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Solid Oxide Fuel Cell Development for Transportation and Stationary Applications: Latest Update on Stack and System Performance

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2009 Fuel Cell Seminar
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Delphi Solid Oxide Fuel Cells Market Opportunities

- Delphi Solid Oxide Fuel Cells Provide:
  - Ultra-clean, near zero emissions
  - High-quality, reliable power
  - High fuel efficiency
  - Fuel flexibility
  - Low noise

Heavy Duty Trucks
Auxiliary Power Units

Residential Power
Stationary CHP Power Units

Commercial Power
Stationary Power Units

Recreational Vehicles
Auxiliary Power Units

Military
Auxiliary & Mobile Power Units

Clean Coal Power Plant
Advanced Power Systems

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Delphi SOFC Development Centers

Fenton, Michigan

- Cell Development
- Manufacturing Development
- Electrochemical Testing
- Material Characterization and Analysis

Rochester, New York

- Stack Development
- System Development
- Reformer Development
- BOP Development

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Cell and Stack Development

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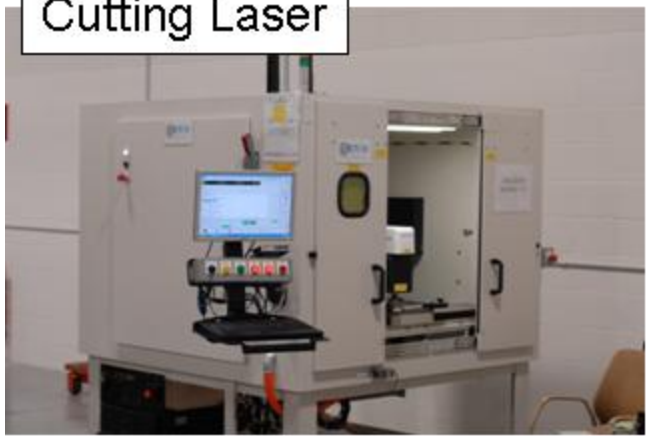
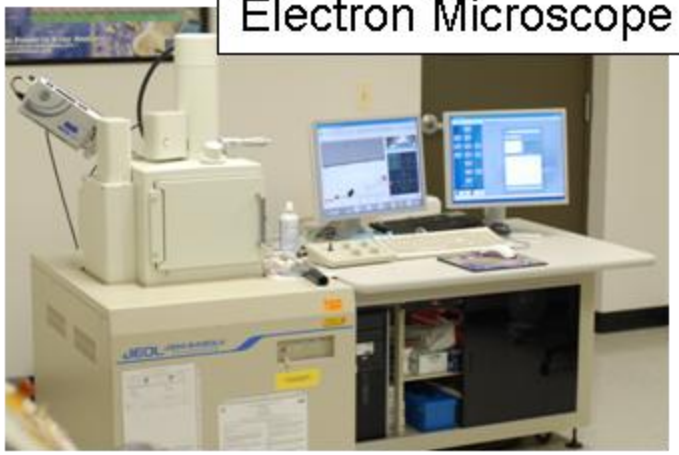
Equipment for Cell Development and Fabrication

Cutting Laser



High Temp Kilns

Electron Microscope



Screen Printer

Laser Interferometer

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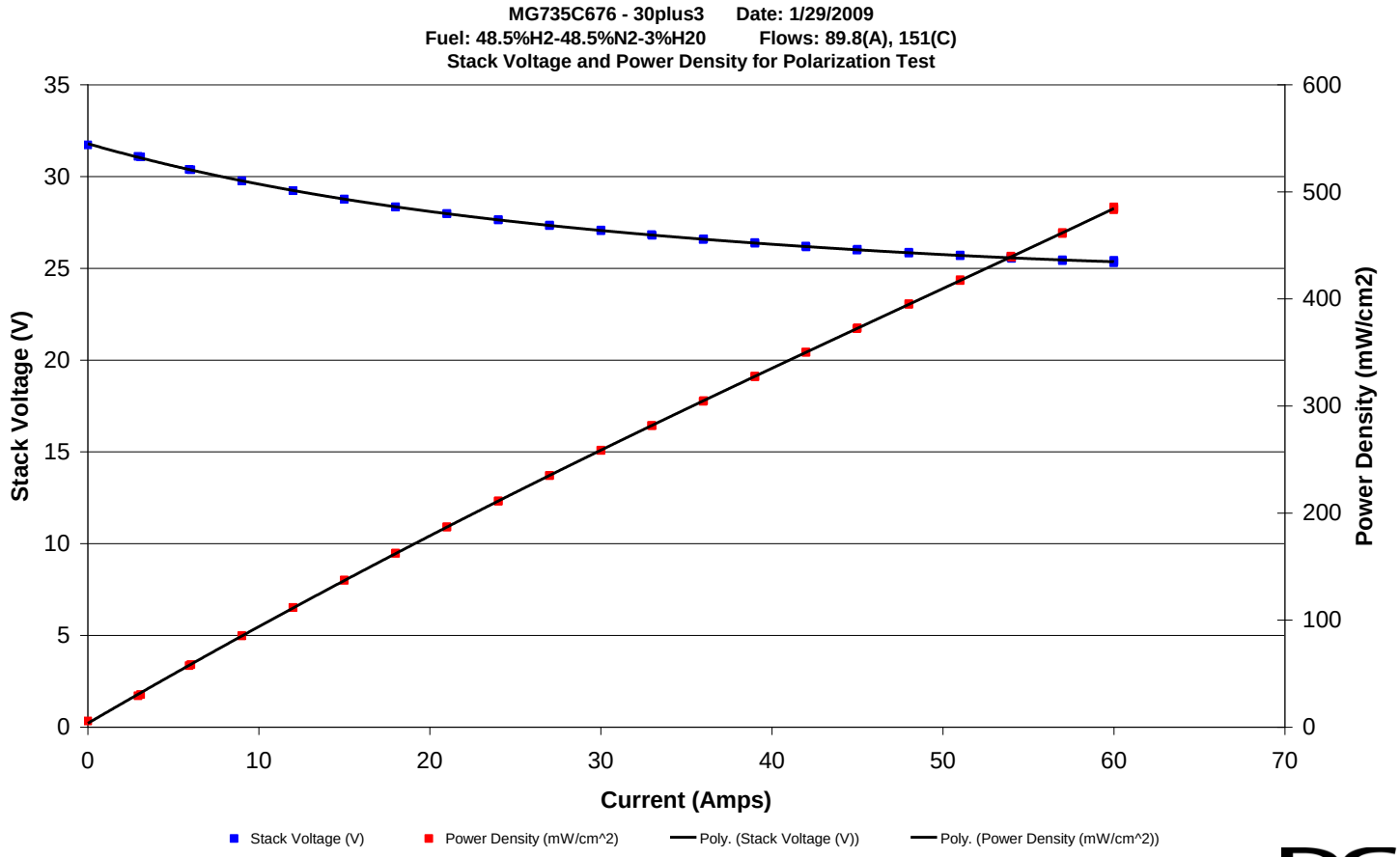
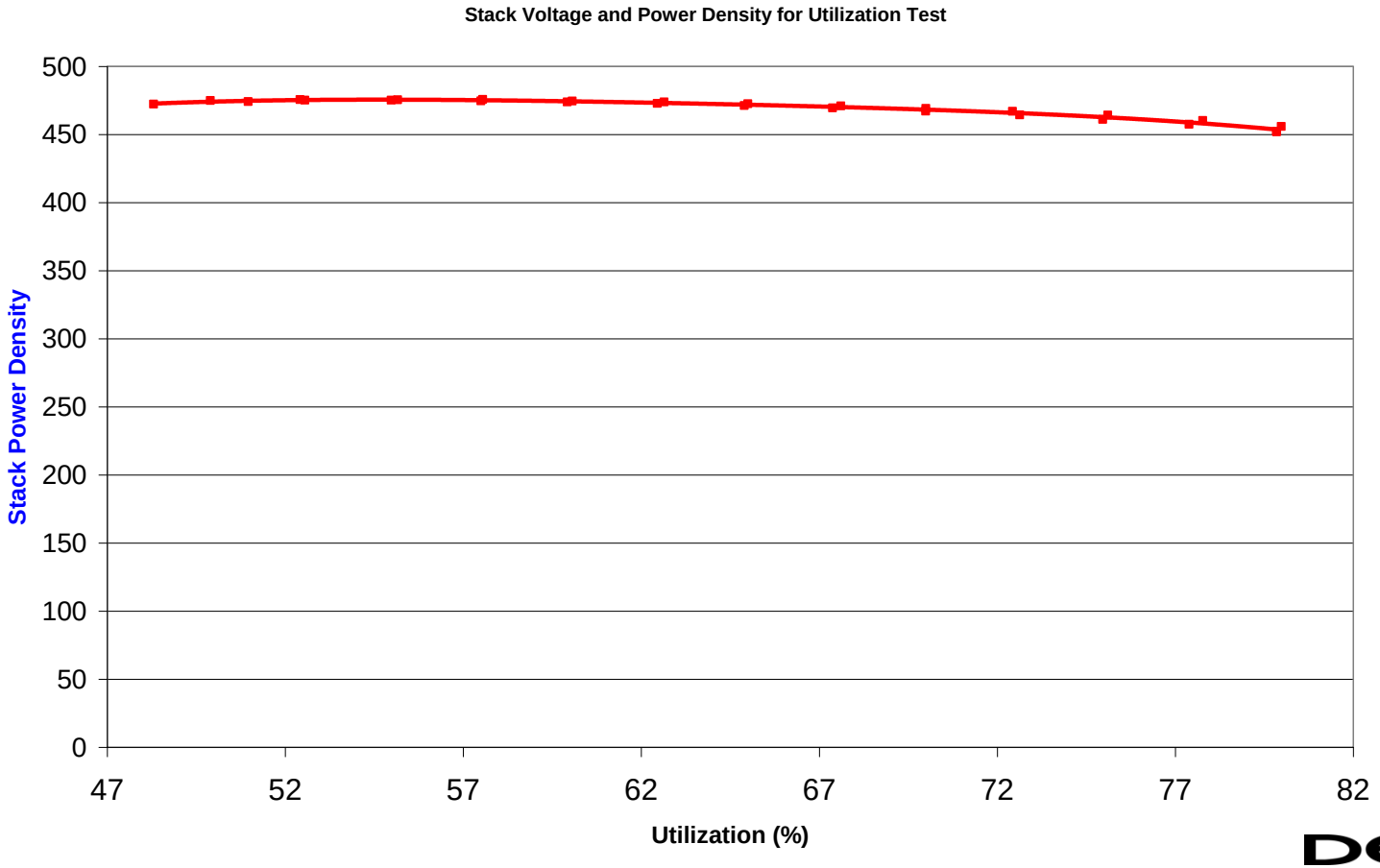
Typical Gen 3 30-Cell Stack Performance

