Impedance spectroscopy  
With different fuel / oxidant combinations



Quantify individual Electrode layers And ohmic components



- Actively drive and monitor degradation
- Target individual degradation processes
- Door opened to accelerated testing

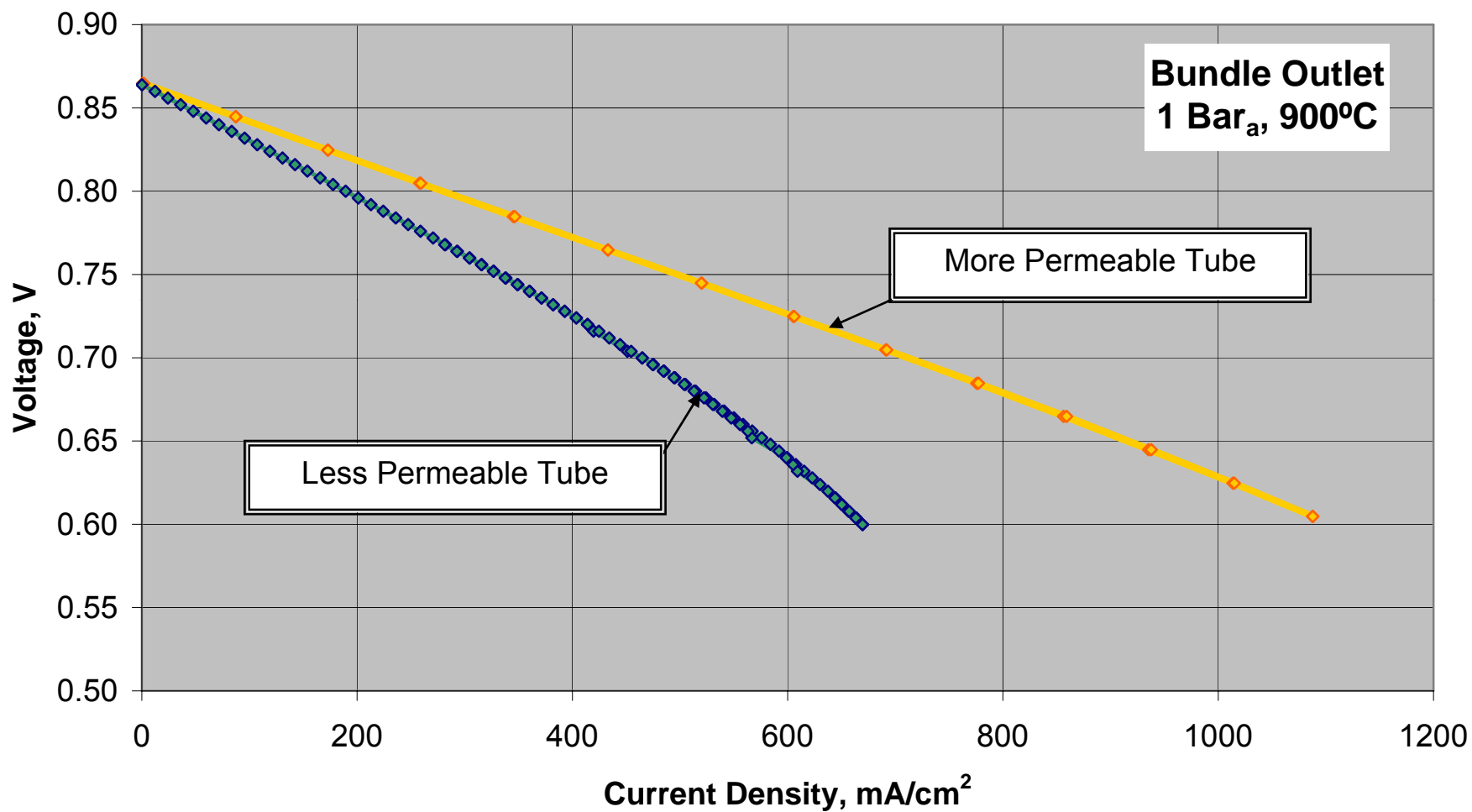
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# Substrate Characteristics Can Impact Electro-Chemical Performance

- **Substrate permeability measured to determine diffusional resistance**
- **Modeling used to relate measured substrate parameters to cell performance**



