Coal-Based IGFC Project Phase I

FC26-08NT0003894

Joseph V. Bonadies – Delphi

14th Annual Solid State Energy Conversion Alliance (SECA) Workshop
July 23-24, 2013
Sheraton Station Square Hotel
Pittsburgh, PA

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Outline

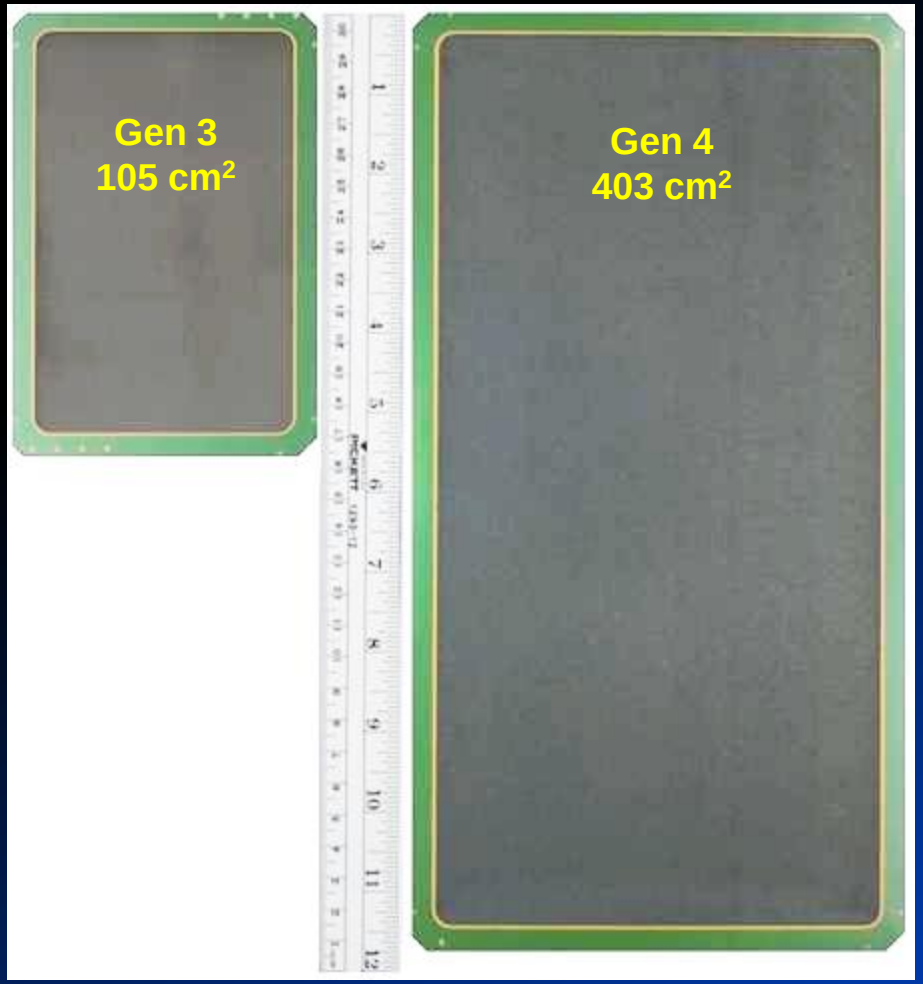
- Summary highlights of past year
- Loss of Methane Reforming
- Water-gas Shift Catalyst
- Repeating unit seal development
- Interconnect and contact material development
- Durability Test Results

Performance Highlights Summary for SECA Coal Based System Stack Development

- Fabricated and tested 19 Gen 4 stacks and 22 Gen 3 stacks in past year
- Demonstrated 5,000+ hours continuous durability on Gen 3.5 stack; demonstrated 2,000+ hours on Gen 4 stack
- Completed 130 full thermal cycles on Gen 4 stack with less than 1% voltage degradation, and 40 full thermal cycles on a second Gen 4 stack with less than 0.5% voltage degradation
- Completed investigations:
  - Improved stack cooling
  - Water-gas shift catalyst application
  - Loss of methane reforming

Cell and Stack Fabrication

- Fabricated in past year
  - About 1,200 Gen 4-sized cells and 440 Gen 3-sized cells
  - 19 Gen 4 stacks of varied configurations (most 38-cells or greater)
  - 22 Gen 3 stacks of varied configurations (5 to 30-cells)



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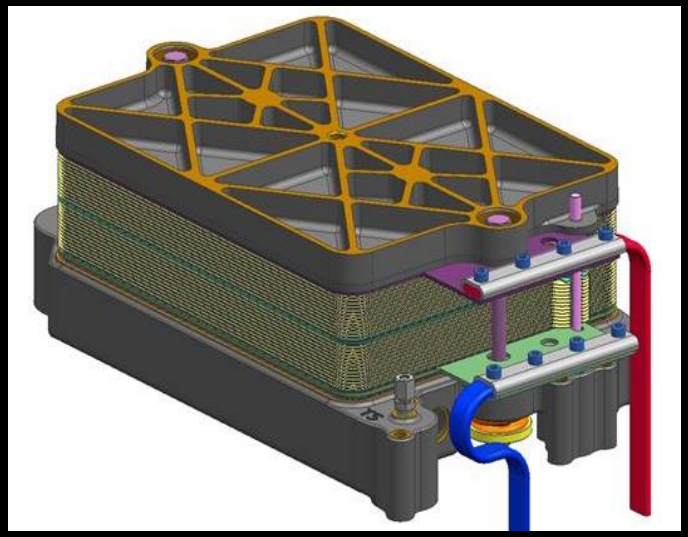
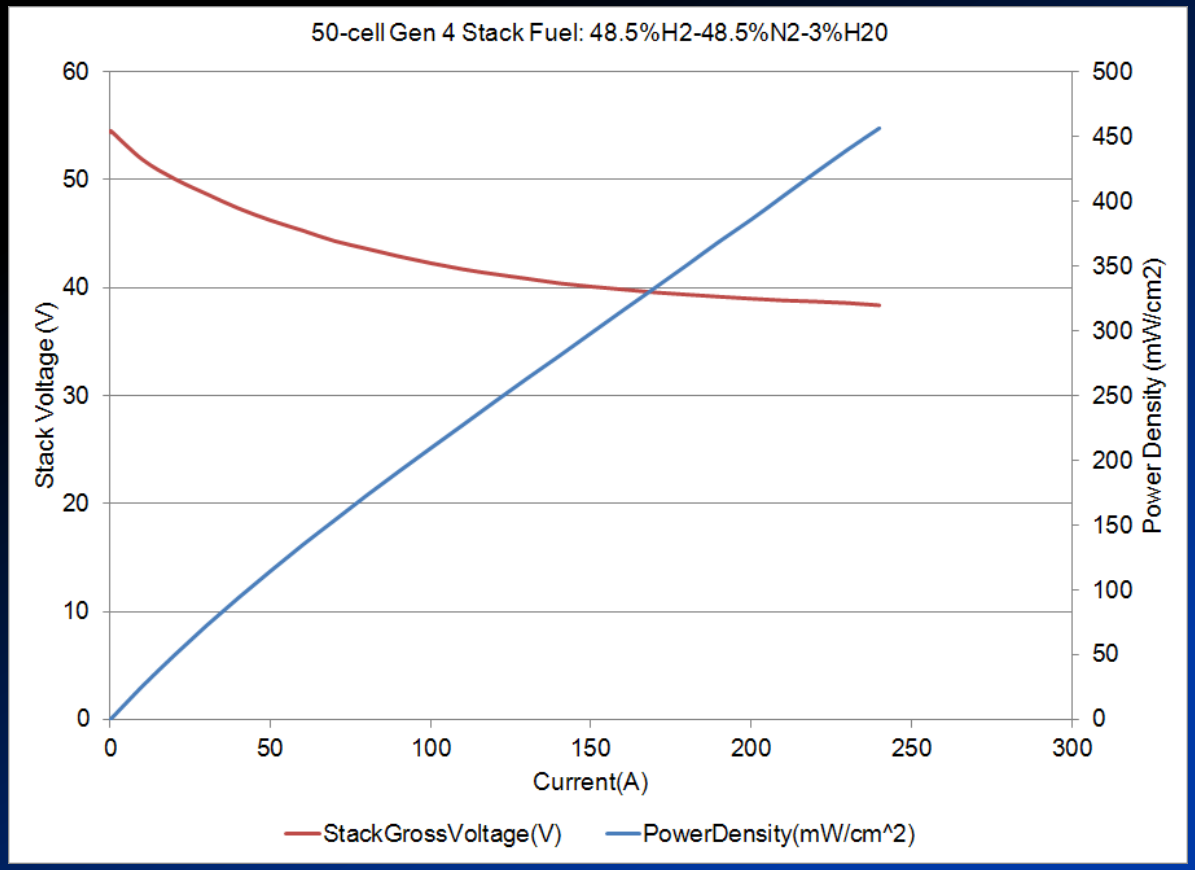
50-cell Gen 4 Stack