- Power: 1.53 kW (486 mW/cm2) @ 60A (570 mA per cm2), 25.5 V (0.85V / cell avg), fuel 48.5% H2 ,3% H2O, rest N2, 750 – 800^{o}C



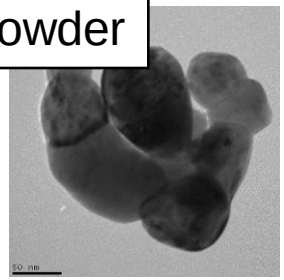
Generation 3 30-Cell Stack

- Minimal lowering of power density (5%) in going from 50% fuel utilization to 80% fuel utilization

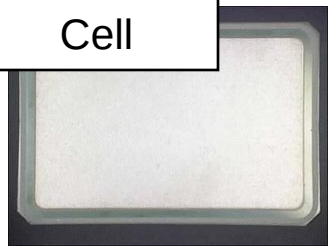


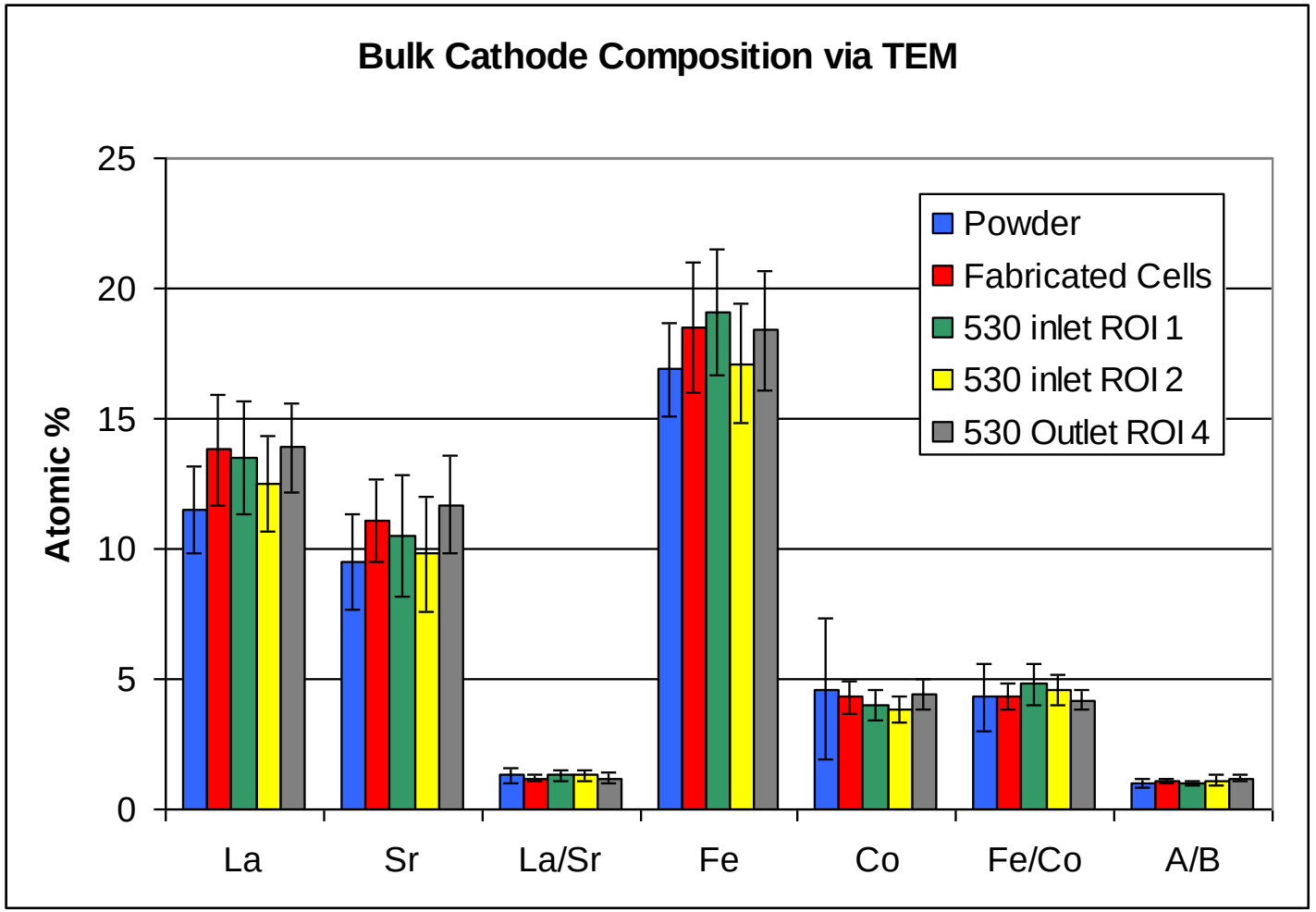
Cathode Stability (at Carnegie Mellon University)

Powder



Fabricated Cell





5-cell stack (#530) tested 3500+ hrs at 0.8 V/cell on 28%H2 – 30%CO – 6%H2O – 2.5 ppmv S