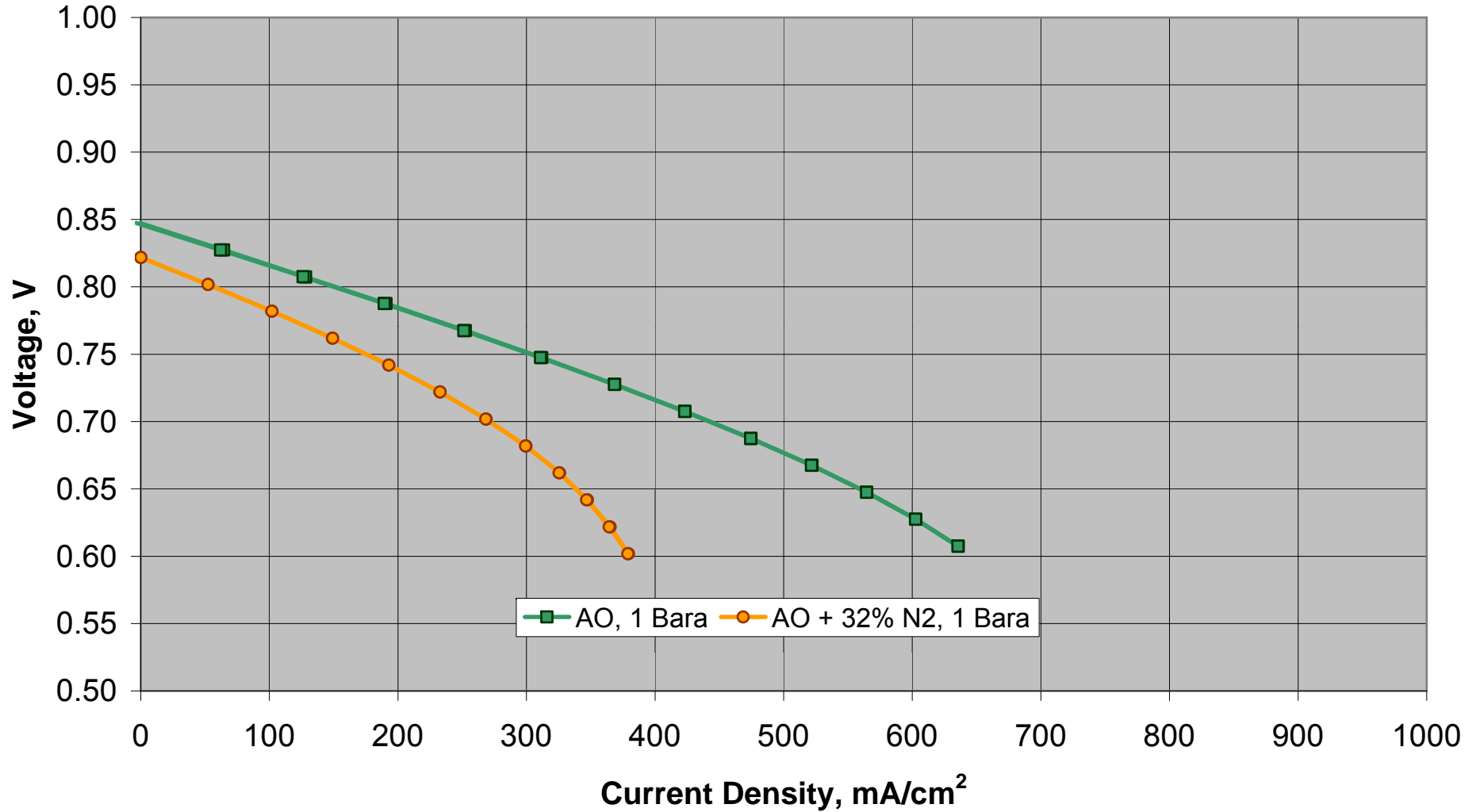
# Impact of Diffusion Resistance



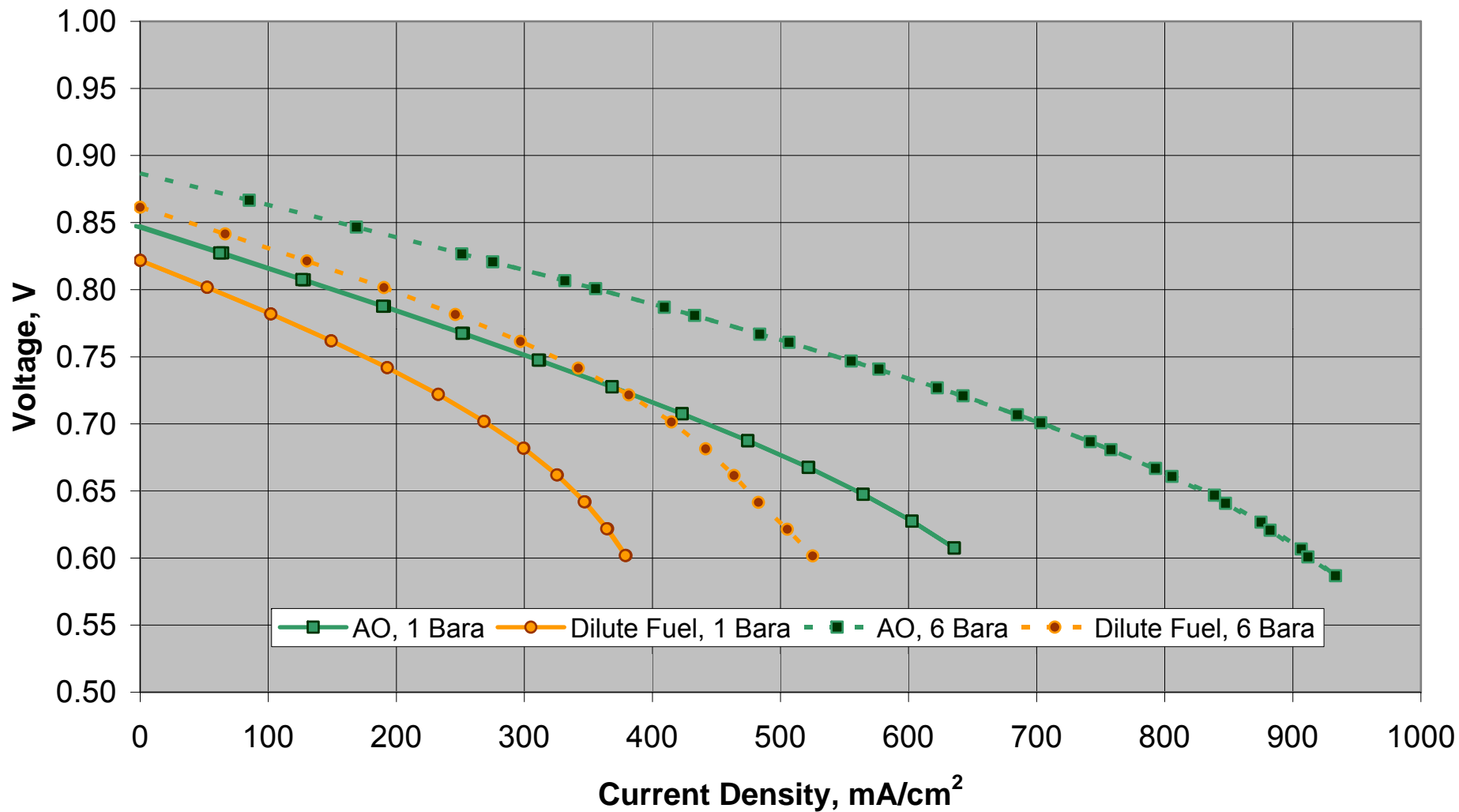
—◇— SCT6-26A —◇— PCT21A

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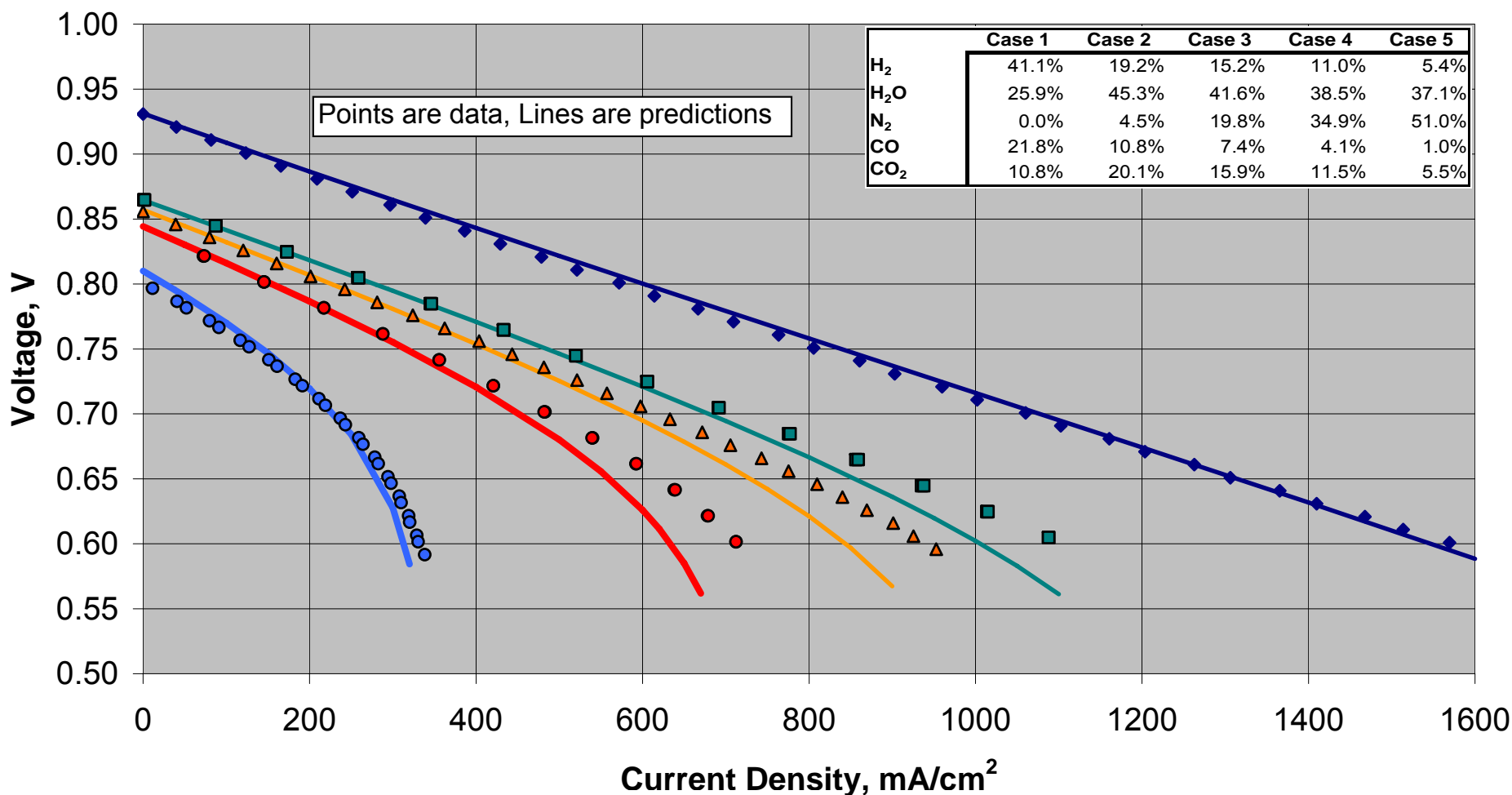
# Benefit of Pressure



# Benefit of Pressure



# Preliminary Predictions Encouraging



◆ Case 1    ■ Case 2    ▲ Case 3    ● Case 4    ● Case 5

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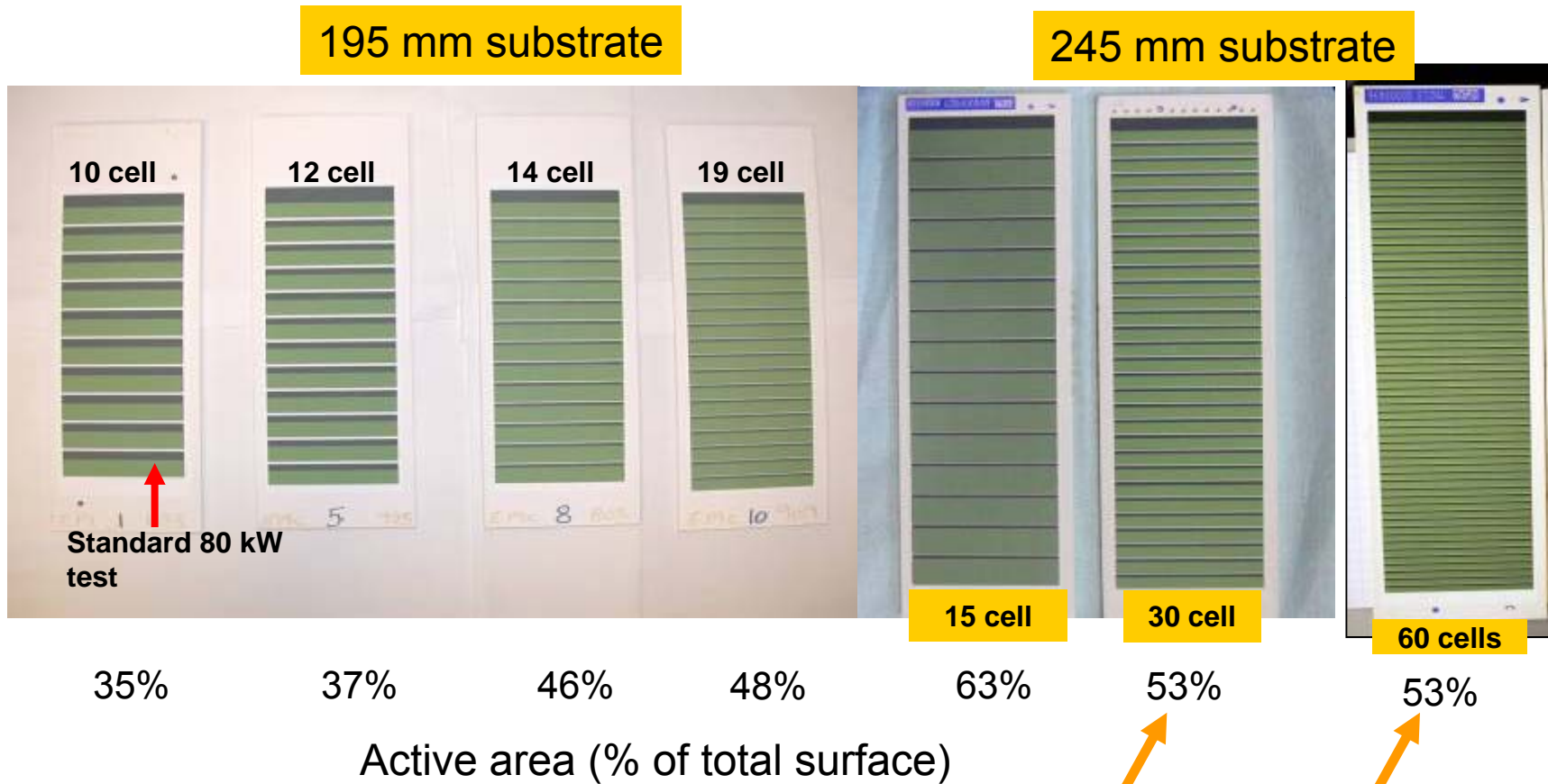