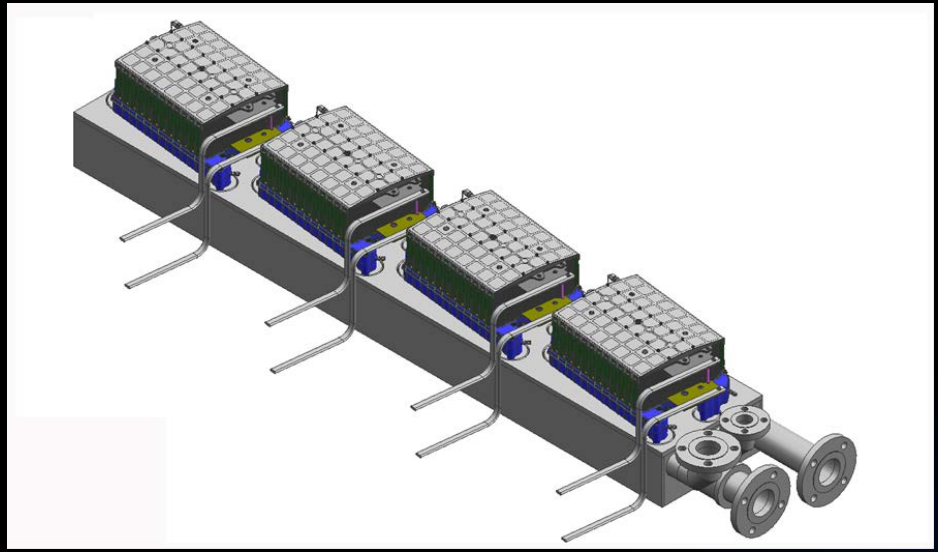


Produced 9.2 kW @ 0.77V



UTC/CLEAR EDGE TESTING

UTC Power/Clear Edge



Provided four (4) 40-cell Gen 4 stacks for stationary multi-stack testing

- Total Power = 27.4kW in $48.5H_2$--$48.5N_2$--$3H_2O$

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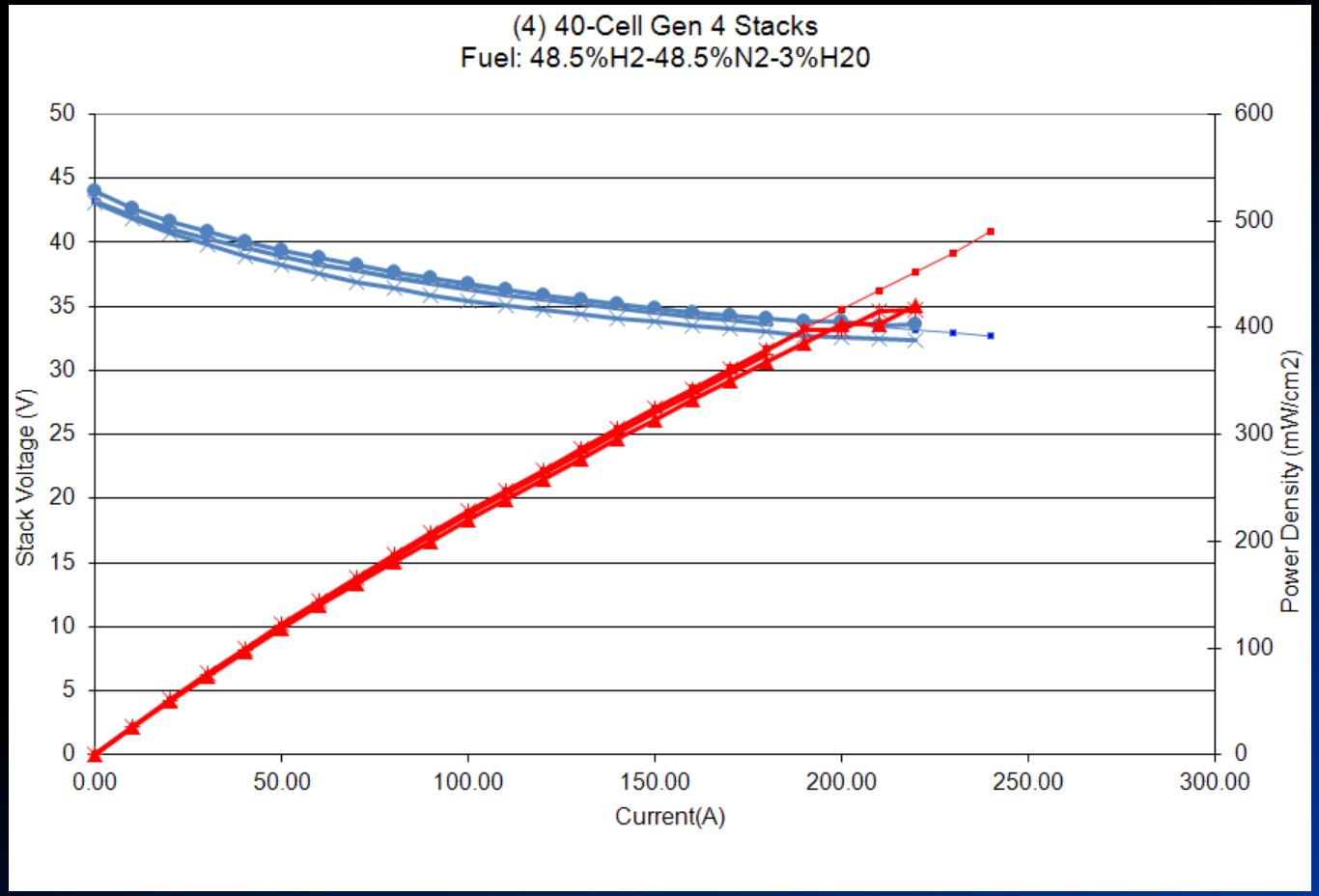
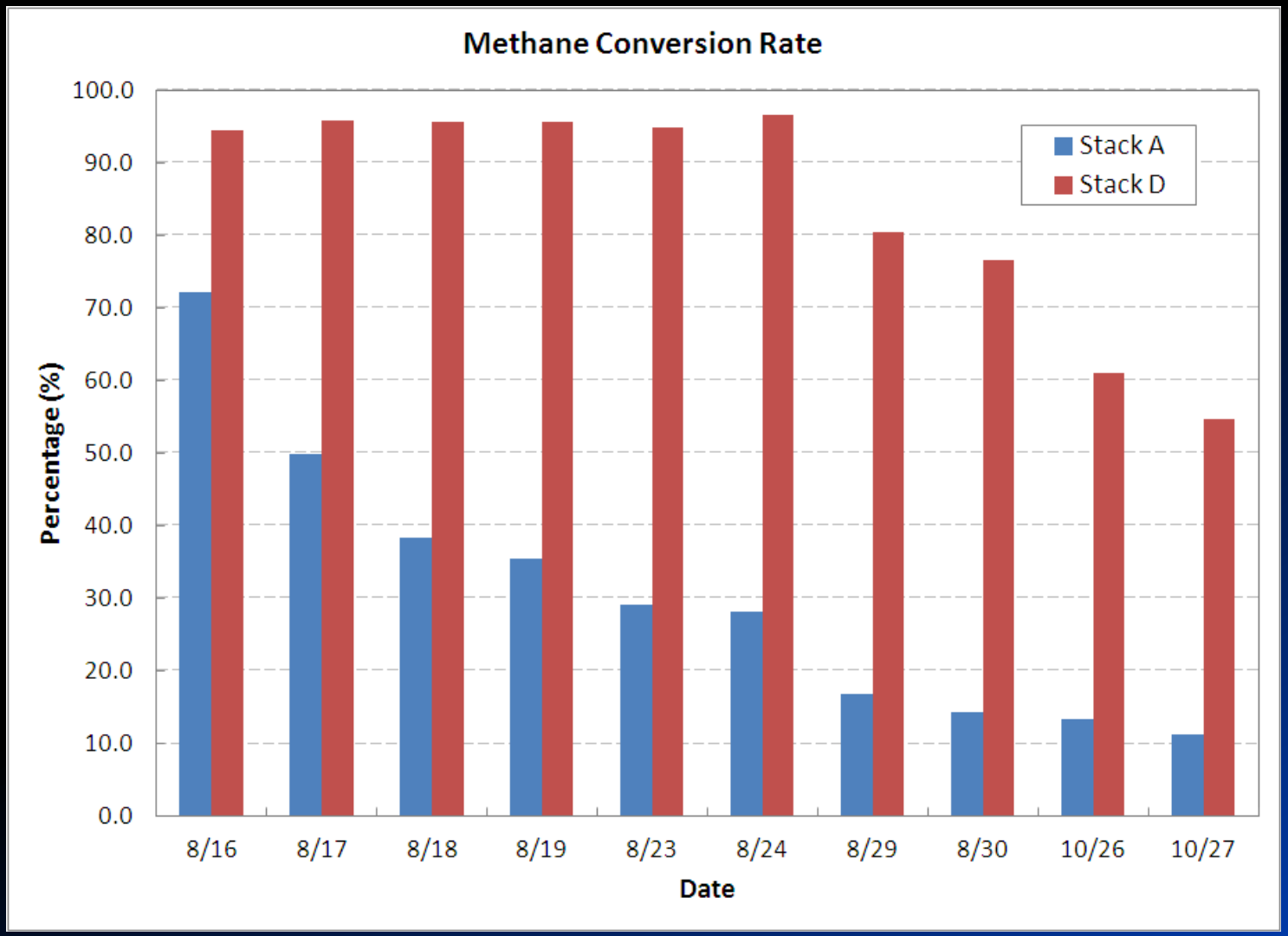
UTC Power/Clear Edge



LOSS OF METHANE REFORMING

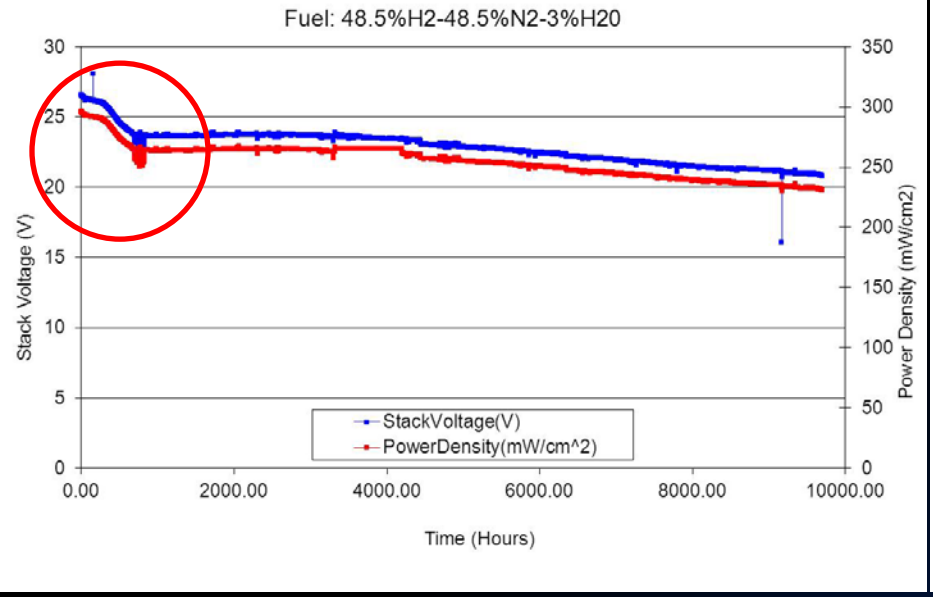
Loss of Methane Reforming

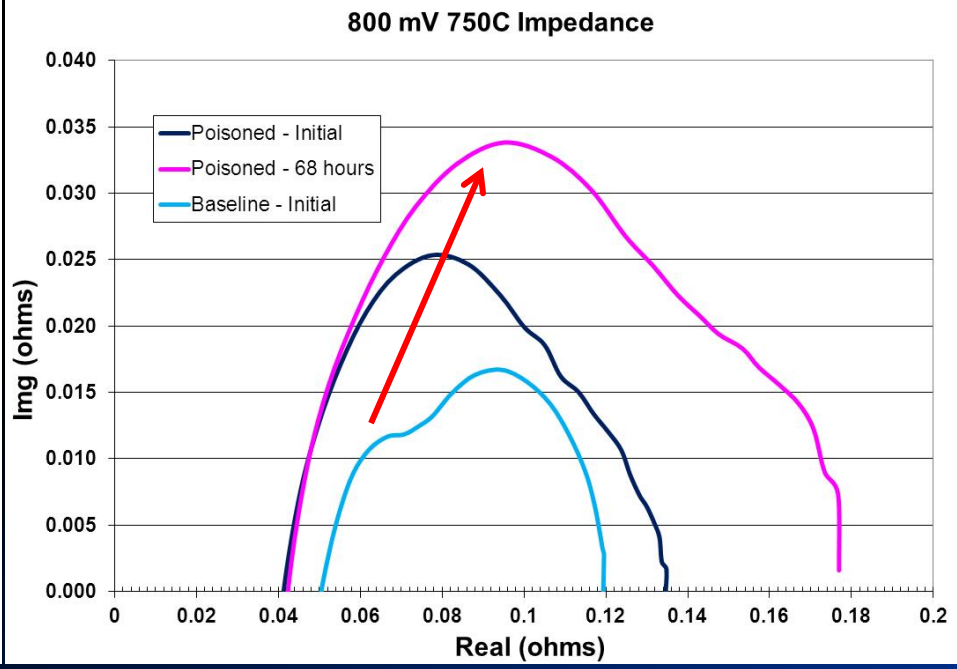
UTC Testing 2011-2012



30-Cell Stack Initial Power Degradation (2011)