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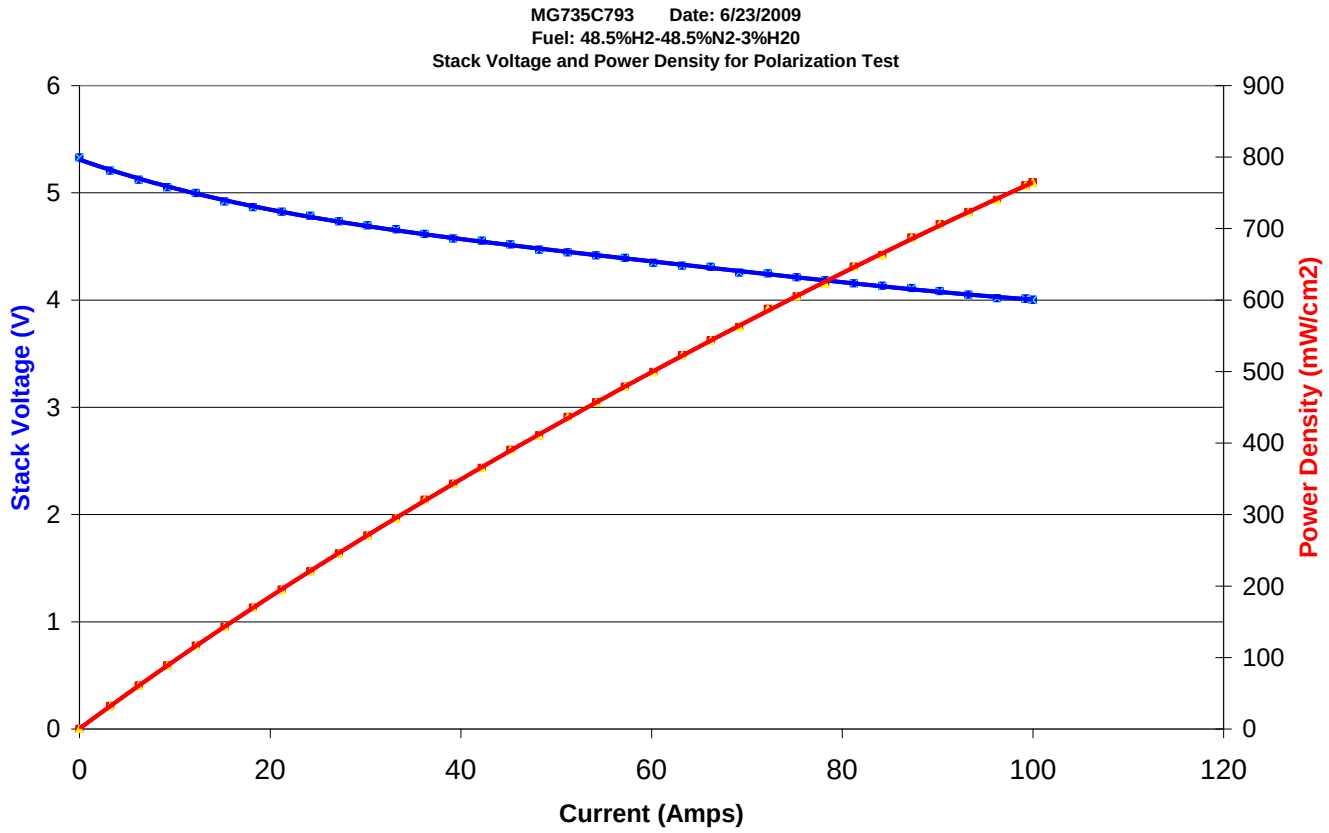
Gen 3 5-Cell Stack – Maximum Power

- Produced 500 mW/cm^2 @ 60A (570 mA per cm^2), 0.87V / cell avg, fuel 48.5% H2 ,3% H2O, rest N2, 750 – 800^{o}C
- Max Power density: 765 mW/cm^2 @ 100 Amps (952 mA per cm^2), 0.80V / cell avg, fuel 48.5% H2, 3% H2O, rest N2, 750 – 825^{o}C



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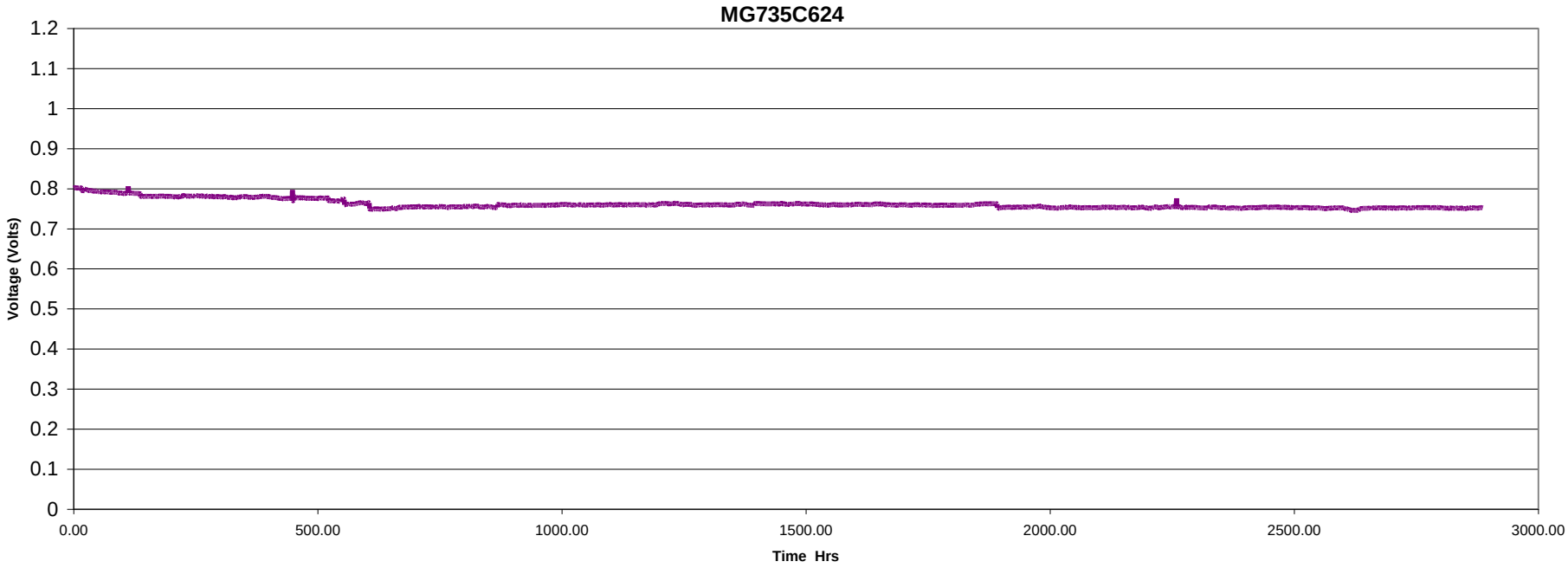
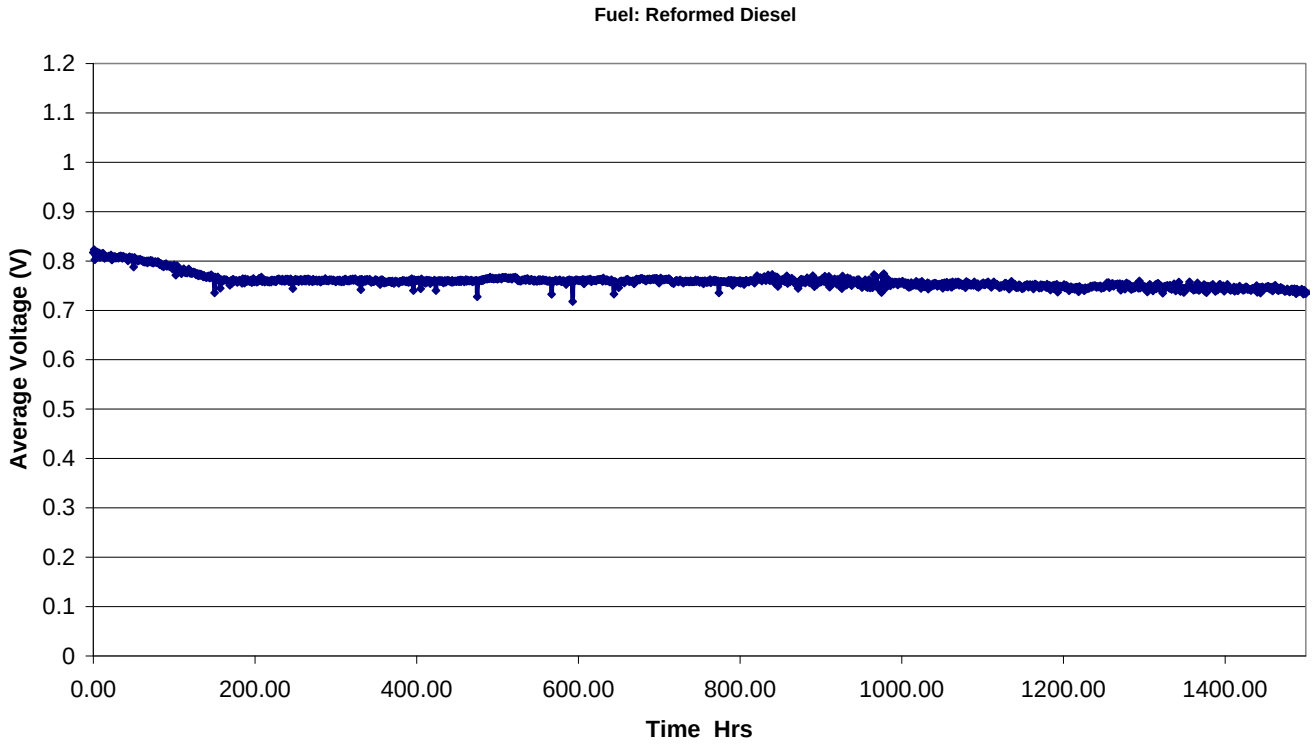
Interconnect Development – Materials & Coatings