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# Cell Pitch Optimization

60-cell design minimizes conductance requirement for ACC and CCC



Current design  
42W

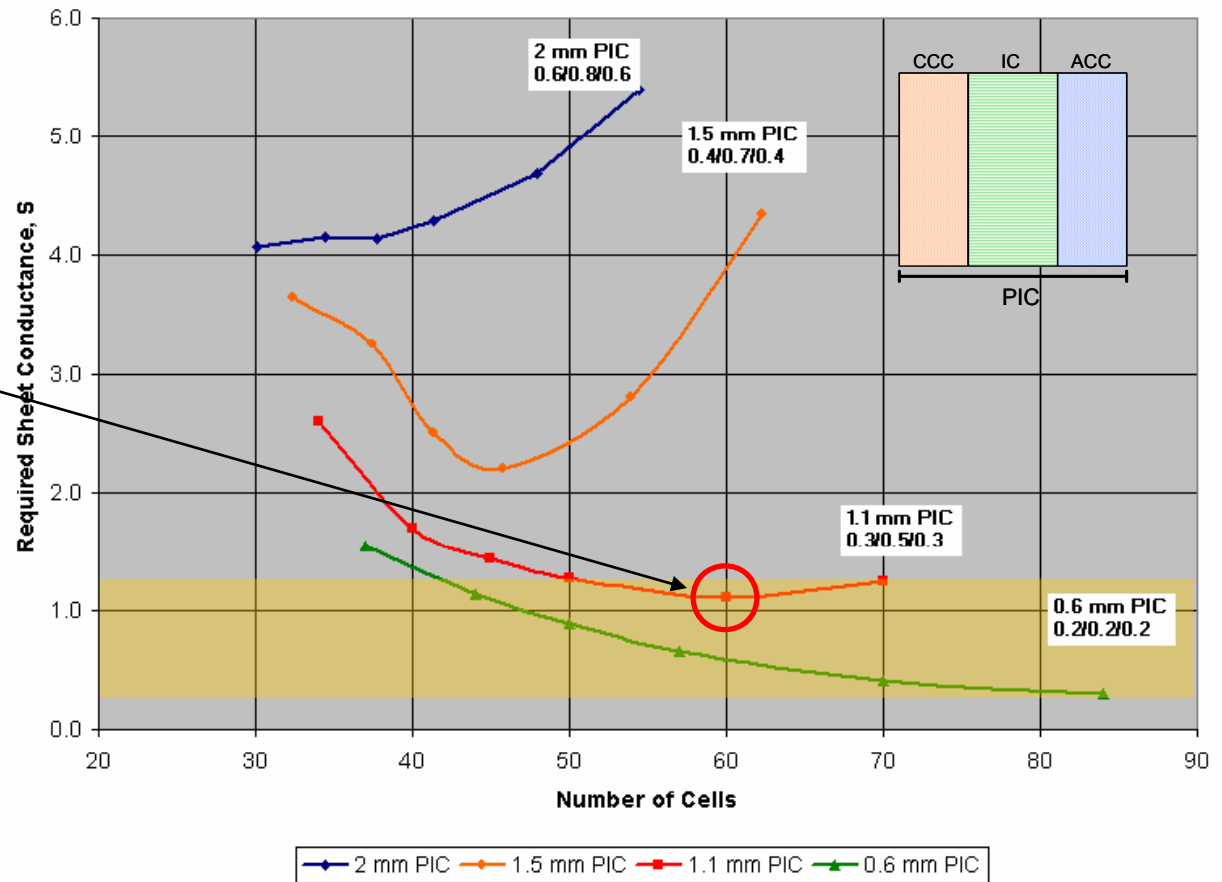
SECA demonstration  
55-60W

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# Benefits of 60-cell Pitch

Map to Achieve 60W

- 1.1 mm PIC width selected for lower cost materials
- Targeting ~1S ACC and CCC Conductance
- Power density = 350 mW/cm<sup>2</sup>