Clue to loss of methane reforming mechanism





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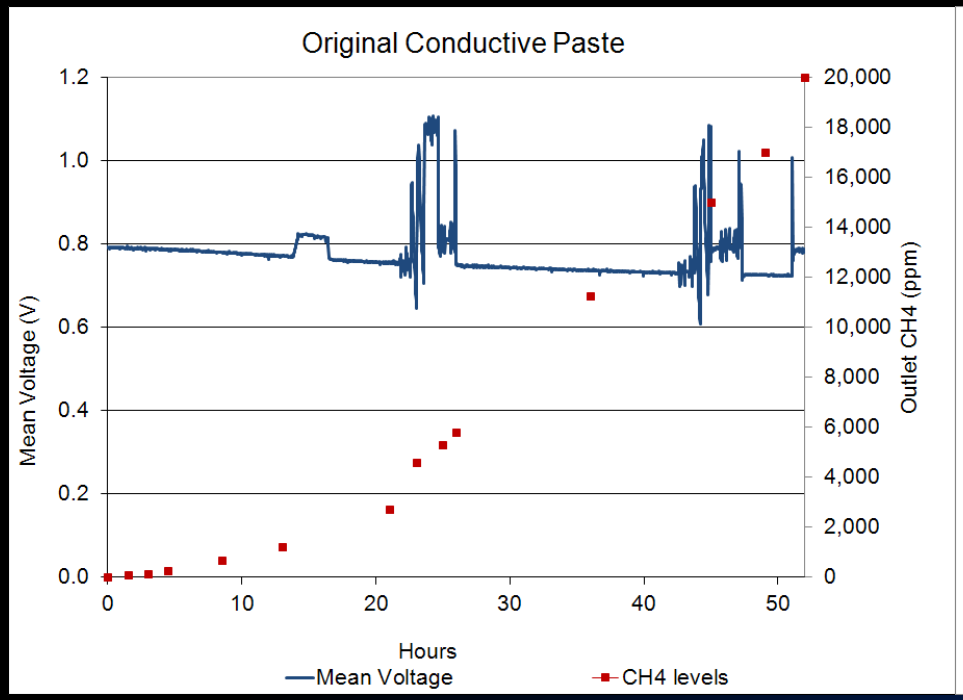
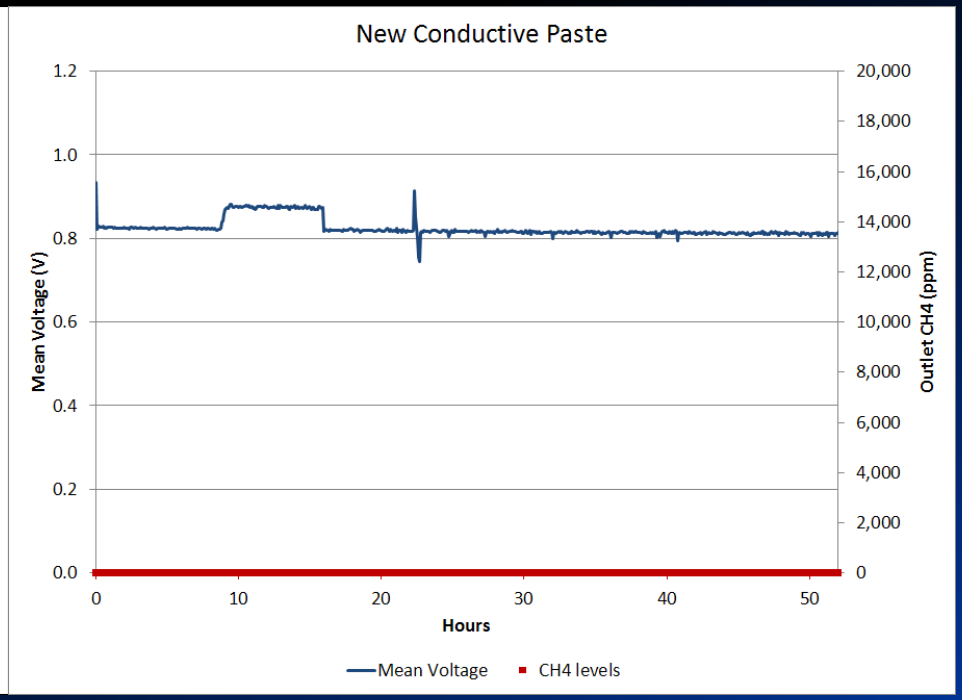
Loss of Methane Reforming

Original conductive paste stack voltage degrades rapidly while stack outlet CH_4 increases

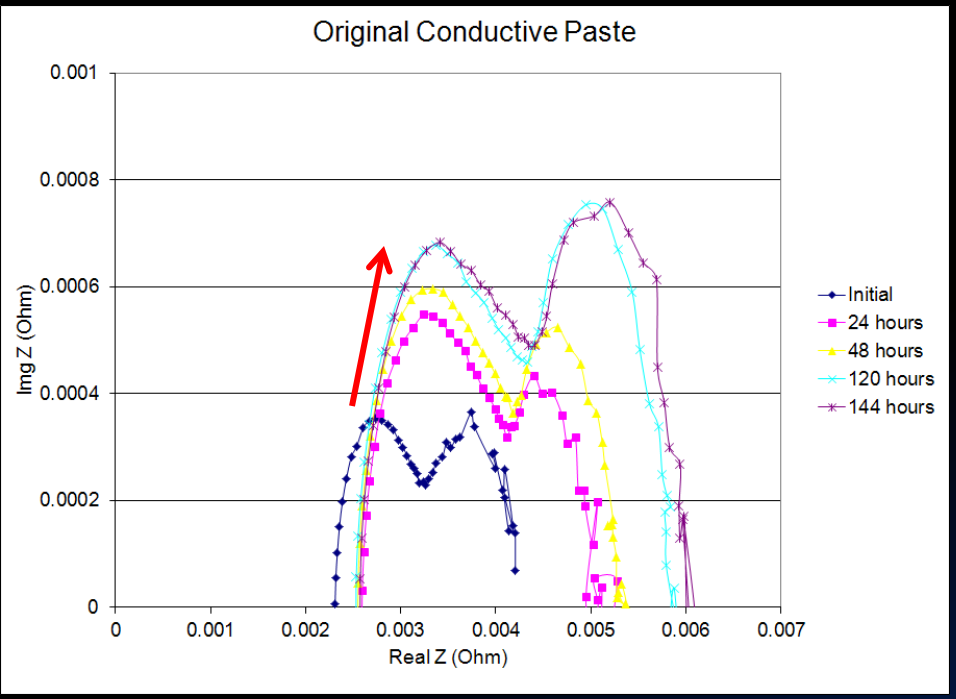


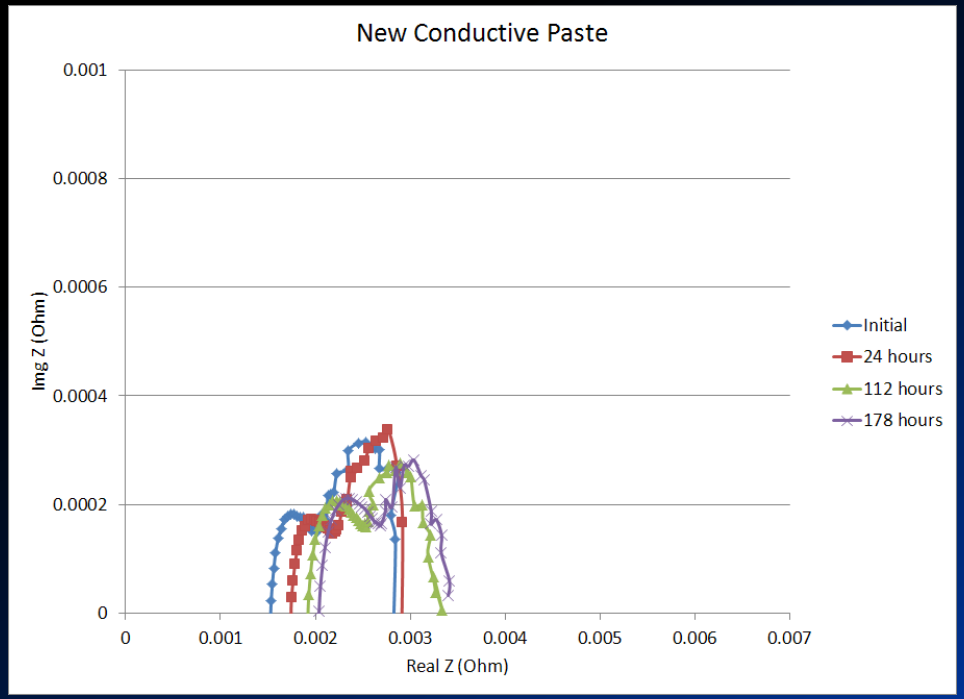


Inlet CH4 concentration = 40,000 ppm

Loss of Methane Reforming

Original conductive paste also poisons methane reforming reaction





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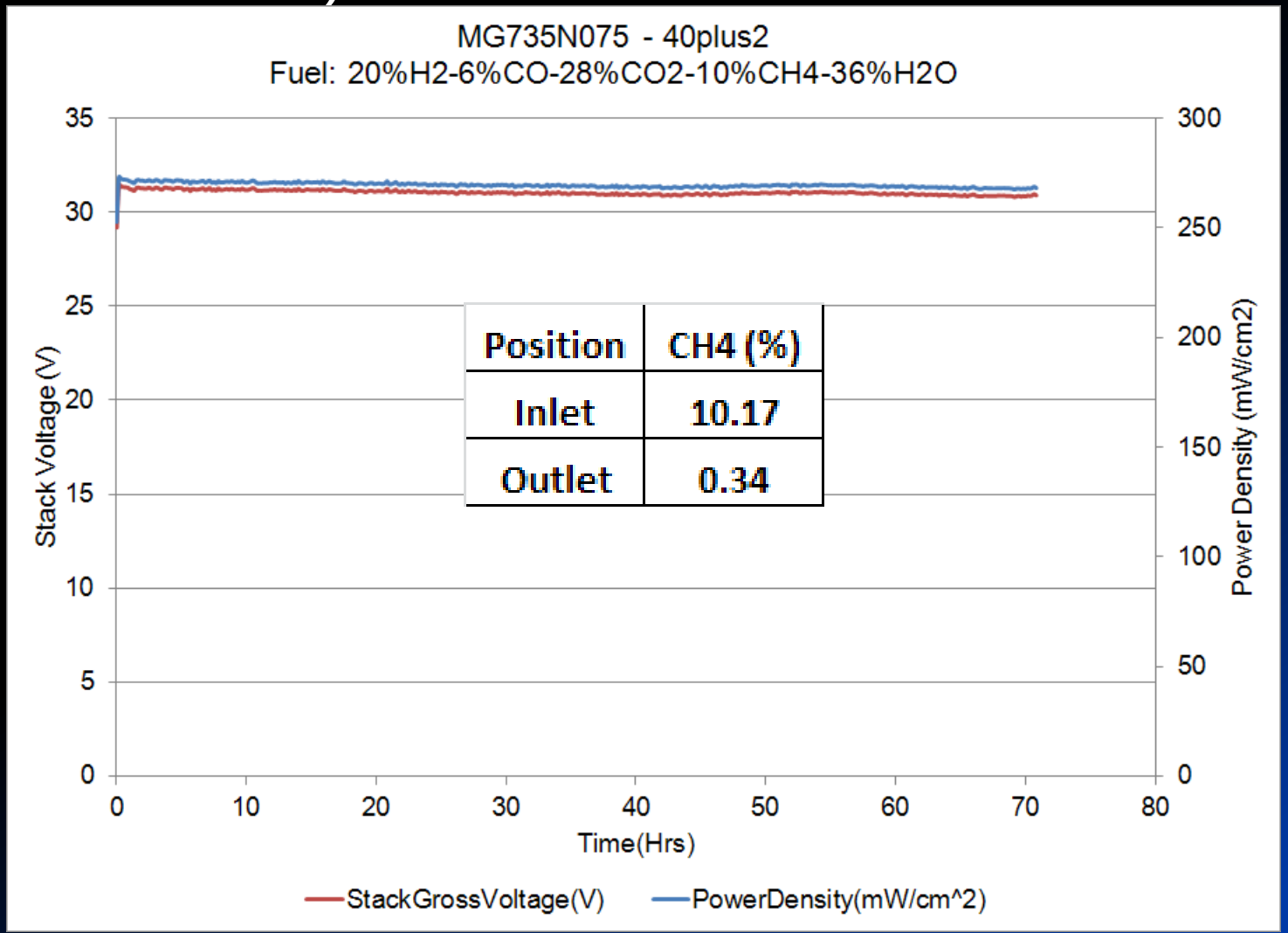
Methane Reforming – Gen 4 40-Cell Stack Confirmation