- Base material is ferritic stainless steel alloy
- Multiple coatings under evaluation
  - Low cost, conventionally processed coating demonstrated good stability in stack test
  - Graph shows typical repeating unit performance in a stack with coating tested for durability (Fuel = 48.5 % H2, 3% H2O, rest N2, constant current of 570 mA per cm2)
  - Further development is ongoing



Gen 3 Stack Durability with Diesel Reformate

- 10-cell Gen 3 stack on Diesel reformate (24%H_2 – 25% CO – 5% CO_2 – 7% H_2O – Bal N_2) at 35 amps and 750C
- Initial voltage drop observed in the first 200 hours due to sulfur
- Minimal degradation in the last 1300 hours



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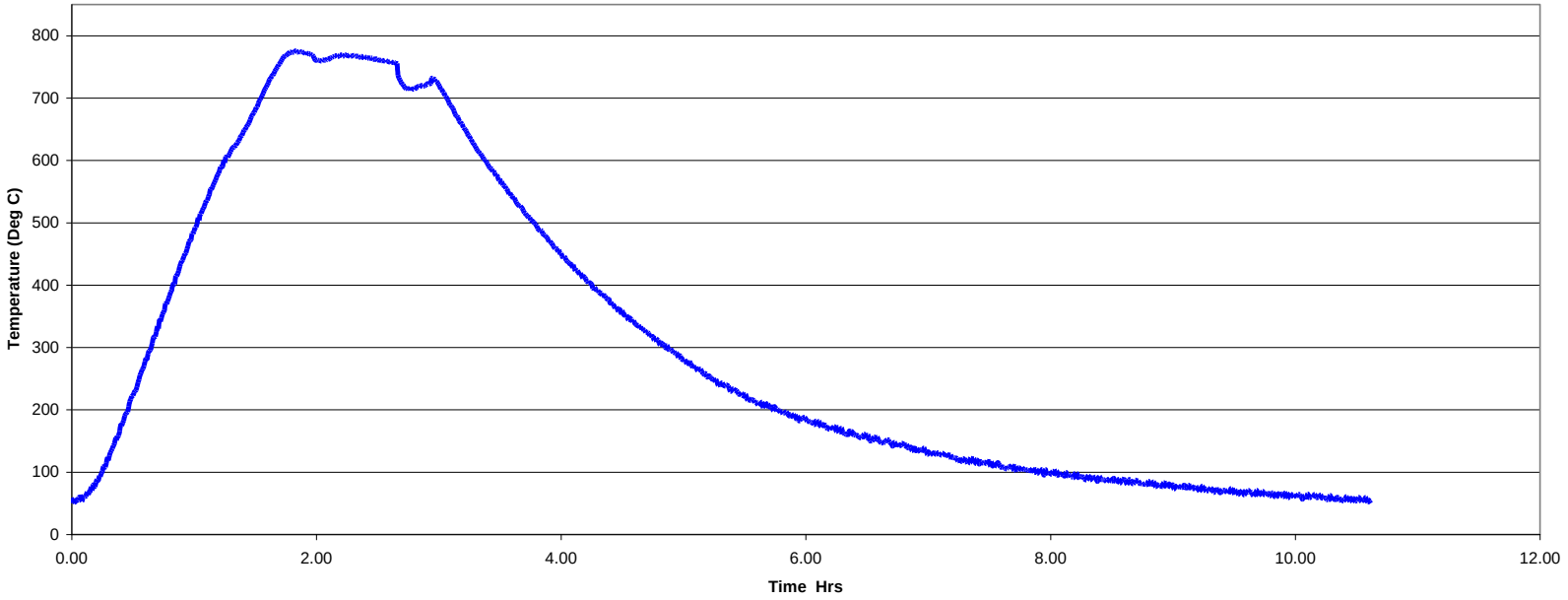
Gen 3 30-Cell Stack - Thermal Cycling

- Gen 3 30-cell stack being thermal cycled
  - 10 hour cycle from 50°C to operating temperature to 50°C
  - Performance evaluated at each thermal cycle
  - Constant current load of 30 Amps at operating temperature
  - Fuel of 48.5% H2, 3% H2O, rest N2



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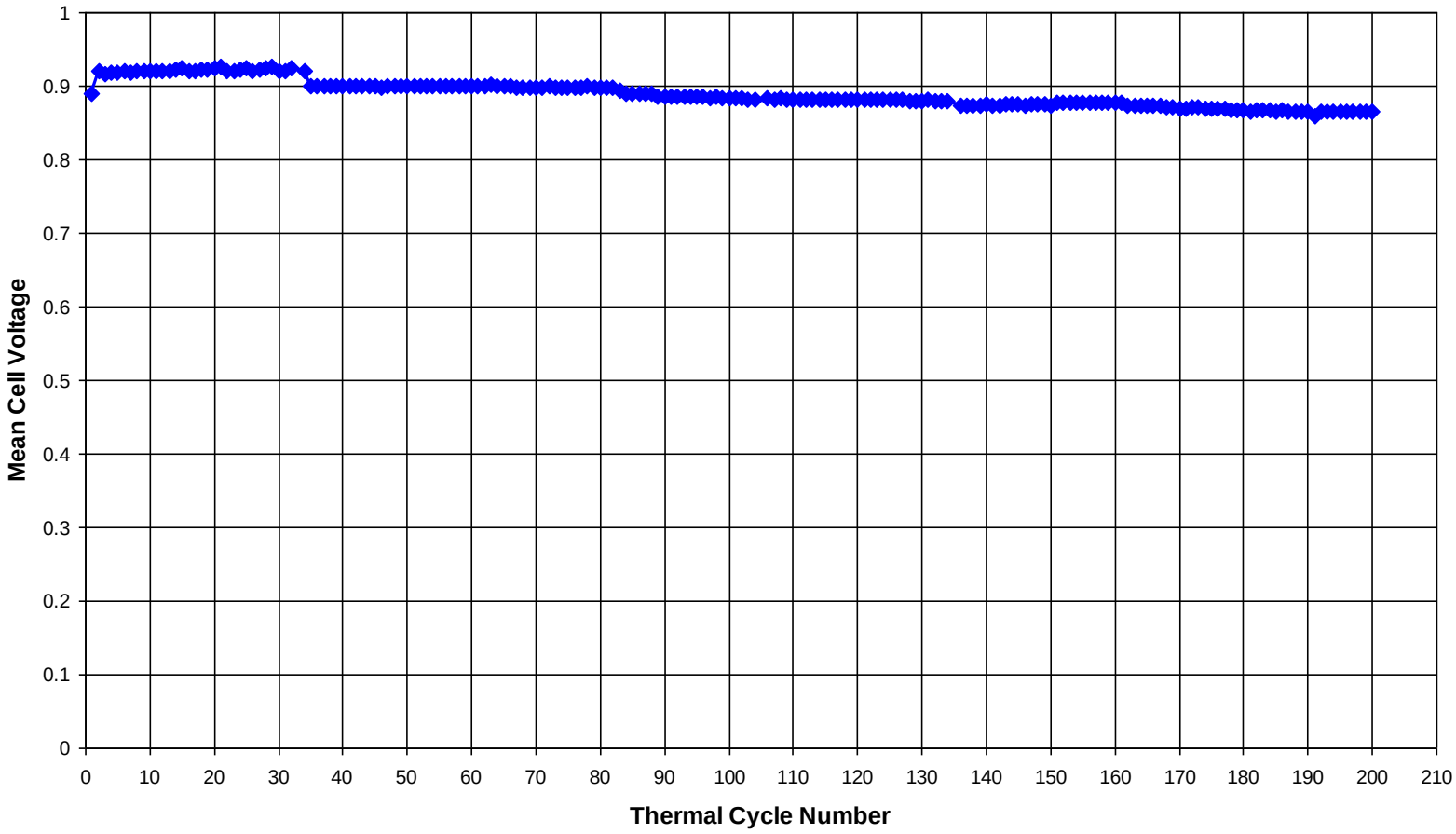
30-Cell Stack Thermal Cycling Results