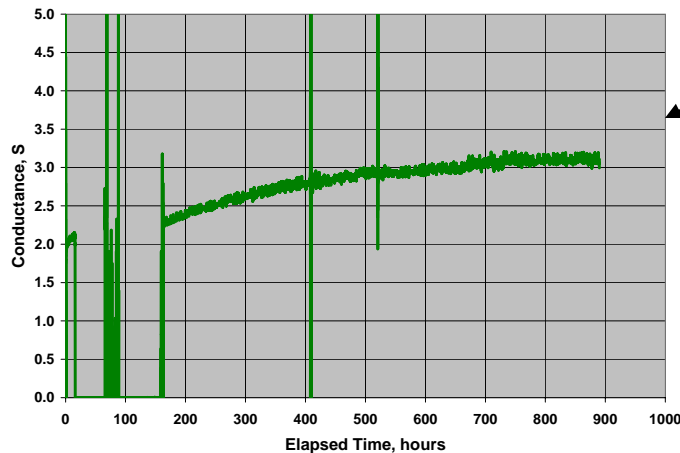
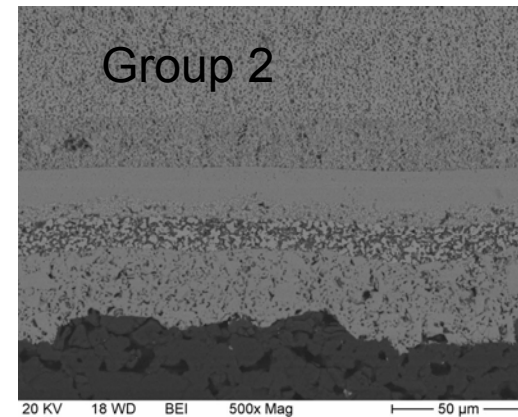
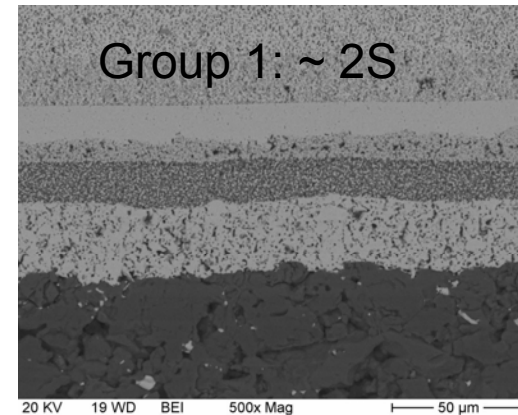
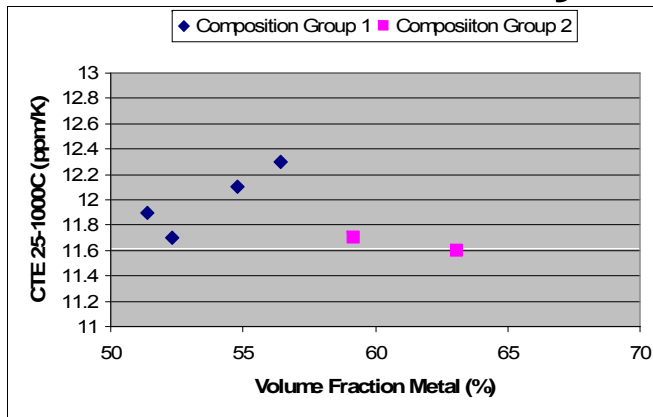
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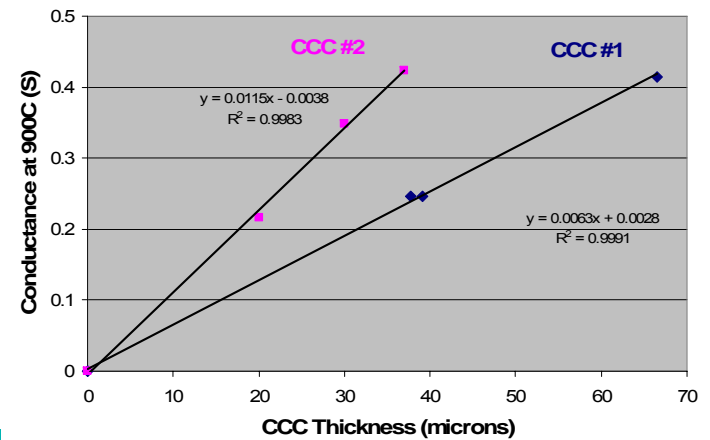
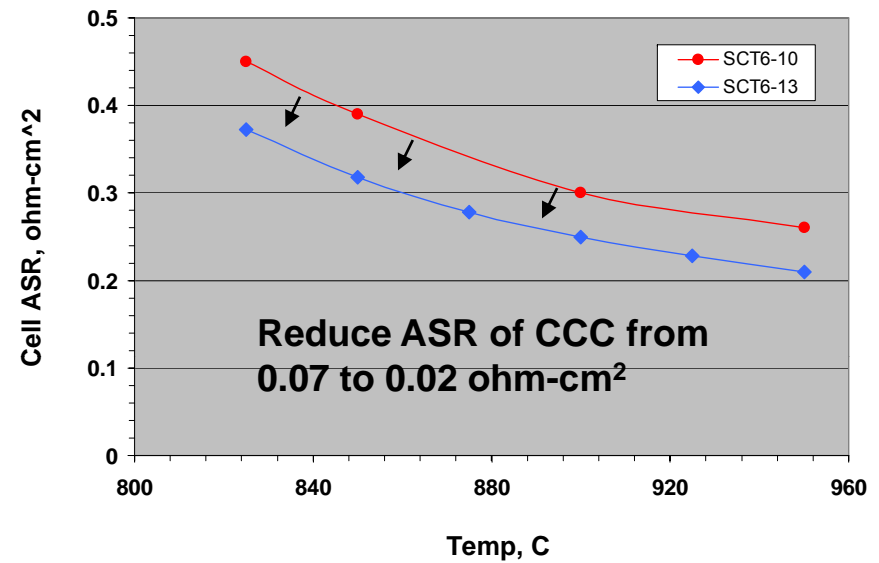
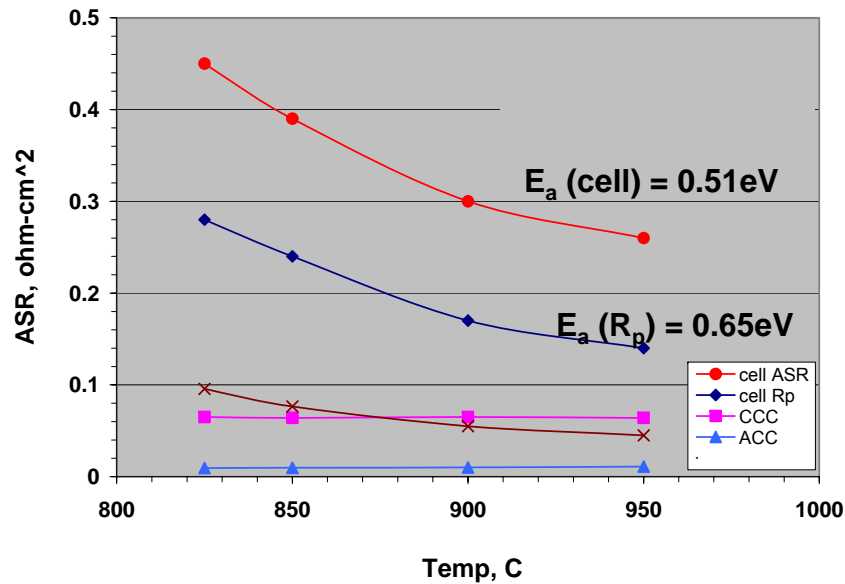
# Anode Current Collector

- Minimize CTE mismatch with substrate
- Maximize conductivity within CTE limits

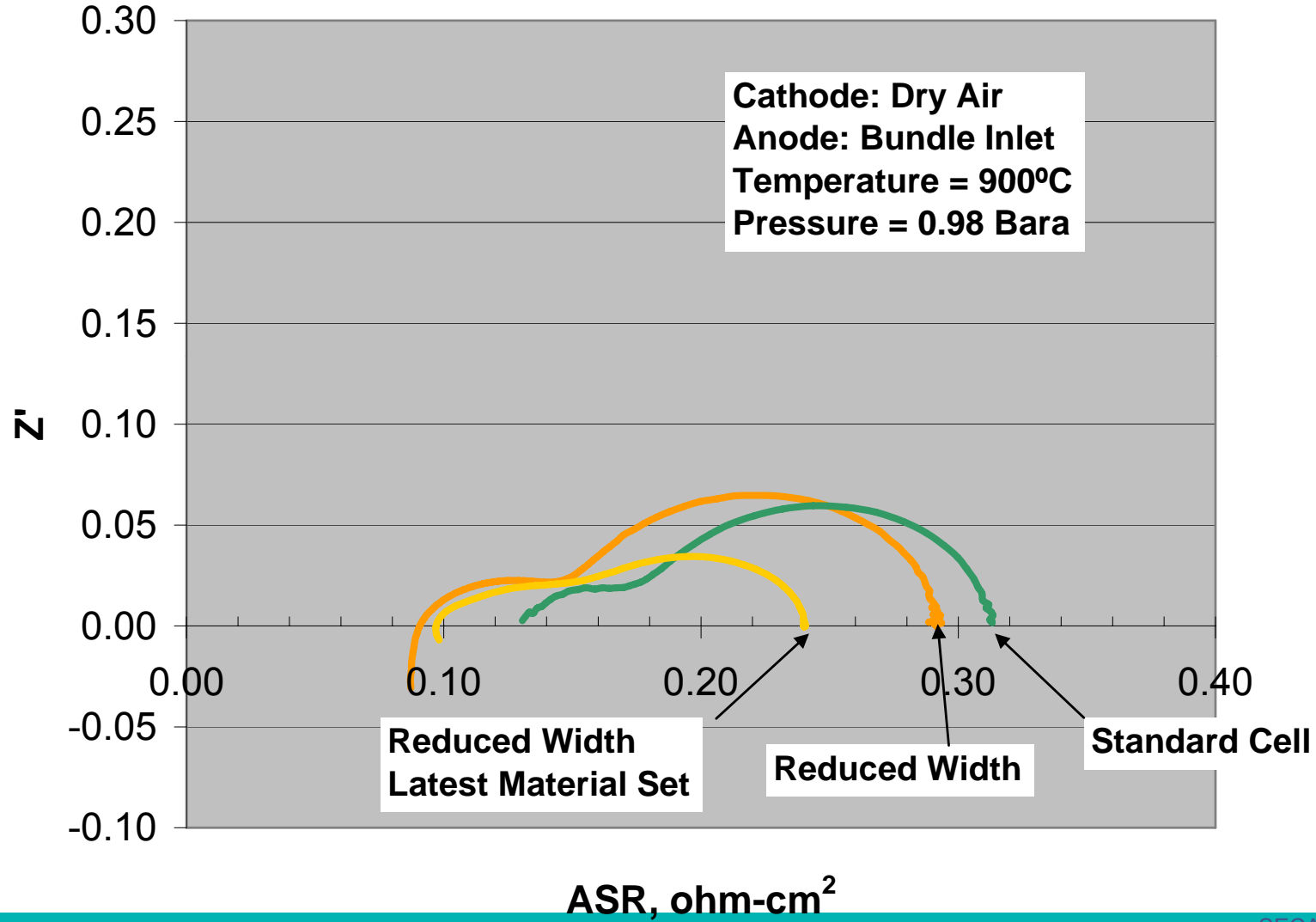


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# Optimization of CCC Ohmic losses critical to hitting ASR targets