Stable performance in 10% CH_4 blend (~97% CH4 conversion)

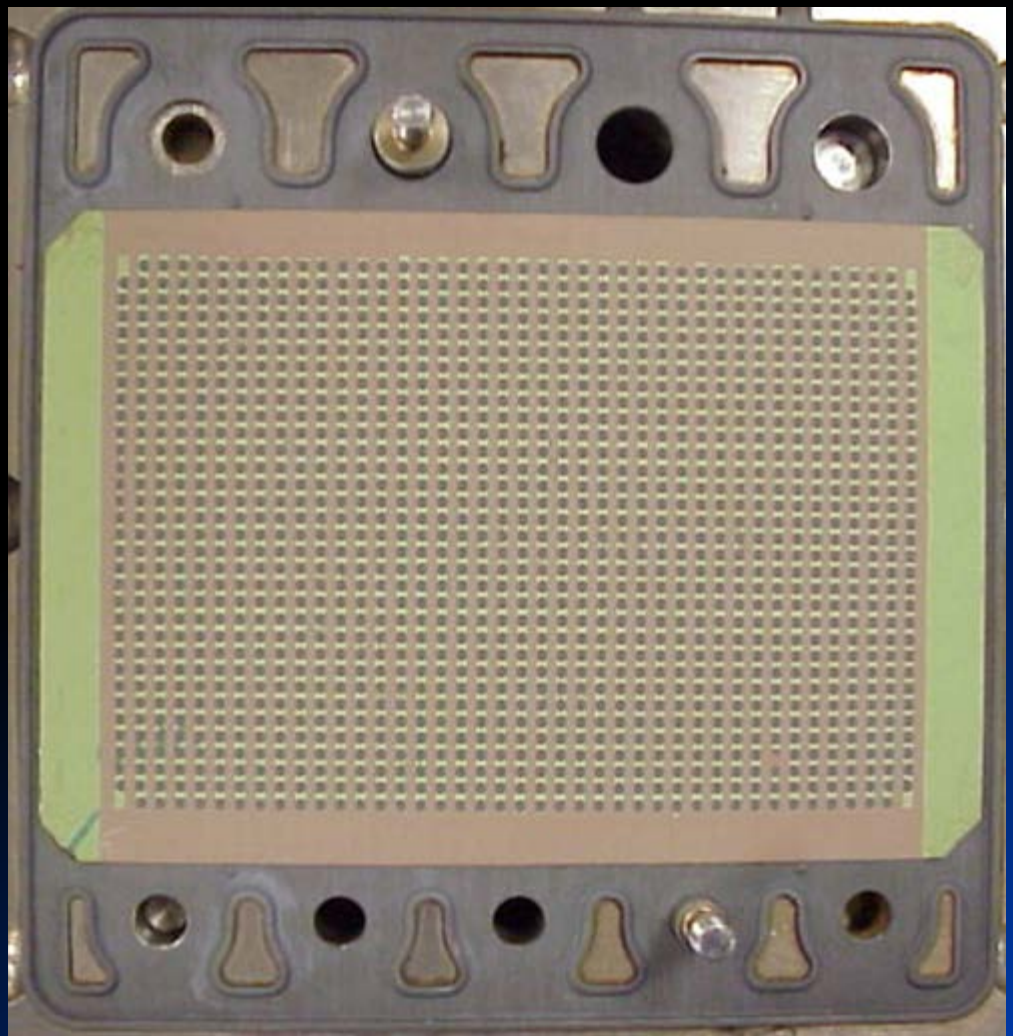


WATER-GAS SHIFT CATALYST

Water-gas Shift Catalyst

Sulfur poisoning of anode inhibits WGS Rx

$$CO + H_2O \longleftrightarrow H_2 + CO_2$$



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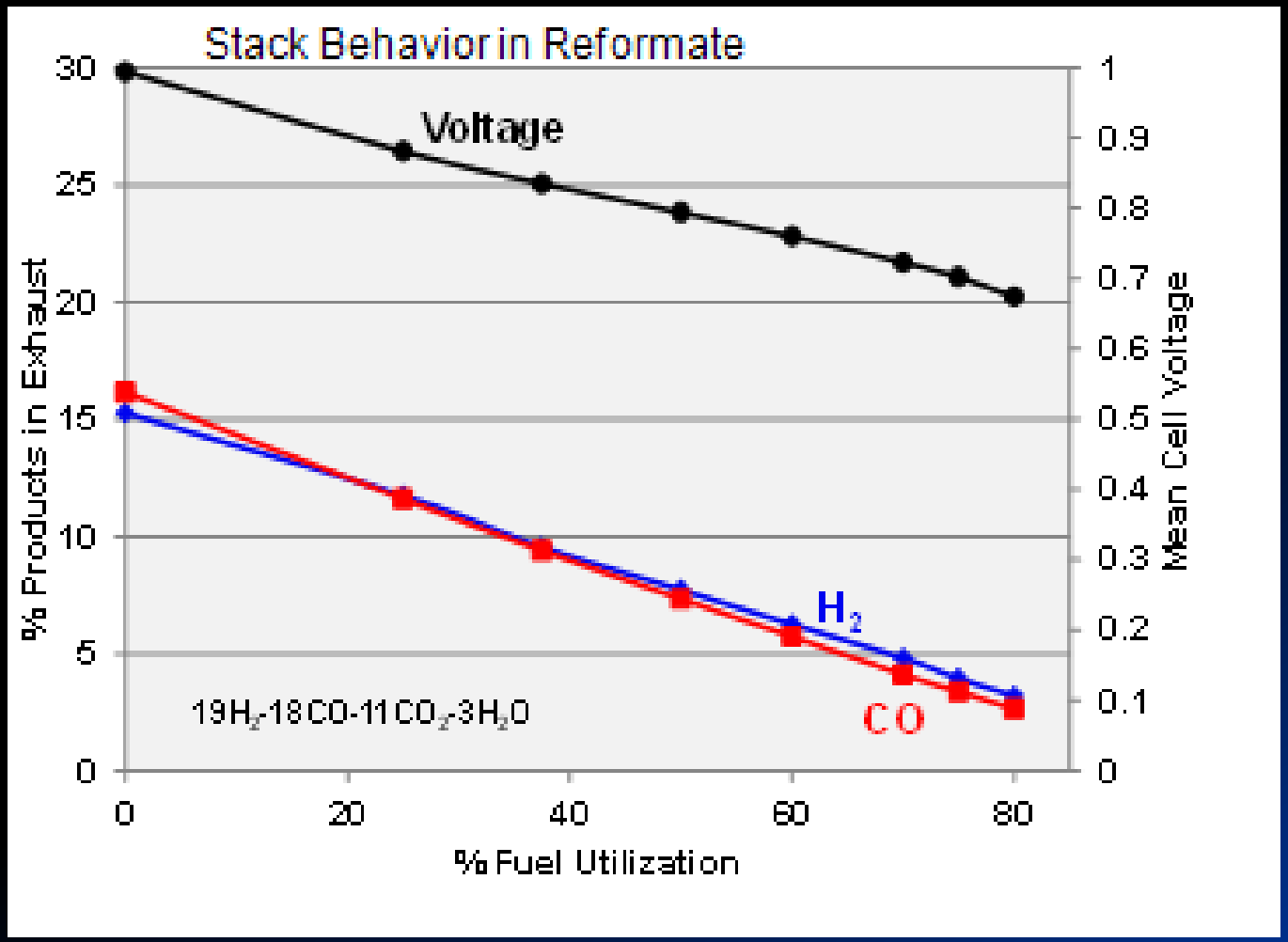
WGS Catalyst

Standard Stack Behavior in Reformate



Both H_2 and CO are utilized by SOFC

Nickel is a WGS catalyst

$$CO + H_2O \longleftrightarrow H_2 + CO_2$$

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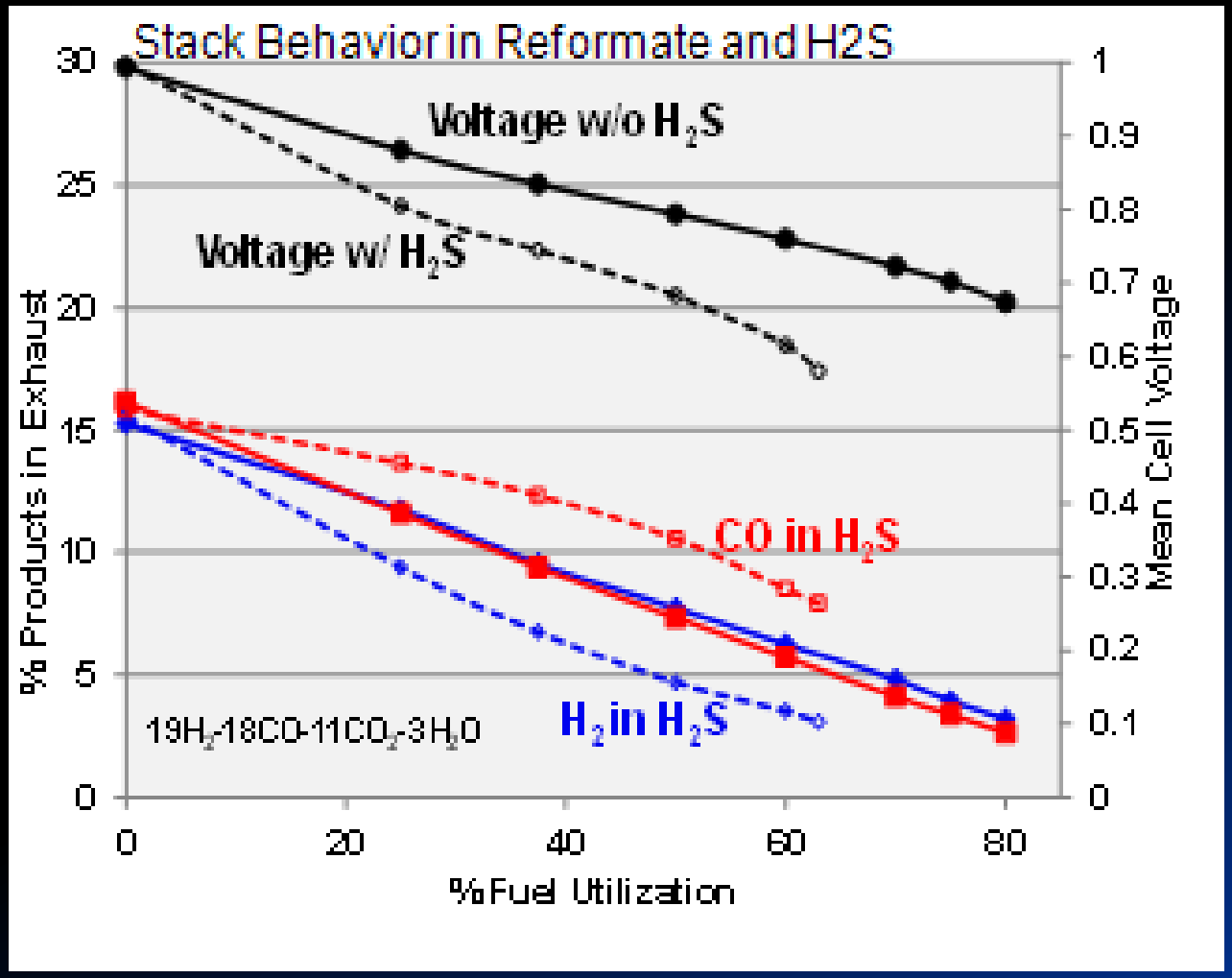
WGS catalyst