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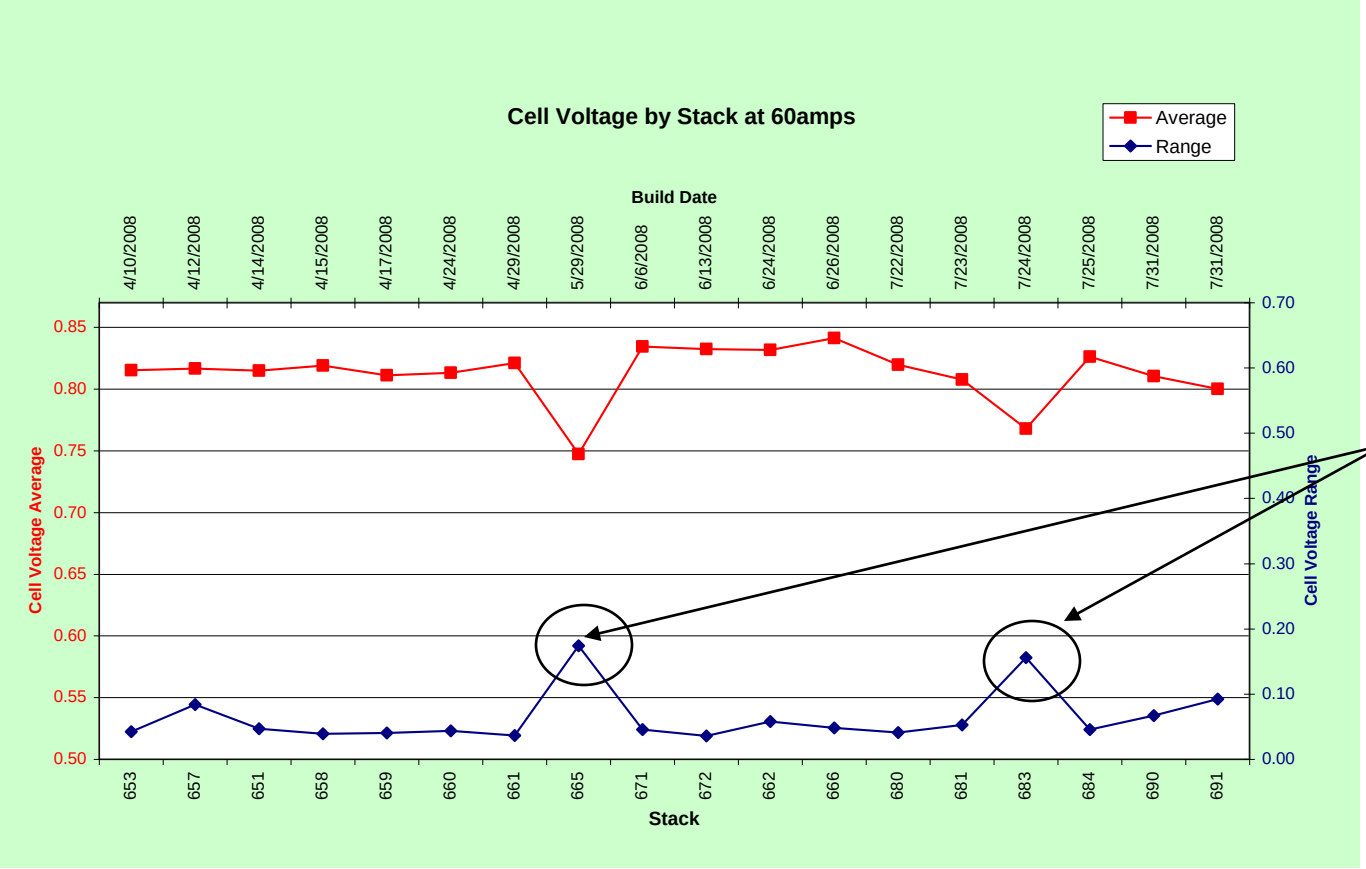
Red X® Problem Solving Tools For Stack Issues

- Problem solving tools like Red X® are being utilized in stack manufacturing
- Lessons learned are being implemented for Gen 4 stack design and manufacturing
- Example: Find & eliminate the Red X® driving high cell voltage range



Did not meet voltage range specs

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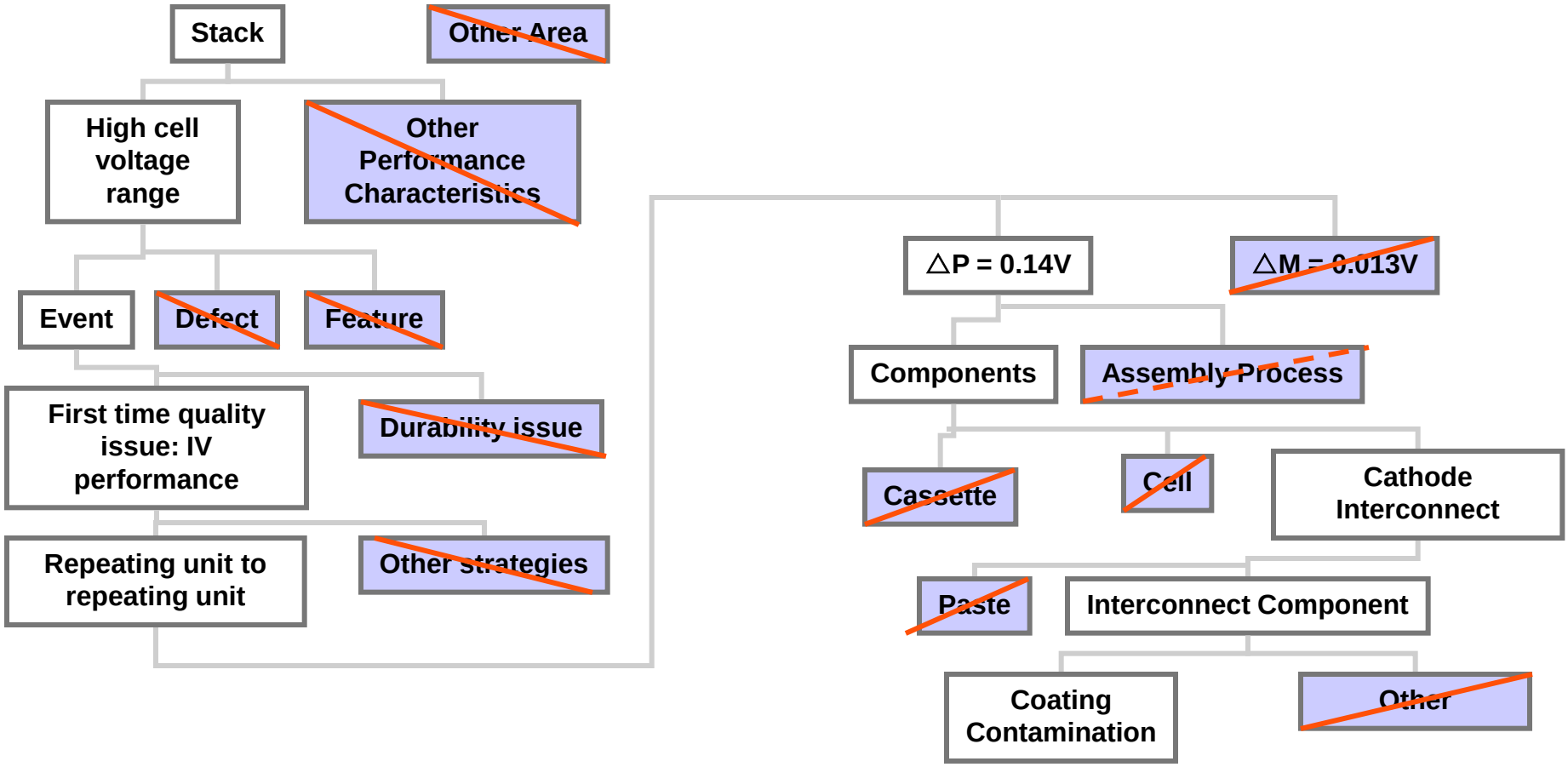
Red X® Problem Definition Tree™