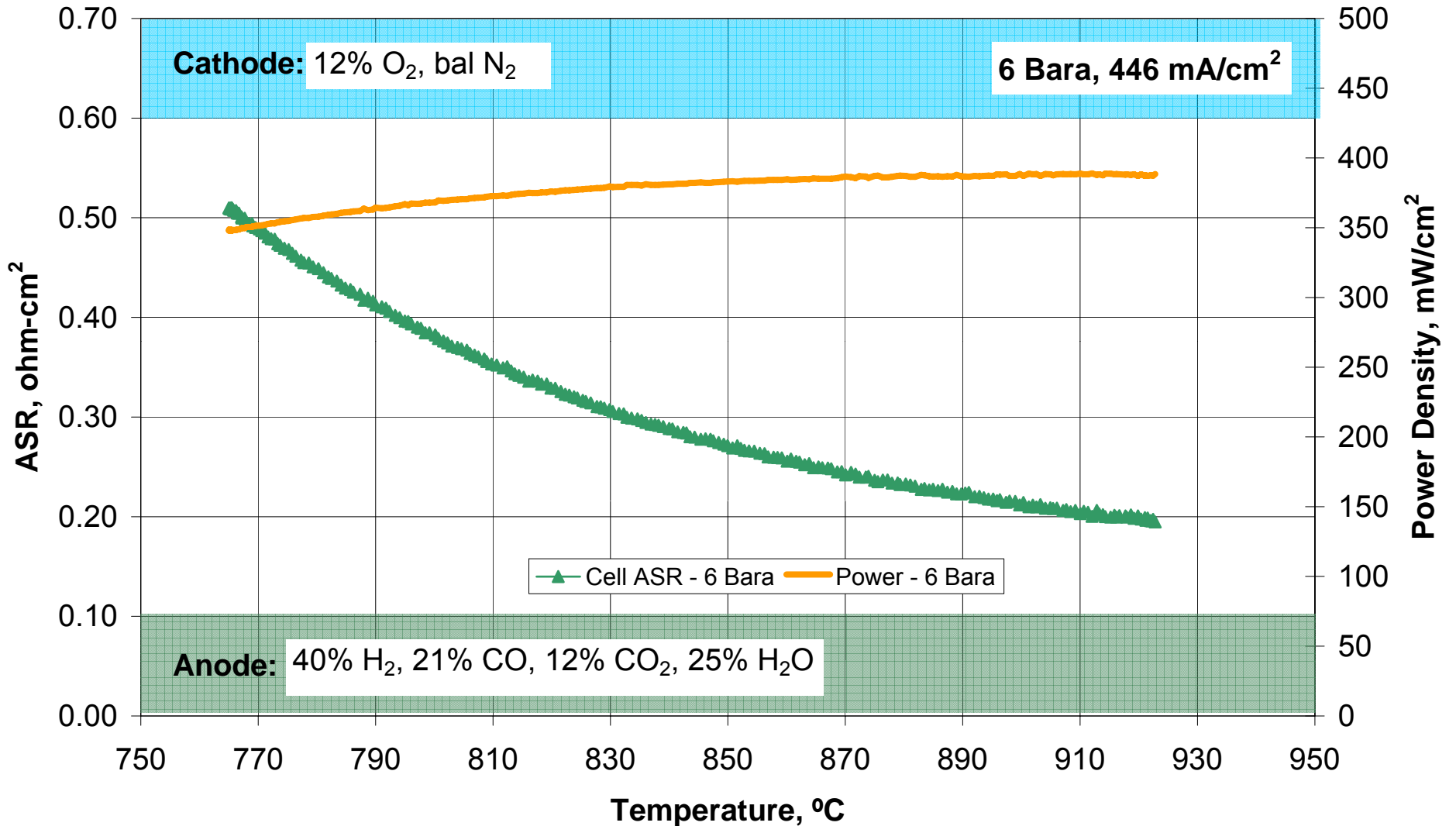


# Lower Cost, Better Performance



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# Latest Single-Cell Performance



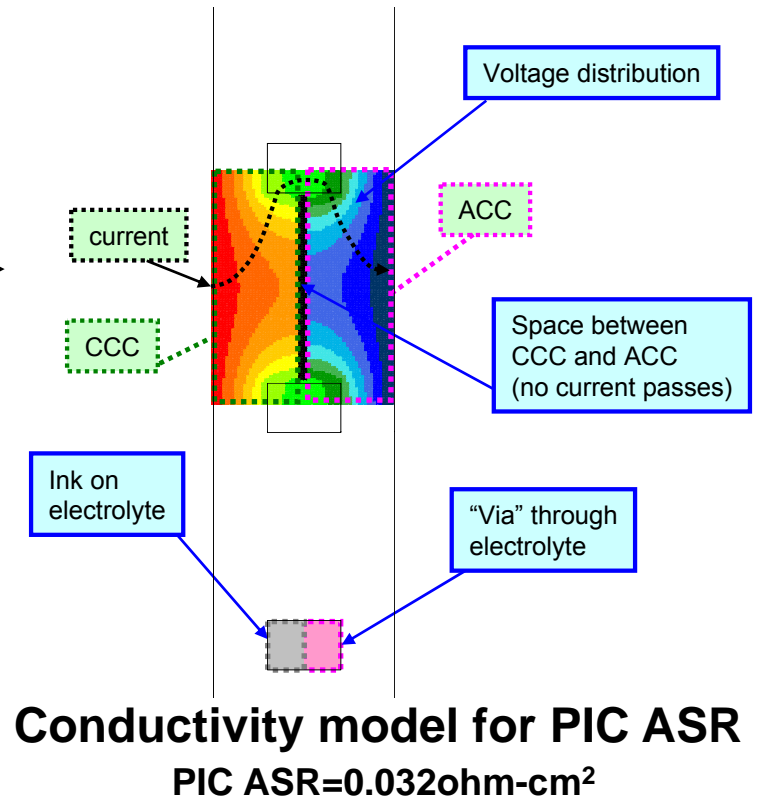
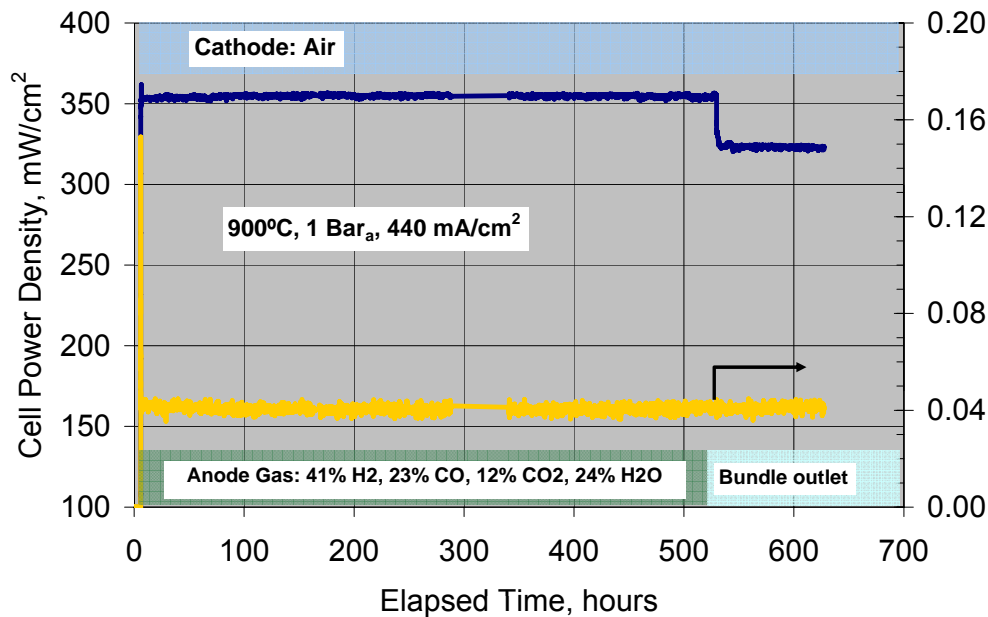
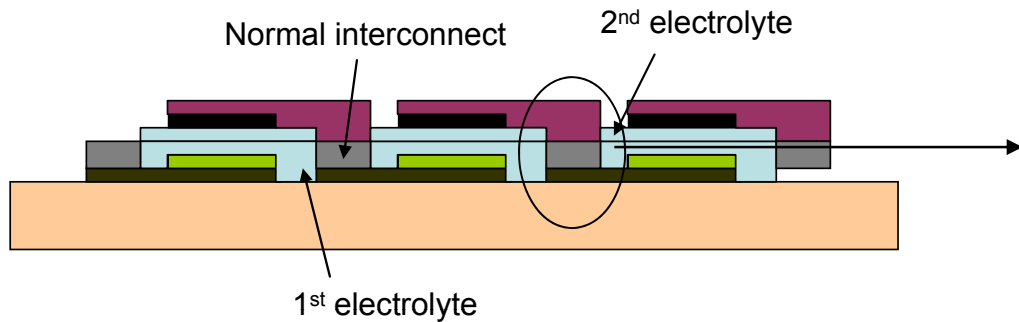
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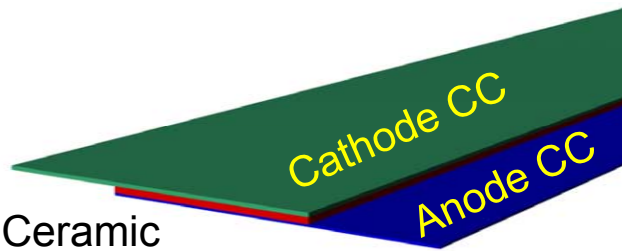
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# Primary Interconnect ASR: Via-based design