Stack Behavior in Reformate and H2S



In H_2S, nickel WGS reaction is inhibited

H_2 levels drop, along with SOFC voltage

$$CO + H_2O \longleftrightarrow H_2 + CO_2$$

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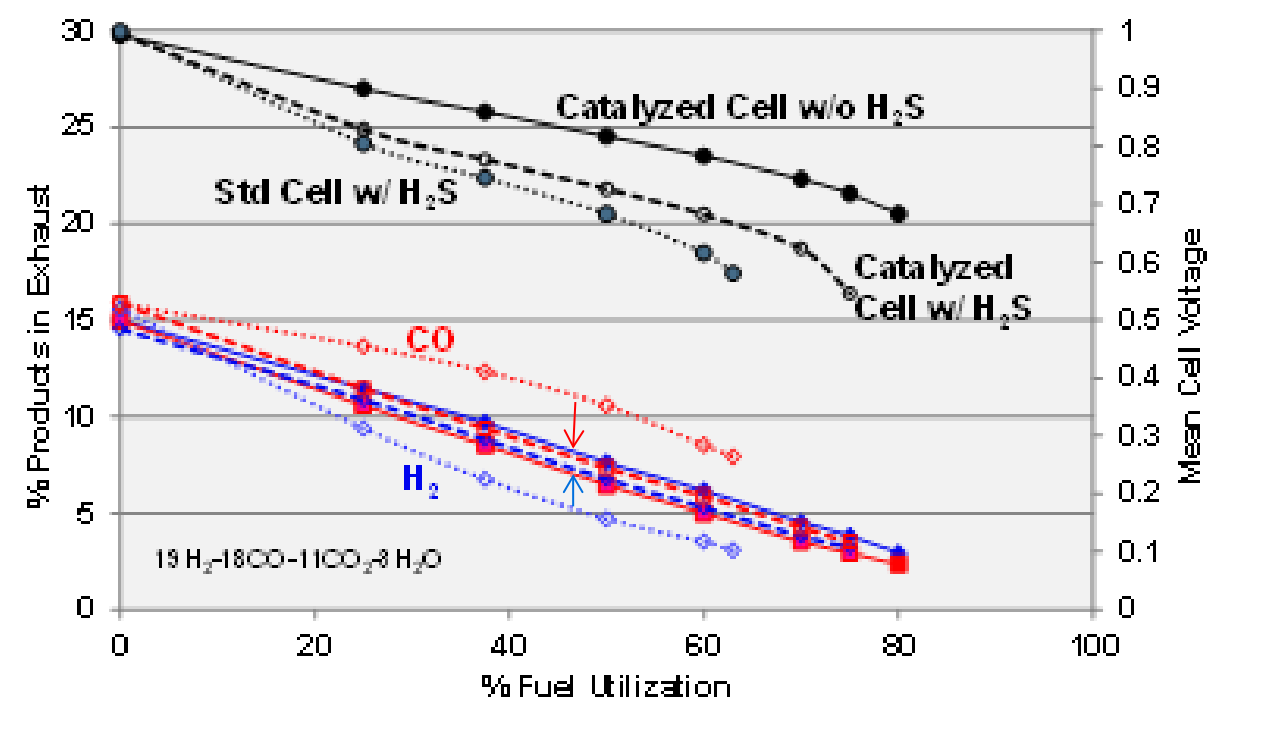
WGS catalyst

Catalyzed Stack Behavior in Reformate and H2S



Substantial voltage increase

H_2 & CO back to original usage levels

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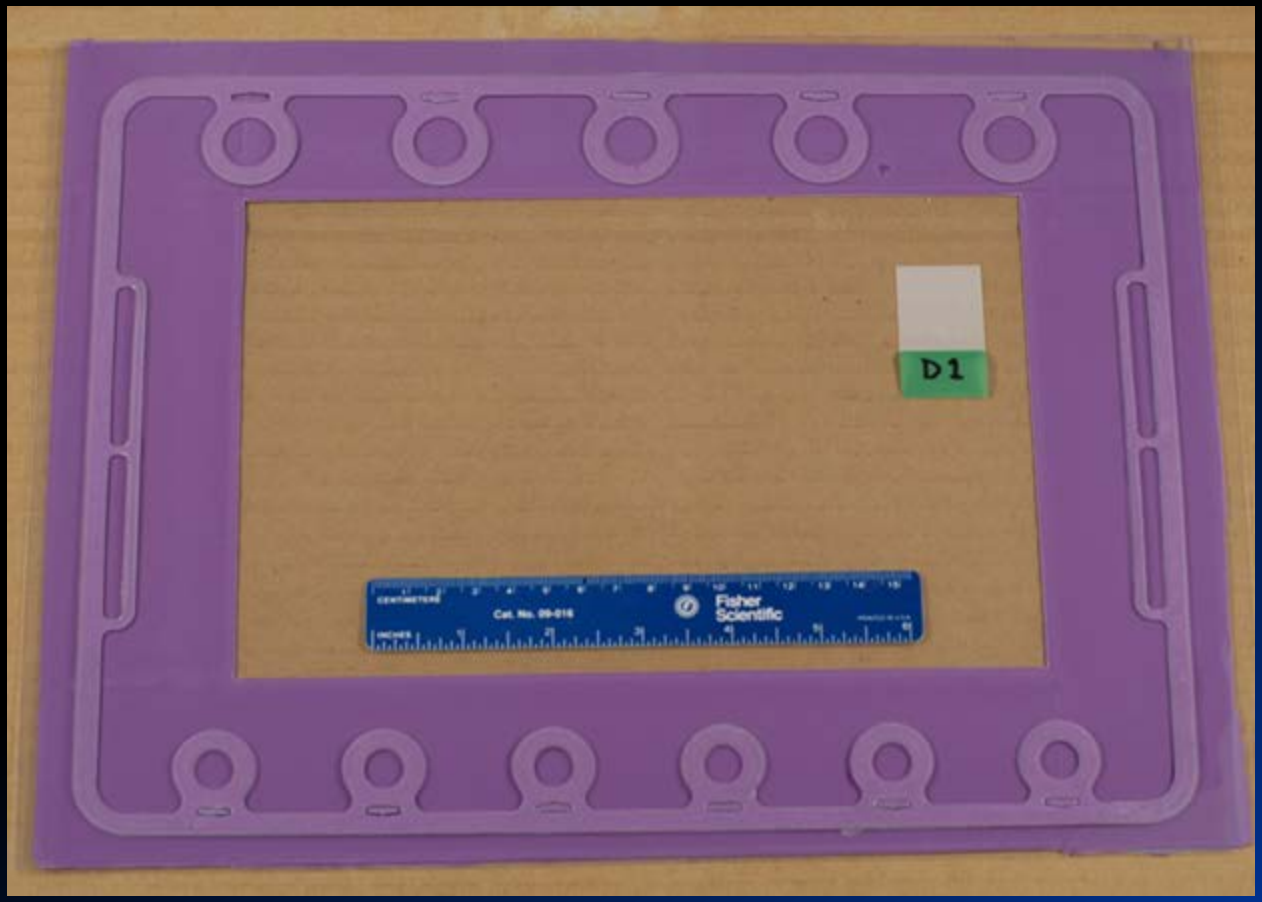
REPEATING UNIT SEAL DEVELOPMENT

Picture-frame Repeating Unit Seal Blank

Die-cut Repeating Unit Seal



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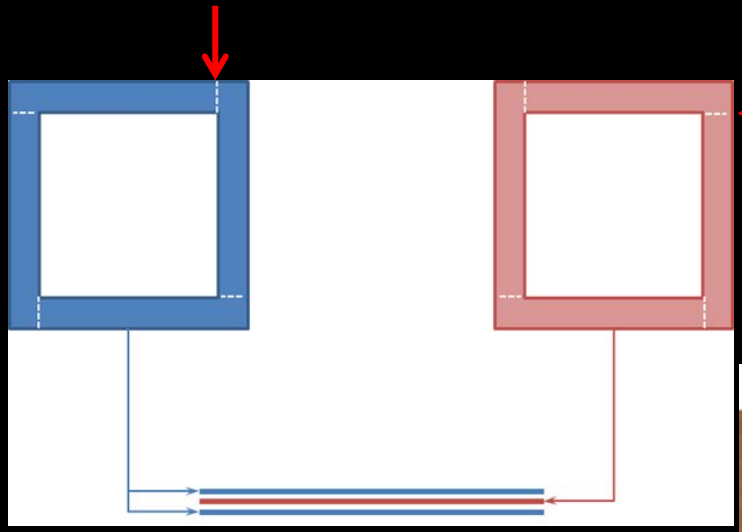
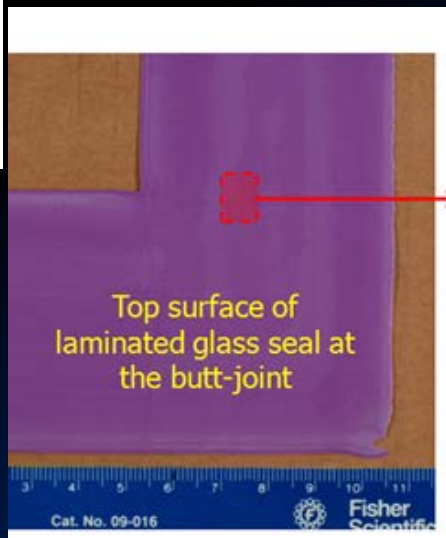
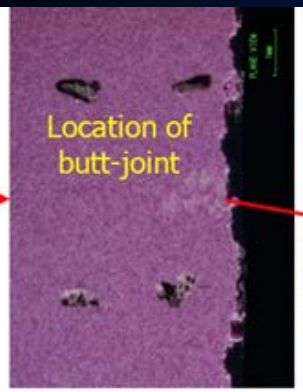
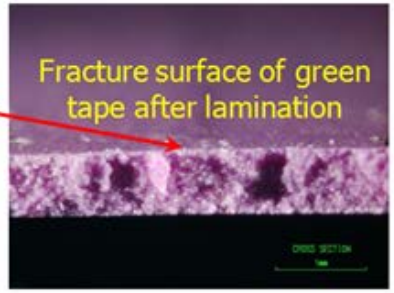
Lay-up of Picture-frame Layers