- Red X® was identified as contamination in the interconnect coating from a specific supplier

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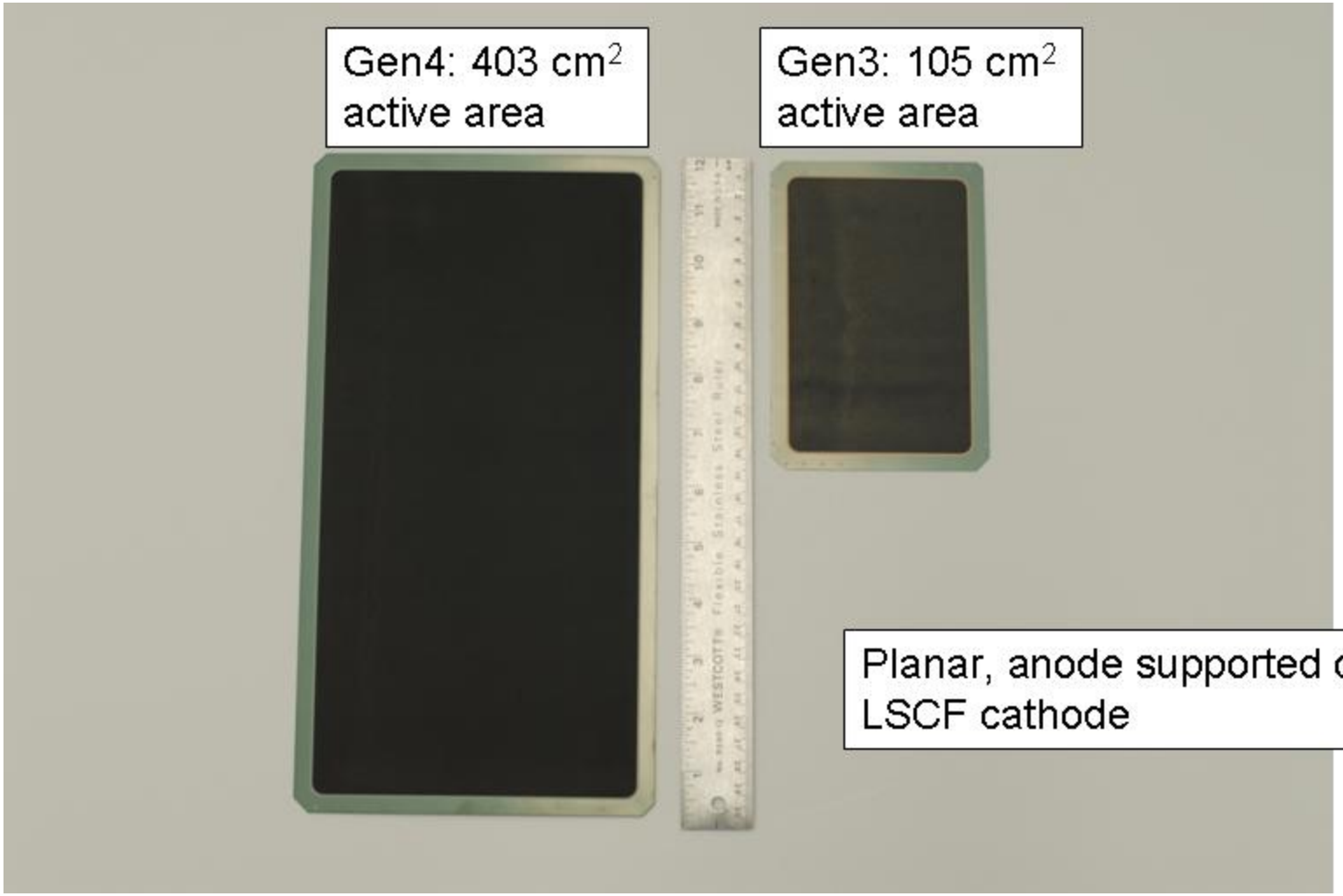
Gen 4 Cell Development for Coal Based Systems



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Gen 4 Stack Design for Coal Based Systems

- Delphi is developing its Generation 4 stack as the module for meeting stationary and transportation application requirements
- Key stack features are:
  - Laser welded cassette repeating unit configuration
  - Stamped metallic cassette components
  - Stamped interconnects
  - Low cost coatings
  - Low cost, conventionally processed balance of stack components

Gen 3 stack

About 4x active area of Gen3
Lower cost interconnects/coatings than Gen3
High volume production processes
5 kW core building blocks

Gen 4 stack

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Gen 4 Stack Development Status

- Gen 4 stack design is complete
- Process development and optimization ongoing to fabricate cells, cassettes, and stacks
- First 5-cell stack fabricated and tested

Laser welding of SOFC parts

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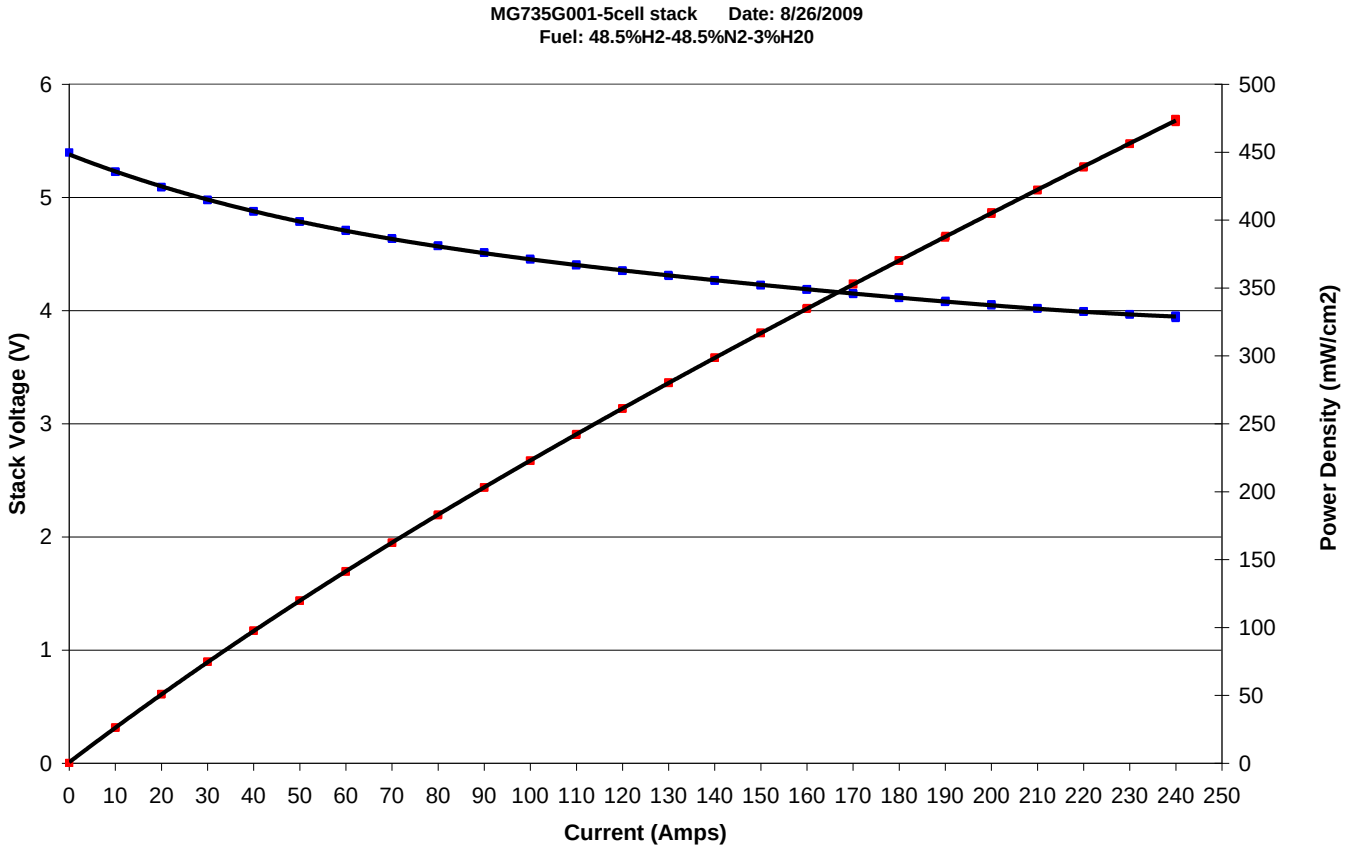
Gen 4 Stack Performance : 5-cell stack