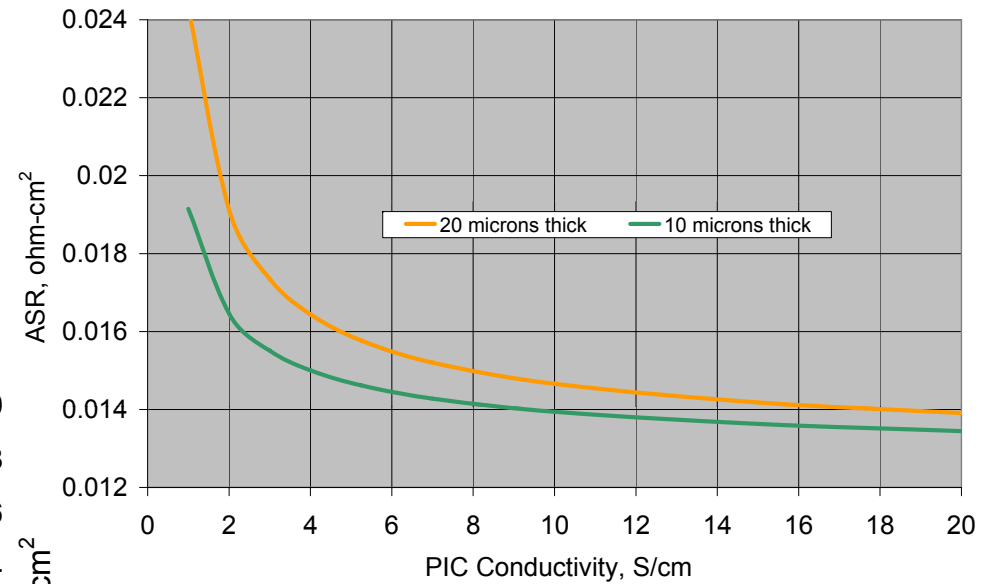
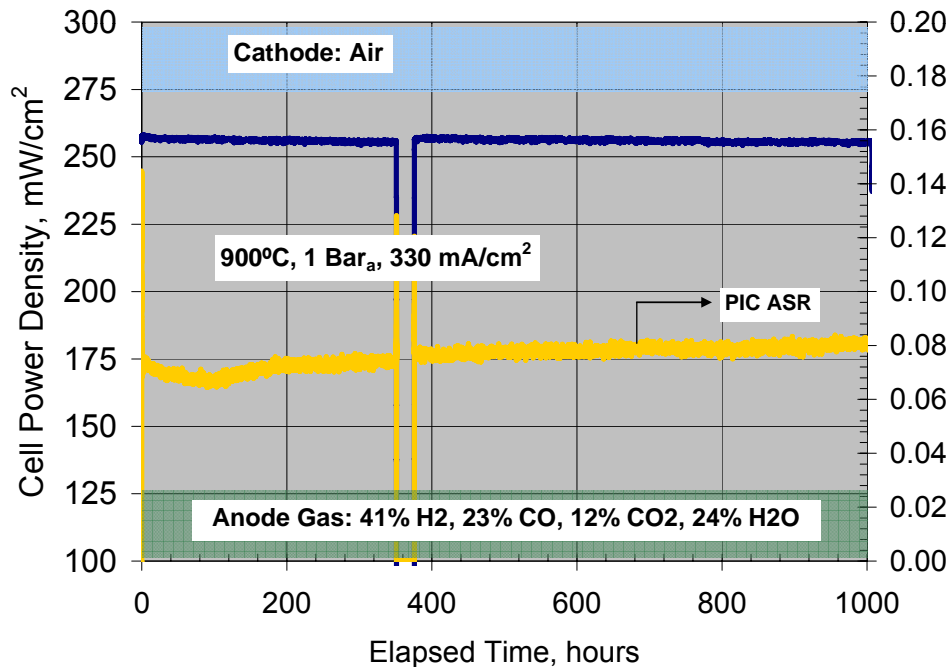


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# Primary Interconnect ASR: Ceramic Strip based design



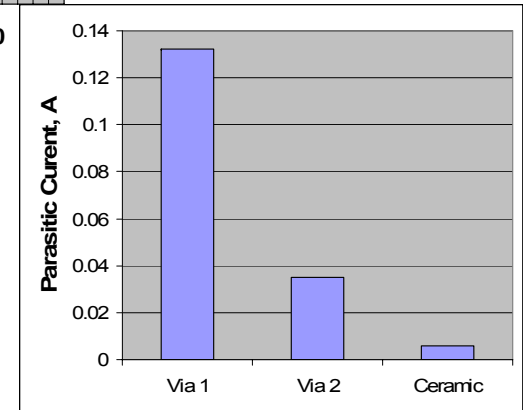
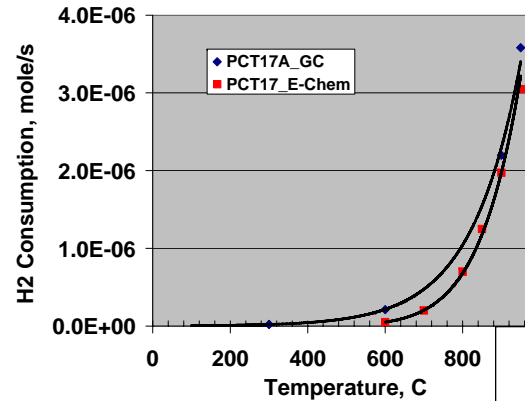
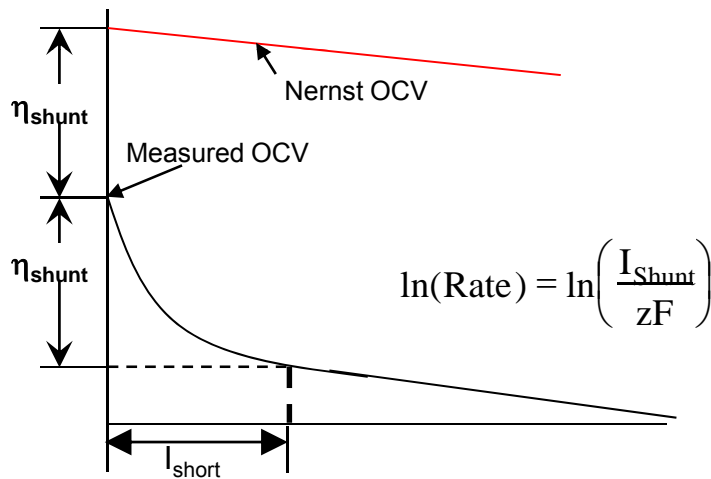
Ceramic Interconnect



**Ceramic interconnect showing feasibility but further optimization required**

# Interconnect Parasitic Losses

- At 60-cell design there is a larger interconnect/cell area ratio
- Must manage local parasitic losses resulting from materials selection, PIC designs and printing accuracy
- Significant improvements achieved through various modifications