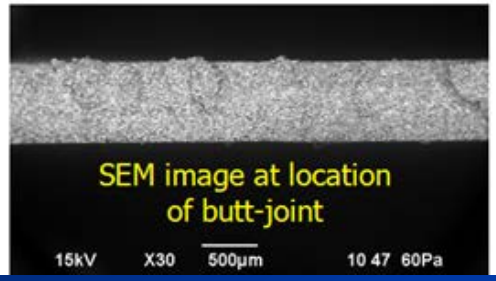
~50% reduction in material usage





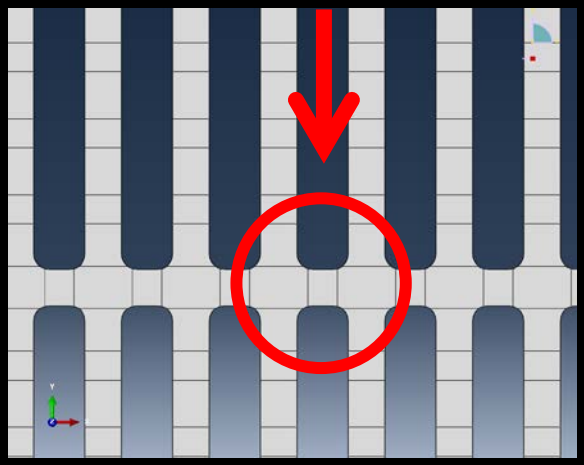




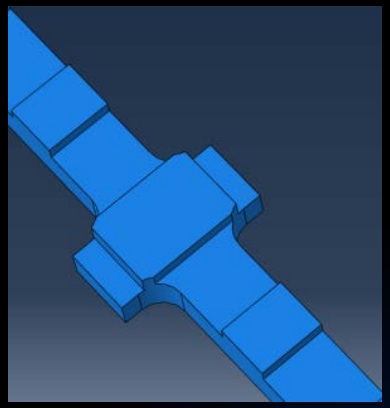


CATHODE FLOW RESTRICTION

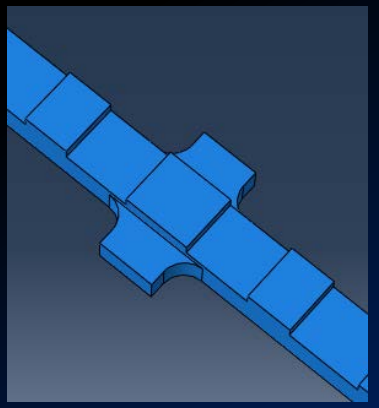
Gen 4 Cathode Flow Restriction → Parasitic Losses

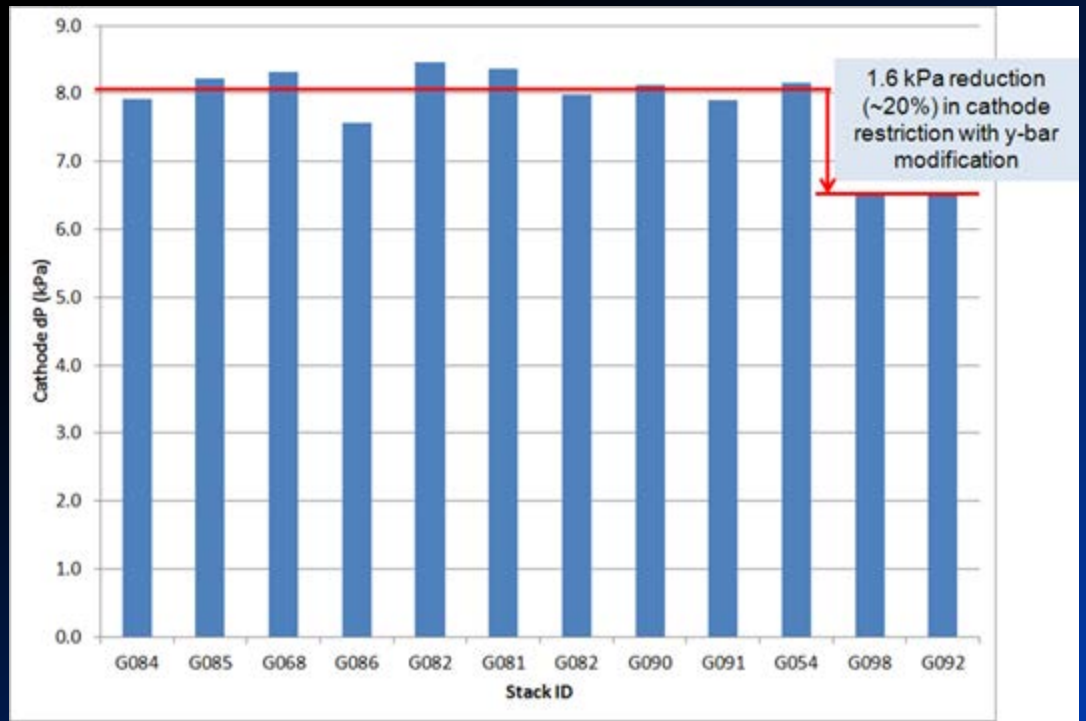


As Designed



Gap Increased





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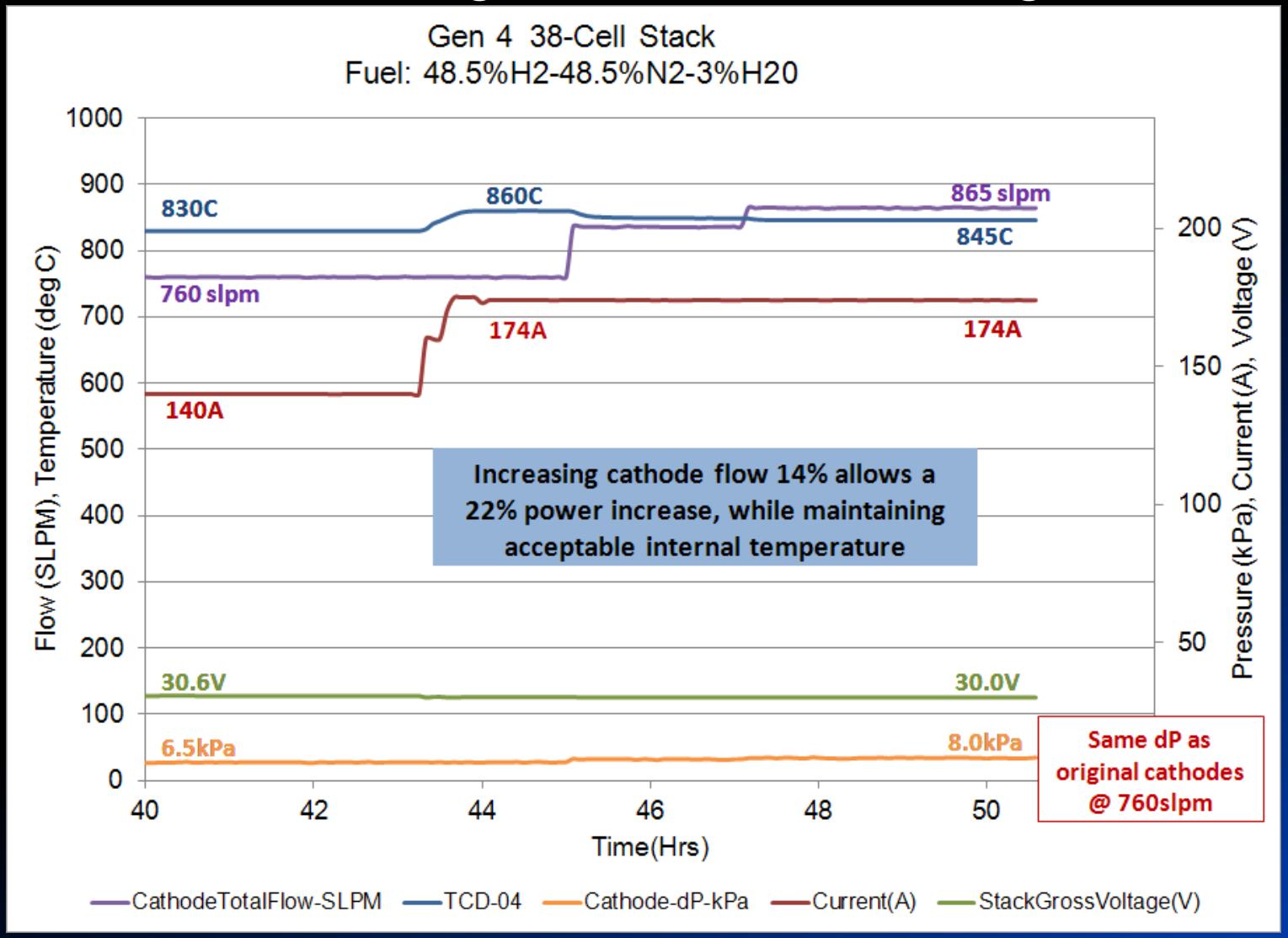
Gen 4 Cathode Flow Restriction

Increased cooling of stack allows larger loads



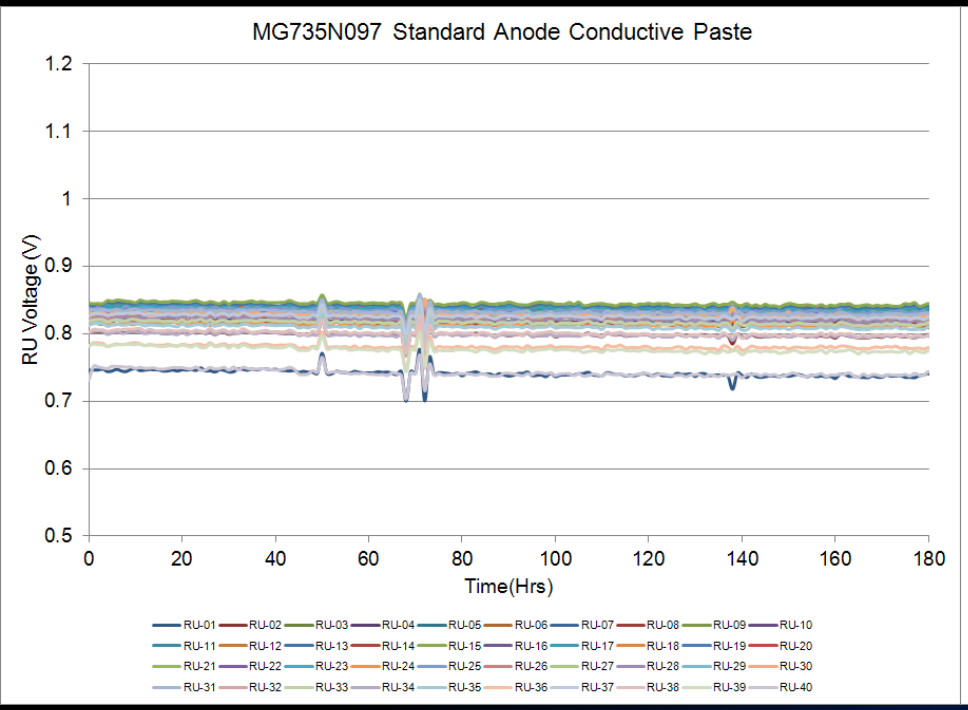
IMPROVED CONDUCTIVE PASTES

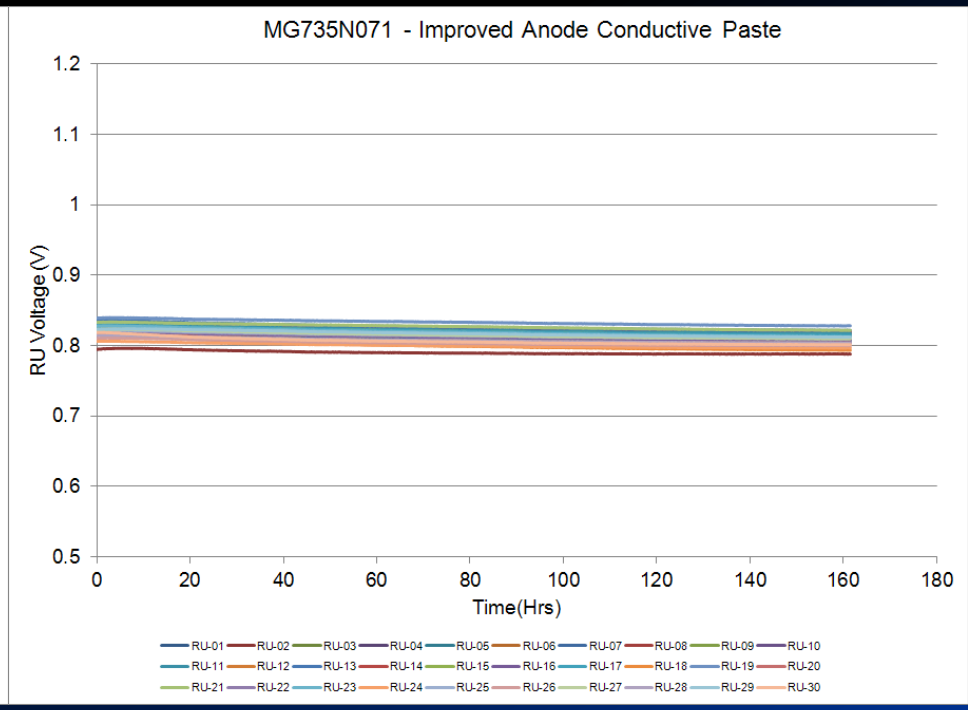
Improved Conductive Pastes

- Changes were made to the anode and cathode conductive pastes to improve the structural stability of the stack
- Initial voltage spread of the repeating units was reduced, and stable voltage over time was realized