- Achieved power density of 474 mW/cm^2 @ 240A (590 mA per cm^2), 0.80V / cell average, fuel 48.5% H_2 ,3% H_2O, rest N_2, 700 – 800^{o}C



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System Development

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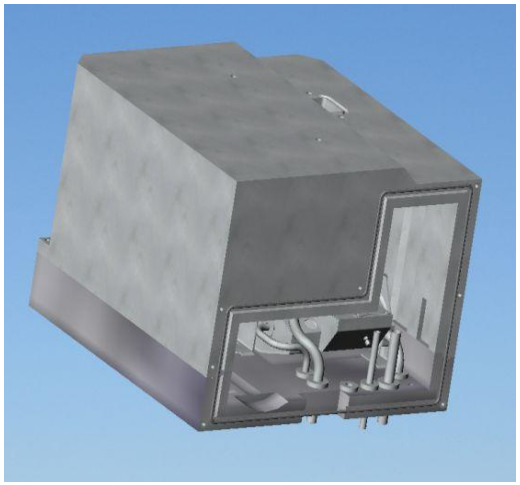
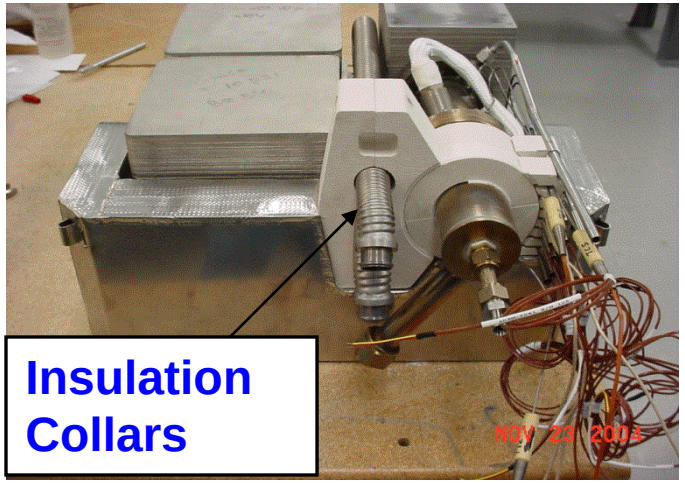
Balance of Plant Components: High Temperature Insulation

Old

New





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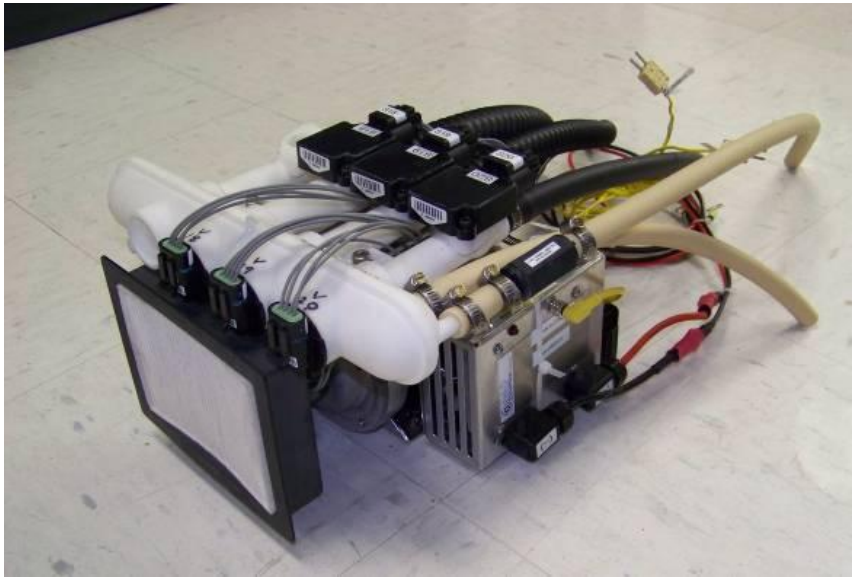
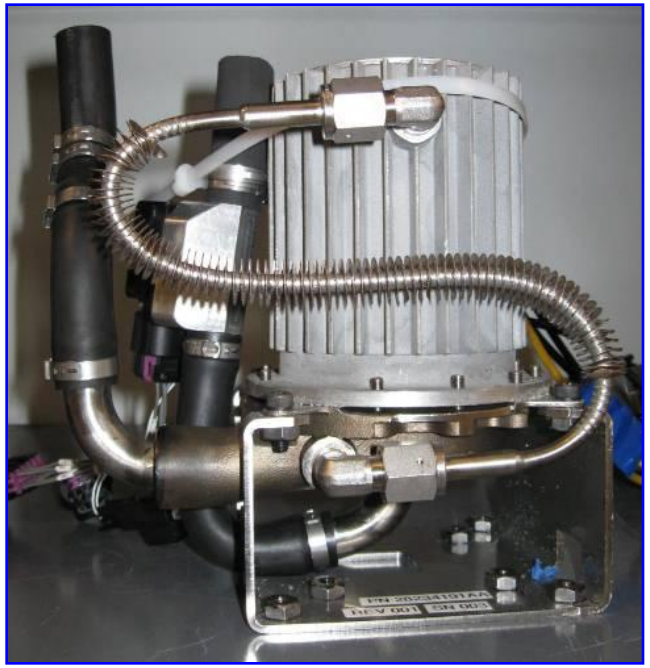
Balance of Plant Components



Process Air Delivery System



Anode Tailgas Recycle Pump

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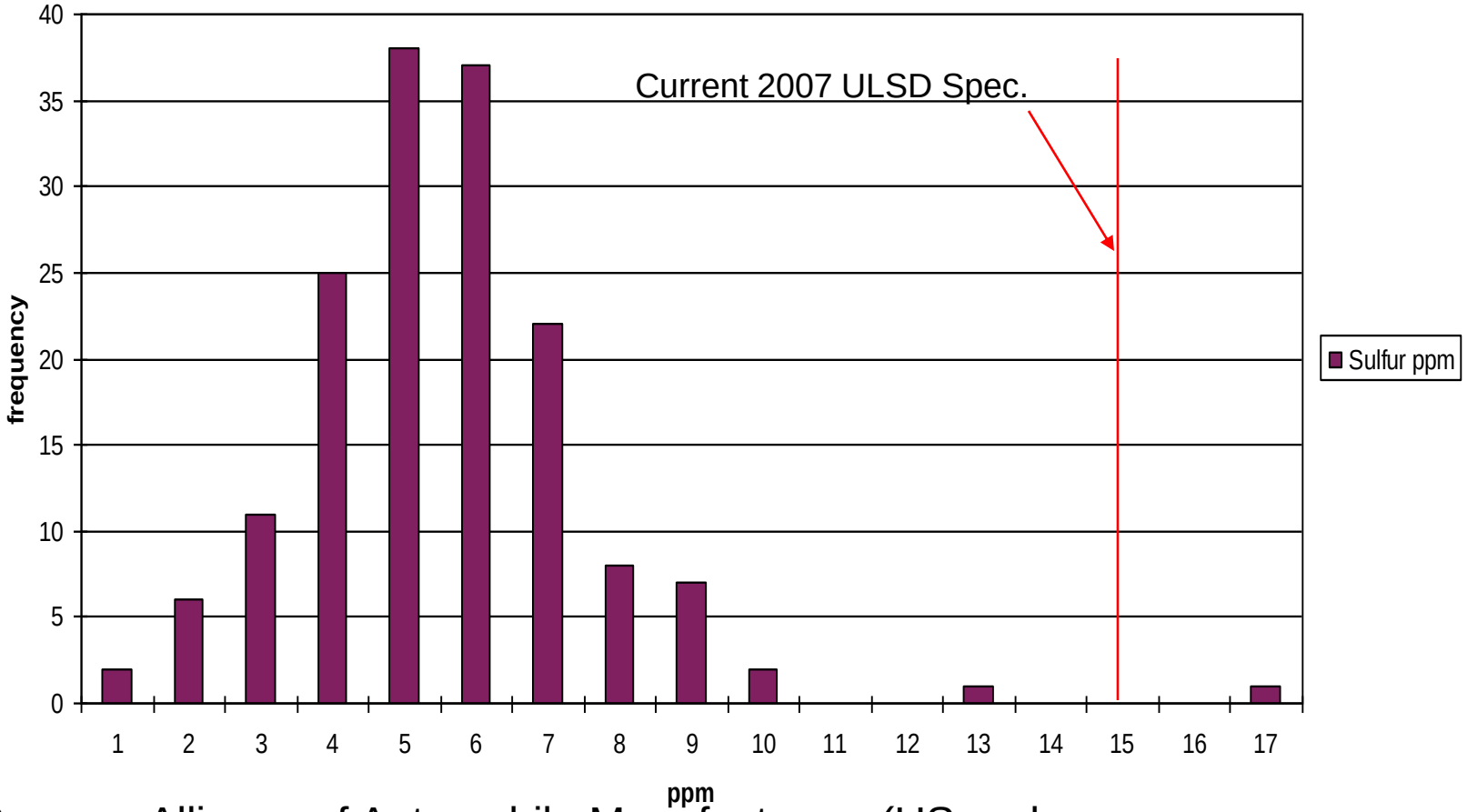
Diesel Fuel Survey Results
Summer 2007 – Sulfur Levels