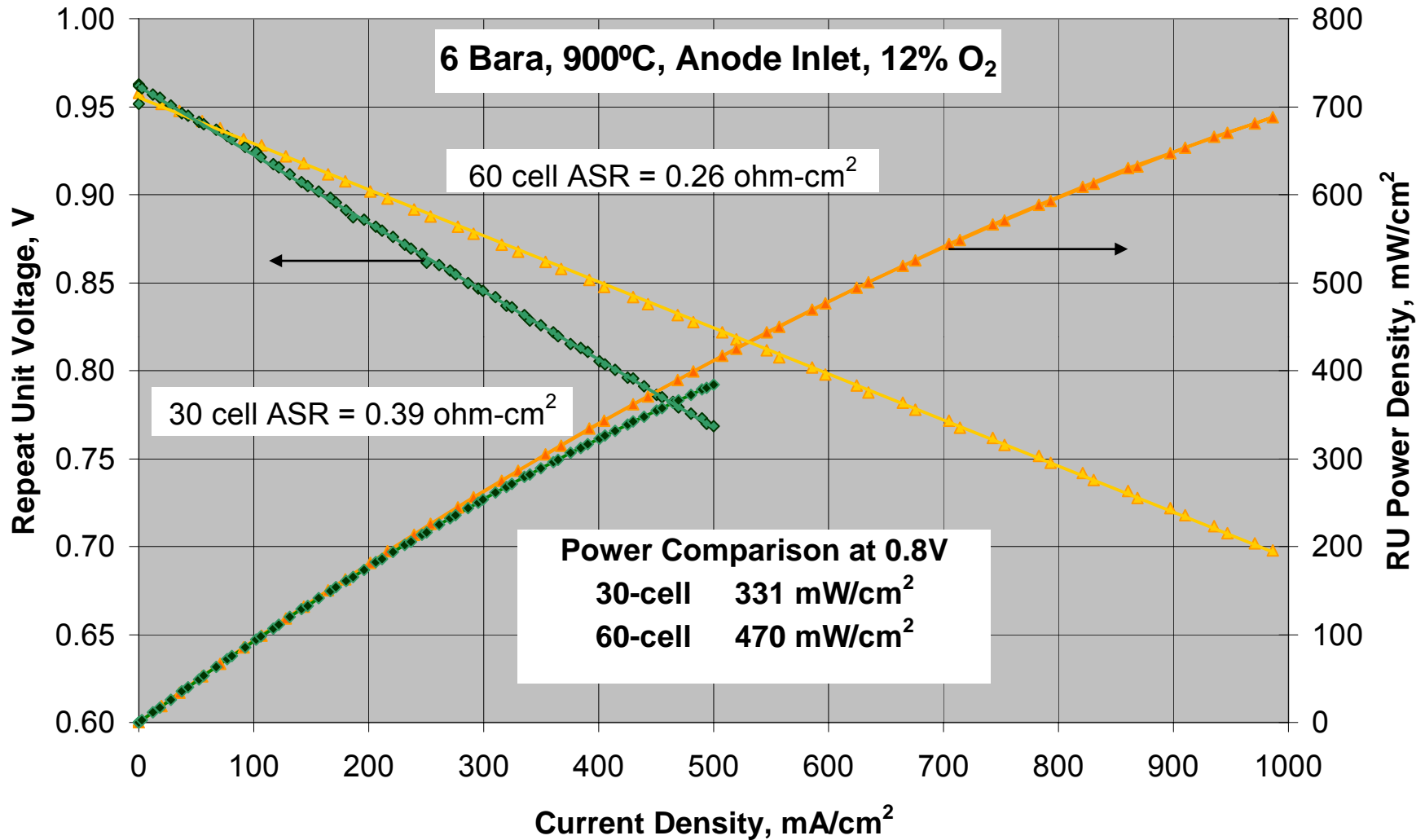




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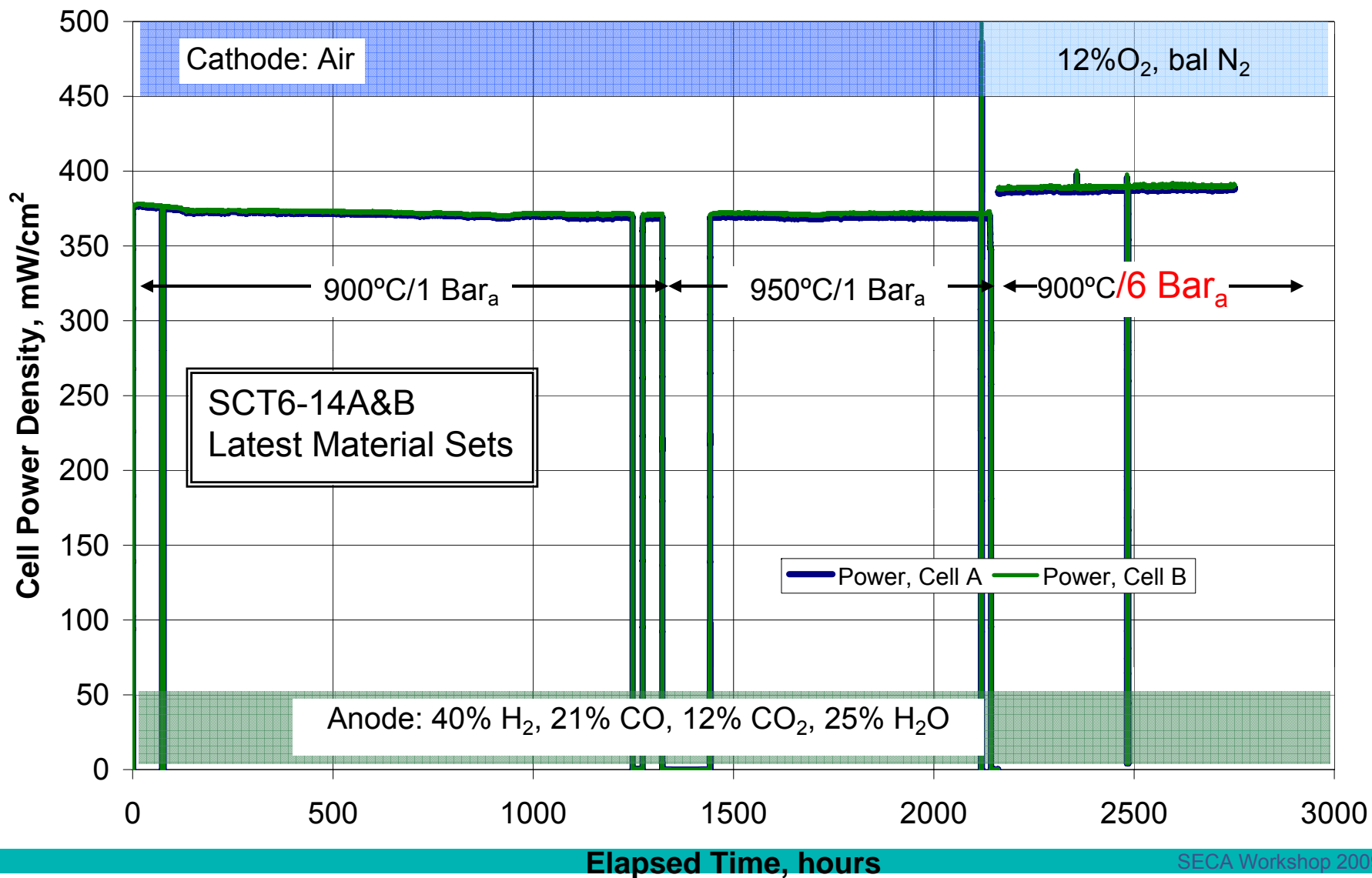
# 40% Improvement in Power



▲ PCT25B Voltage    ◆ TCT35 Voltage    ▲ Power Density    ◆ Power Density

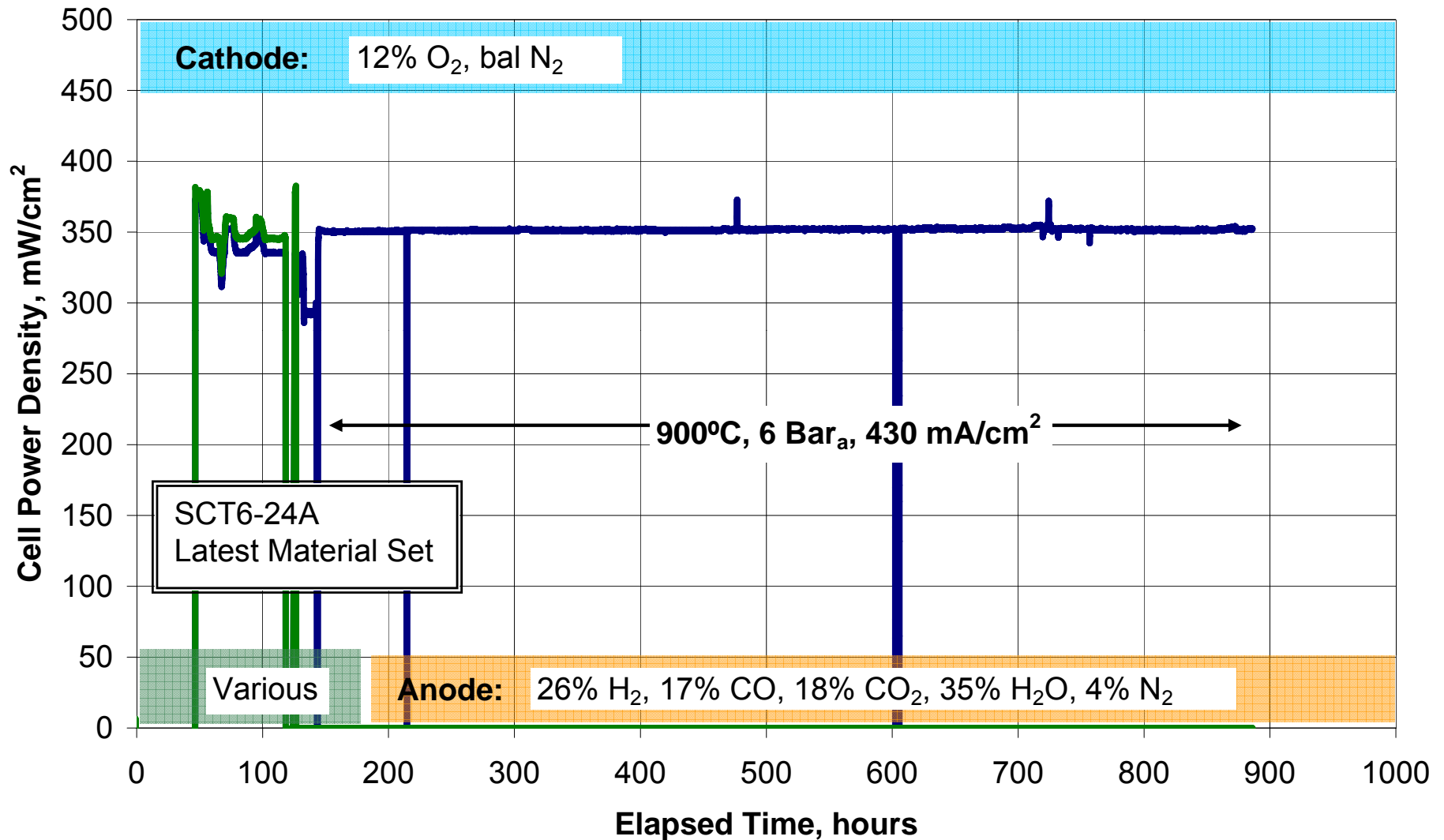
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# Single-Cell Degradation Performance