Improved Anode Conductive Paste

Reduced voltage spread from 0.11V to 0.04V





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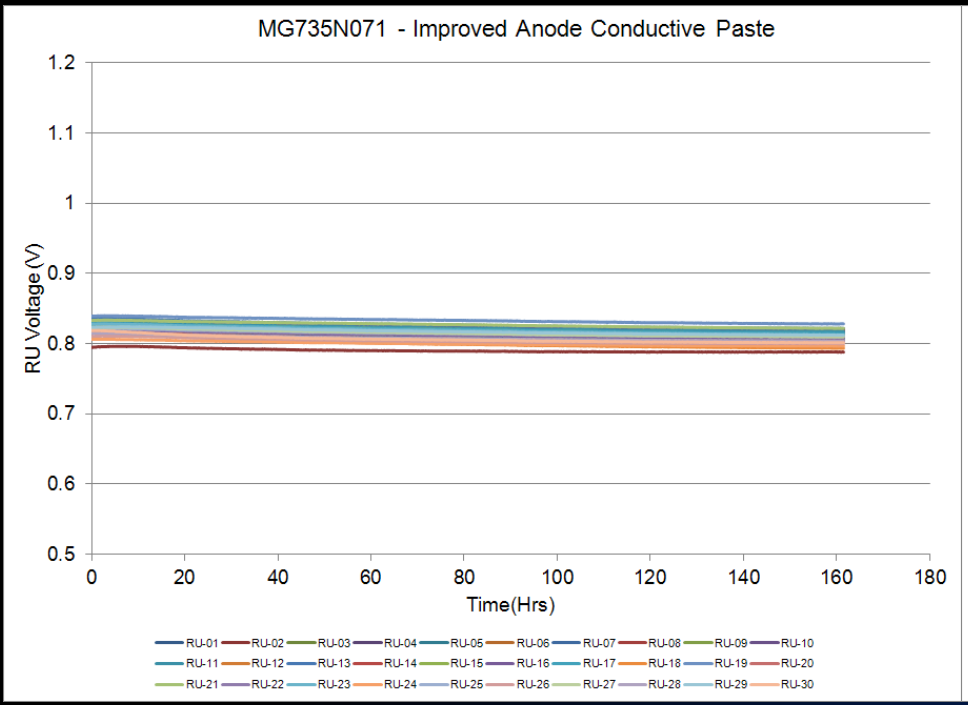
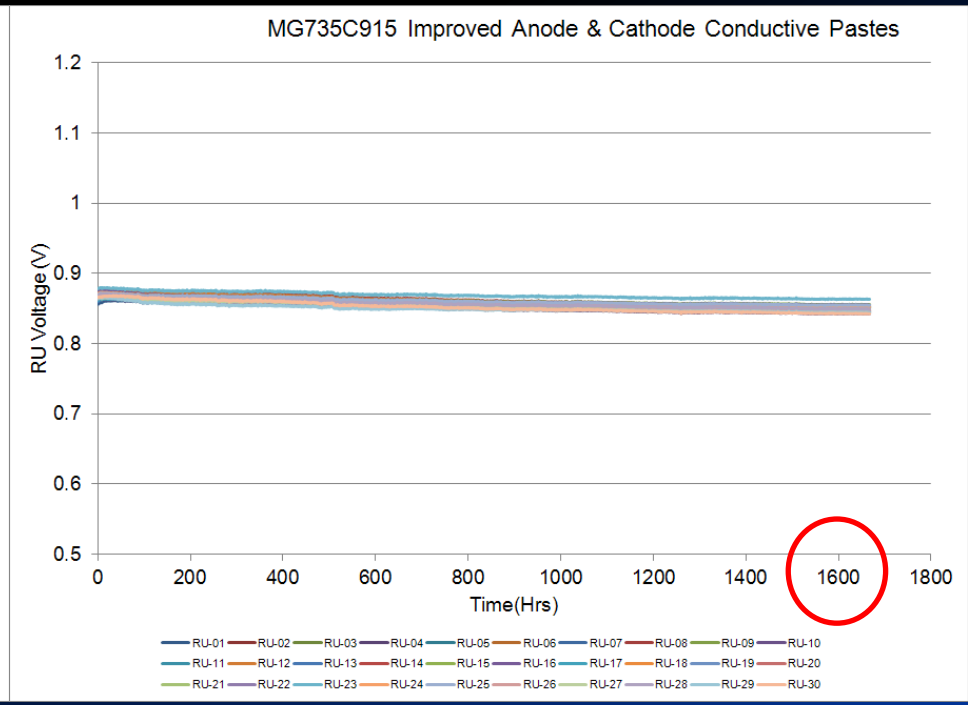
Improved Anode and Cathode Conductive Pastes

Reduced voltage spread from 0.04V to 0.02V





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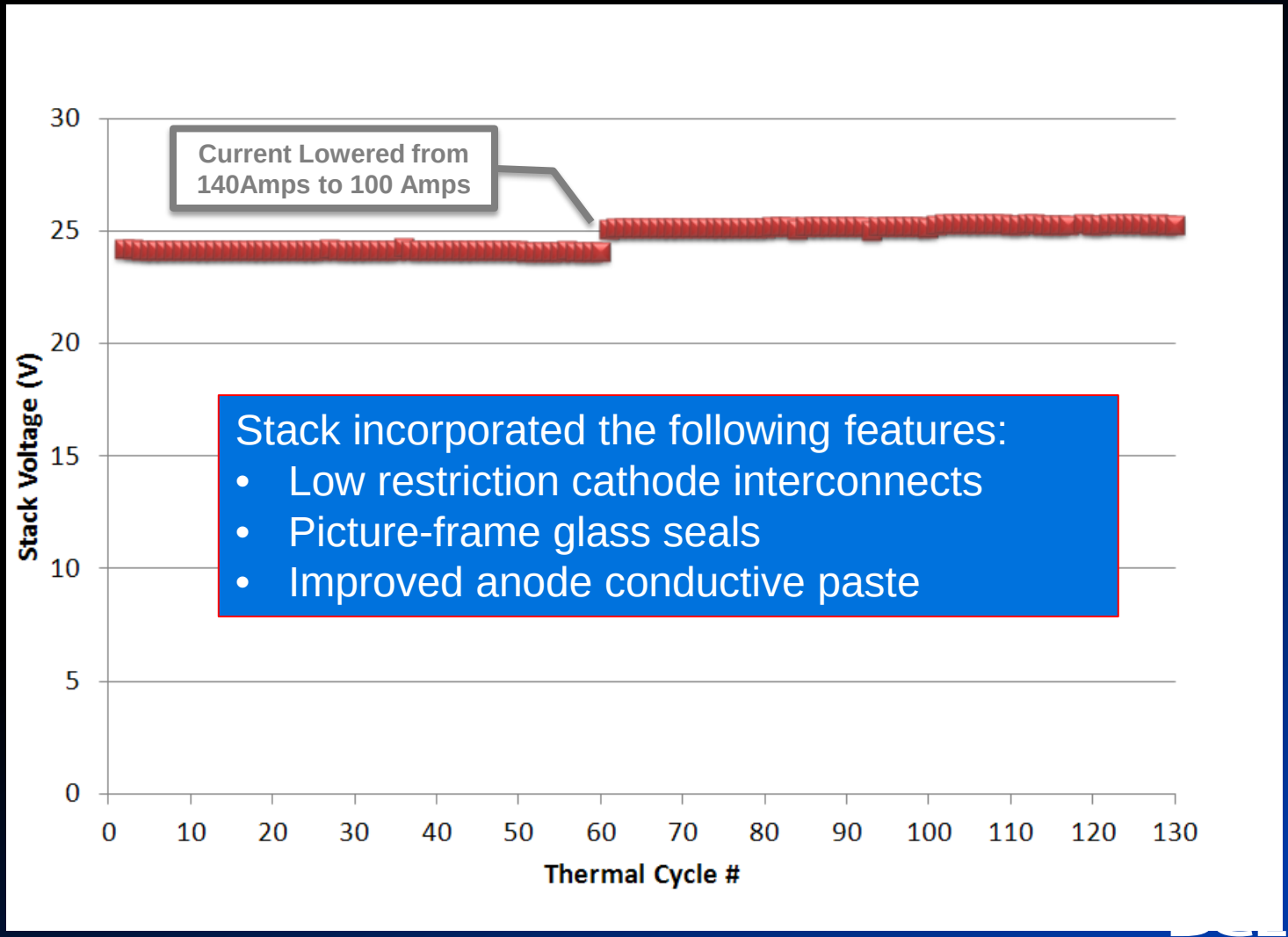
DURABILITY TEST RESULTS

STACK THERMAL CYCLING

30-Cell Gen 4 Stack Thermal Cycling Performance

Negligible leaks in glass seals after 130 cycles



CONSTANT CURRENT TESTING

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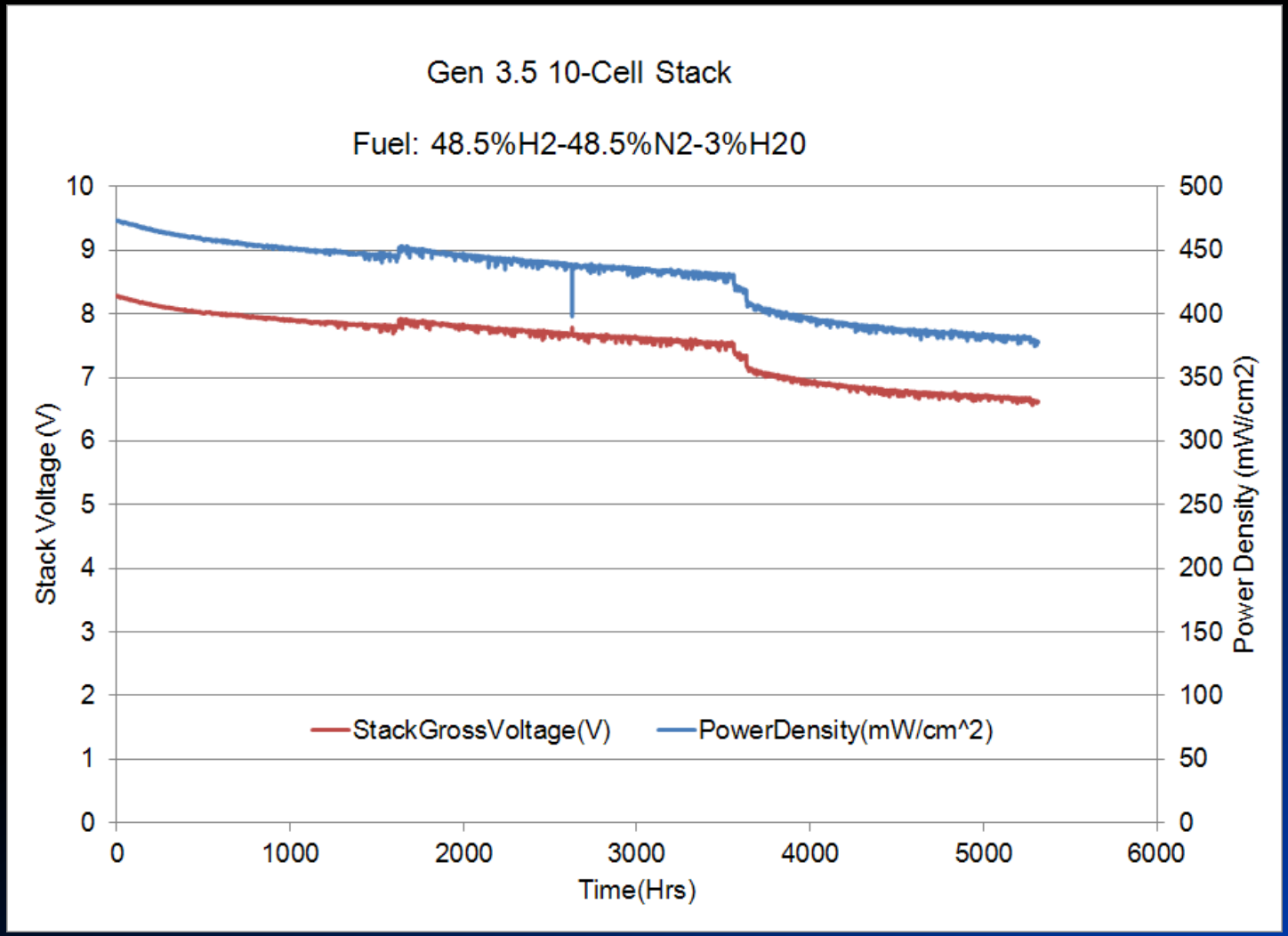
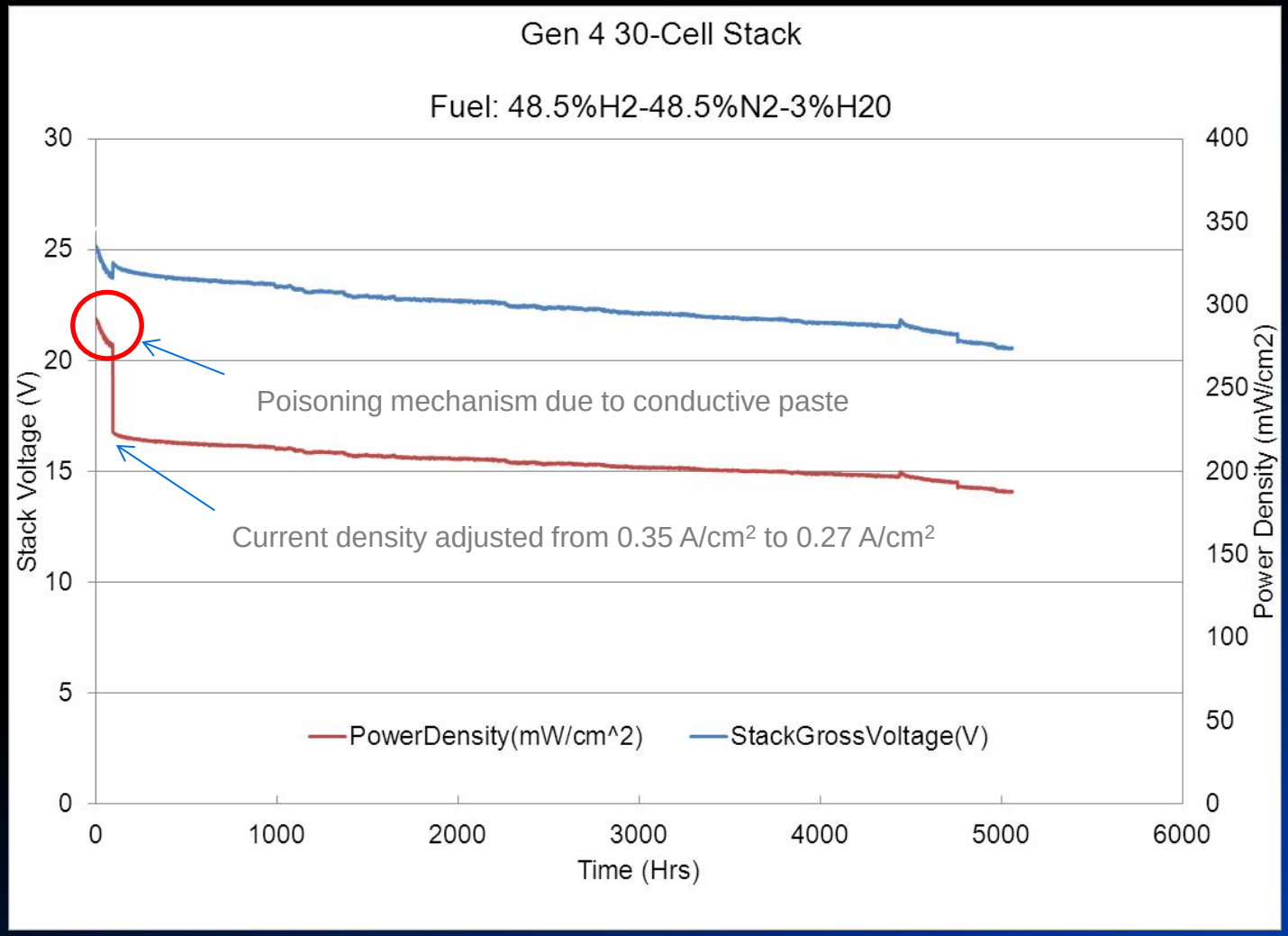
10-cell Gen 3.5 Stack Accelerated Durability Test

5,300 hours at rated conditions of 0.57 A/cm^2



30-Cell Gen 4 Stack Durability Test (2011-2012)

10 unique repeating unit treatment combinations



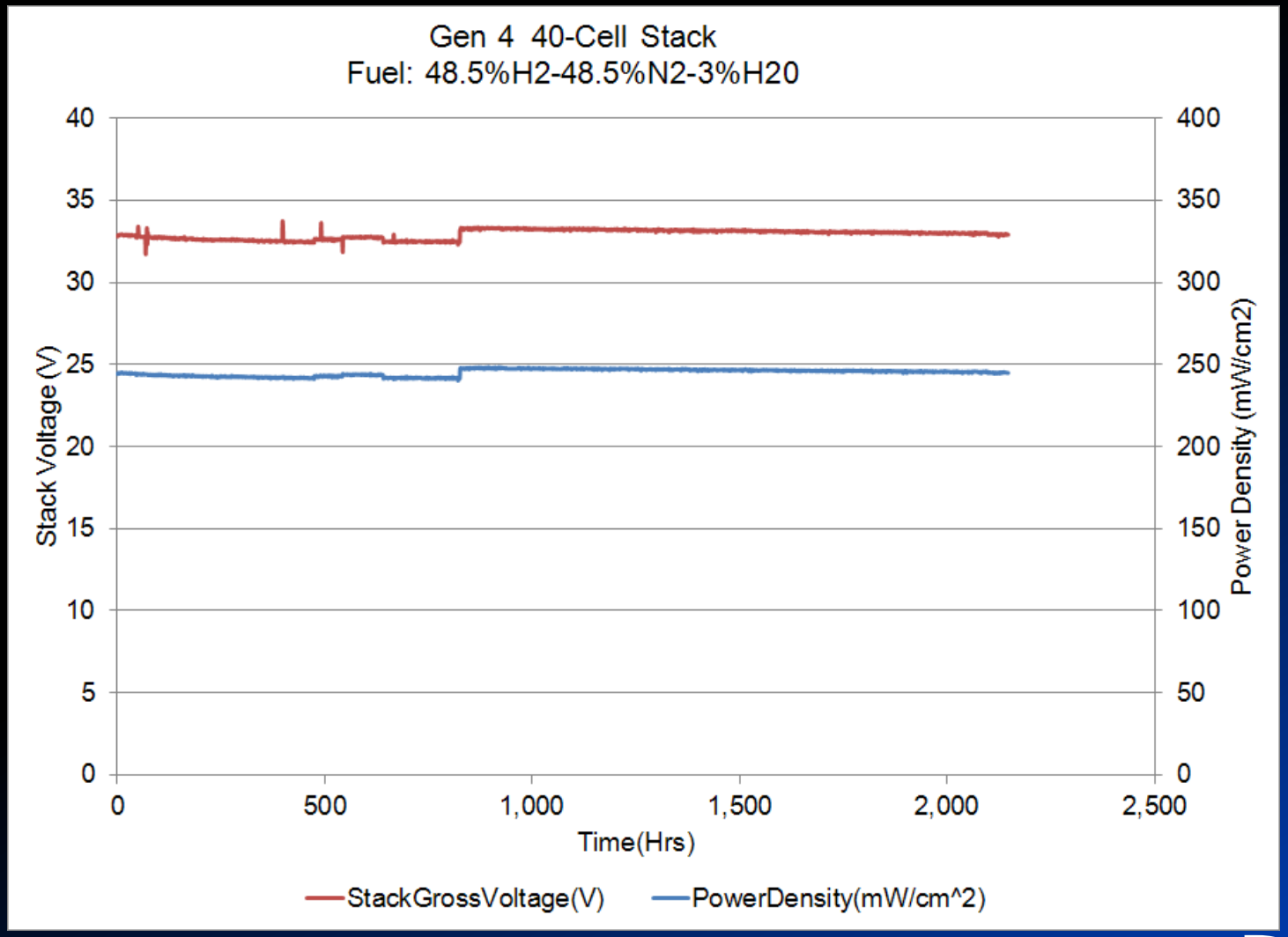
30-Cell Gen 4 Stack Durability Test Autopsy Results

At end of test, cathode attachment material was the most significant contributor to degradation

- One particular material used to attach the interconnects accelerated to oxidation of stainless steel causing gross porosity and high electrical resistance

40-Cell Gen 4 Stack Durability Test - Ongoing

2,100 hours at NOC of 0.3A/cm^2



Goals for 2013-2014

- Identify the mechanisms of long-term power degradation (> 2000 hours)
  - Durability stacks being built using lessons learned from previous 5,000+ hour stacks
- Separate the cathode and anode contributions to power degradation
  - De-convolution of impedance spectroscopy from long-term, full stack durability tests
- Cost reduction

Acknowledgements

Thanks to Joe Stoffa, Briggs White, Dan Driscoll, Shailesh Vora, and Heather Quedenfeld of the DOE for their support and technical guidance