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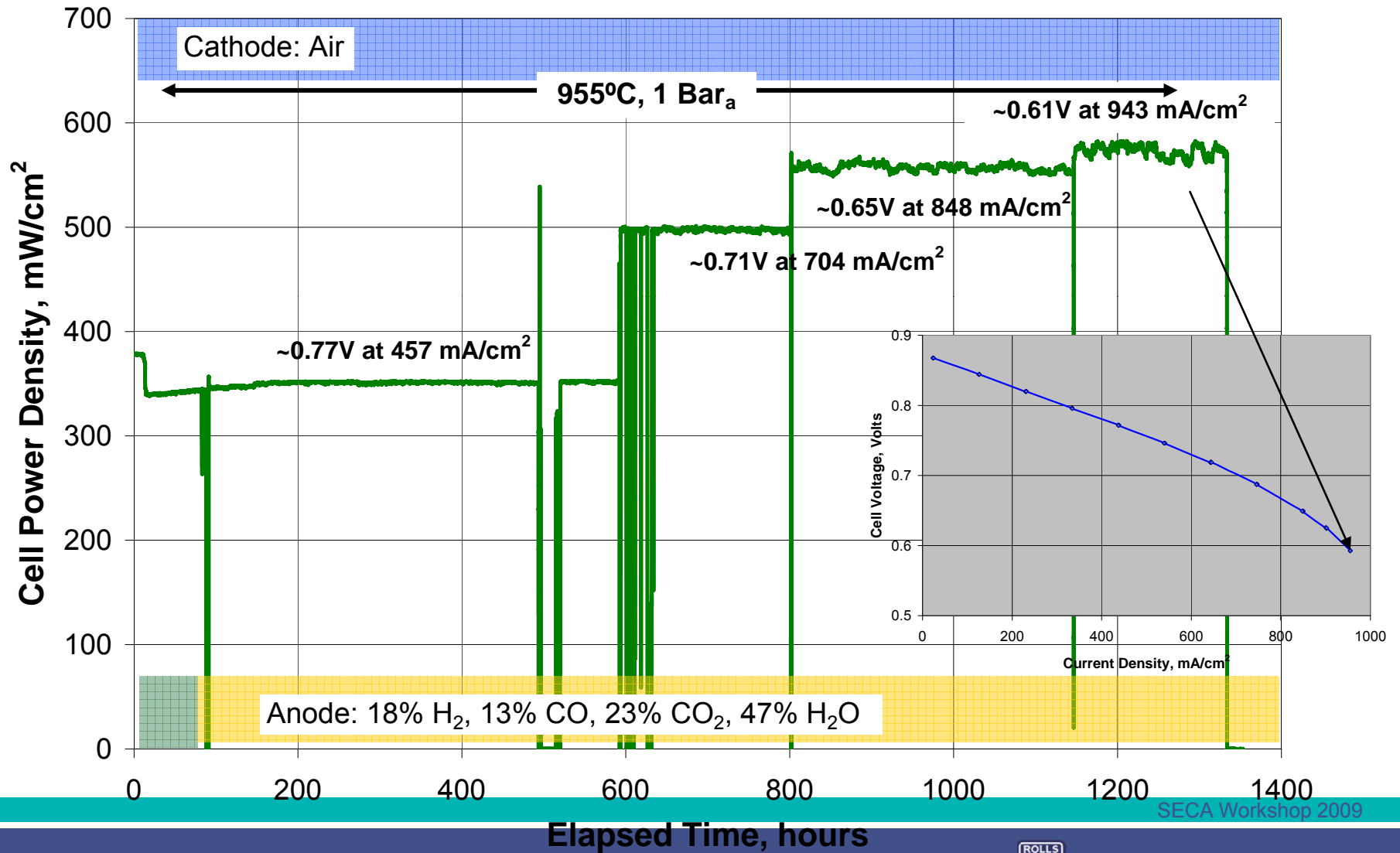
# Single-Cell Degradation Performance



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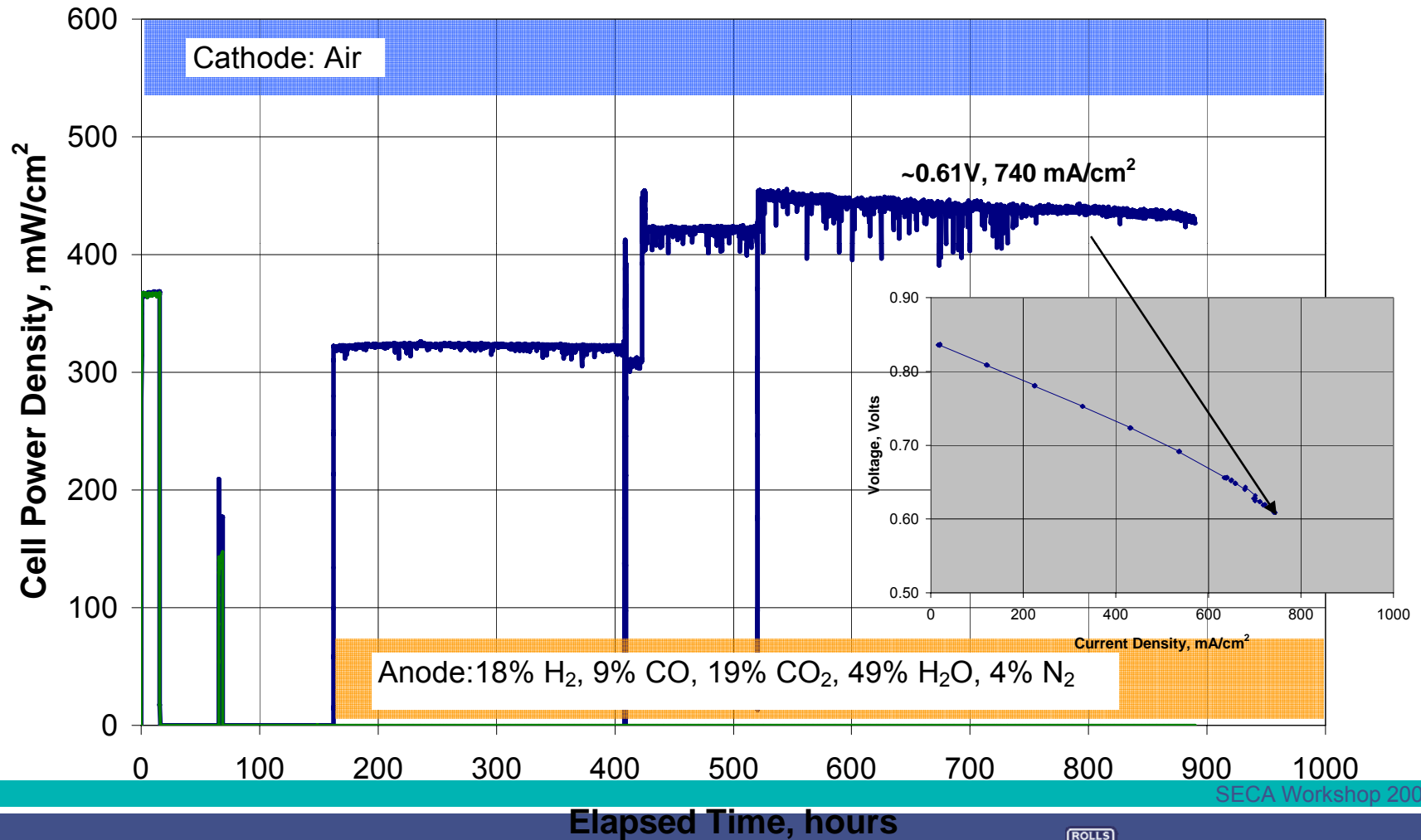
# Anode+ACC Candidate #1 Durability

- Cells can sustain high current density at outlet fuel and 950°C



# Anode+ACC Candidate #2 Durability

- This cell displays more diffusive resistance and higher degradation



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# Acknowledgements

- **This material is based on work supported by the Dept. of Energy National Energy Technology Laboratory under Award Number DE-FC26-08NT0003893**
- **RRFCS project manager Travis Shultz and the entire SECA program management team**
- **UK and US based RRFCS team**

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