Source: Alliance of Automobile Manufacturers (US and Canada, 160 samples)

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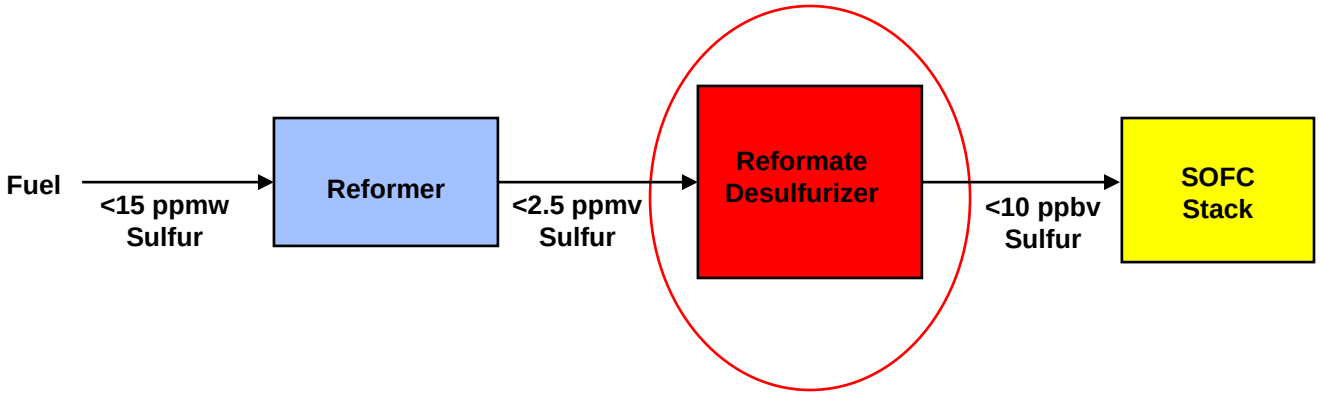
Delphi Solid Oxide Fuel Cells
Hot Reformate De-Sulfurization

- Hot Reformate De-Sulfurization Development
  - Remove H_2S to levels below 10 ppbv (parts per billion volume) from an input of 2.5 ppmv (parts per million volume)
    - » Sulfur acts as a poison to SOFC
  - Maximize operation time between sorbent exchanges
  - Minimize device volume and operation pressure drop



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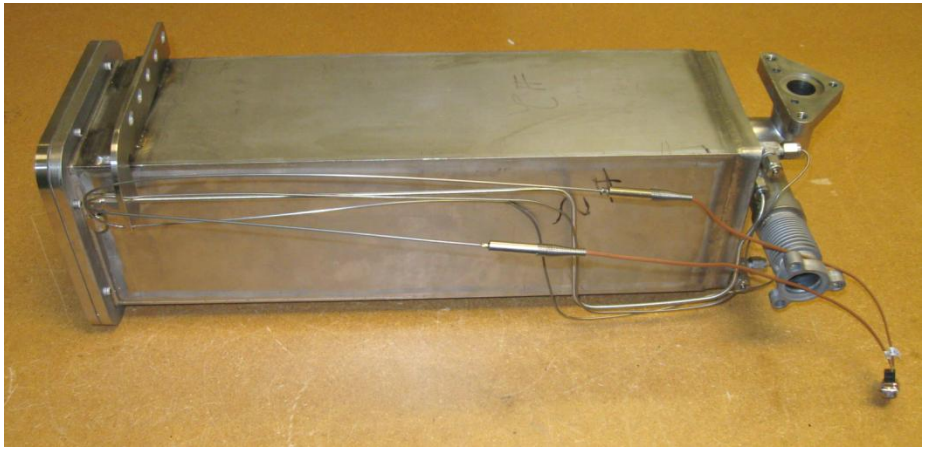
Delphi Solid Oxide Fuel Cells
Hot Reformate De-Sulfurization

- A non-regenerating sorbent has been selected that:
  - Meets maximum 10 ppbv output
  - Meets operating temperature requirements
  - Capacity is such that a bed operates for at least 6 months prior to requiring bed exchange for the 95th percentile driver
  - System pressure drop requirements were met at full system reformate flow



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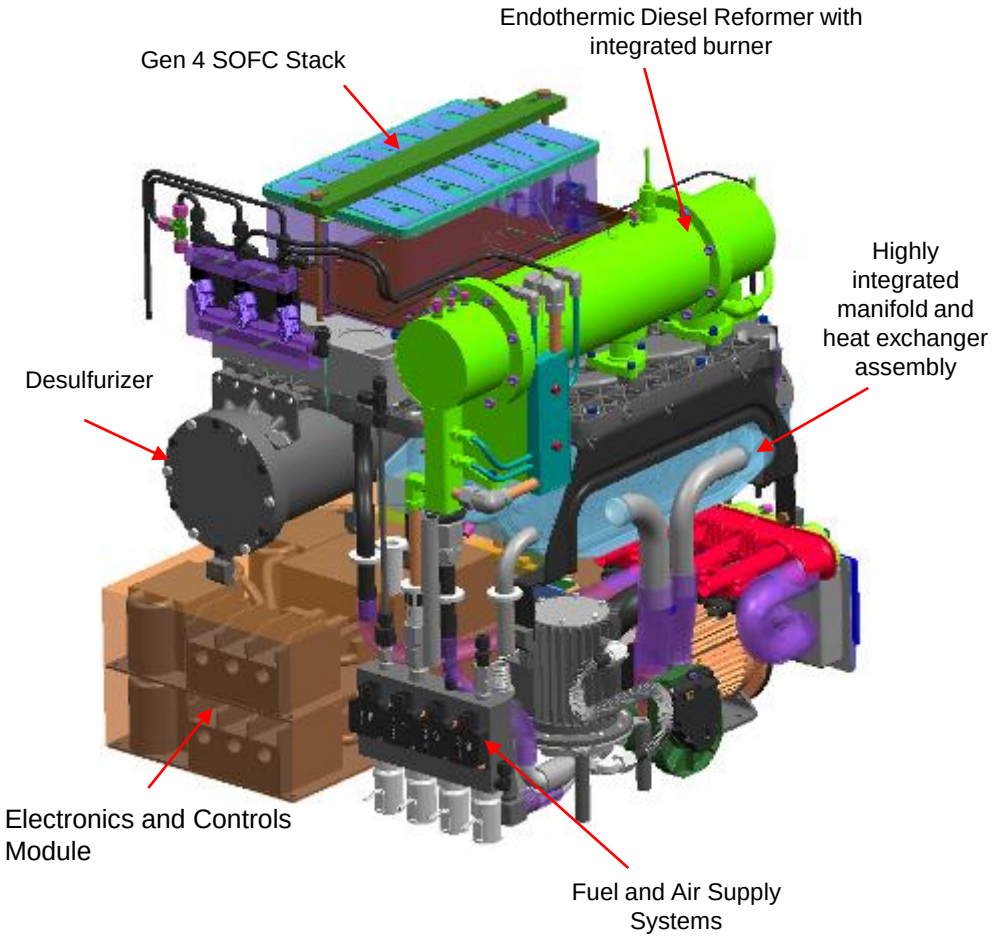
Delphi Solid Oxide Fuel Cell
Design of New Diesel APU Platform

DPS 3000D

3 kW net output power



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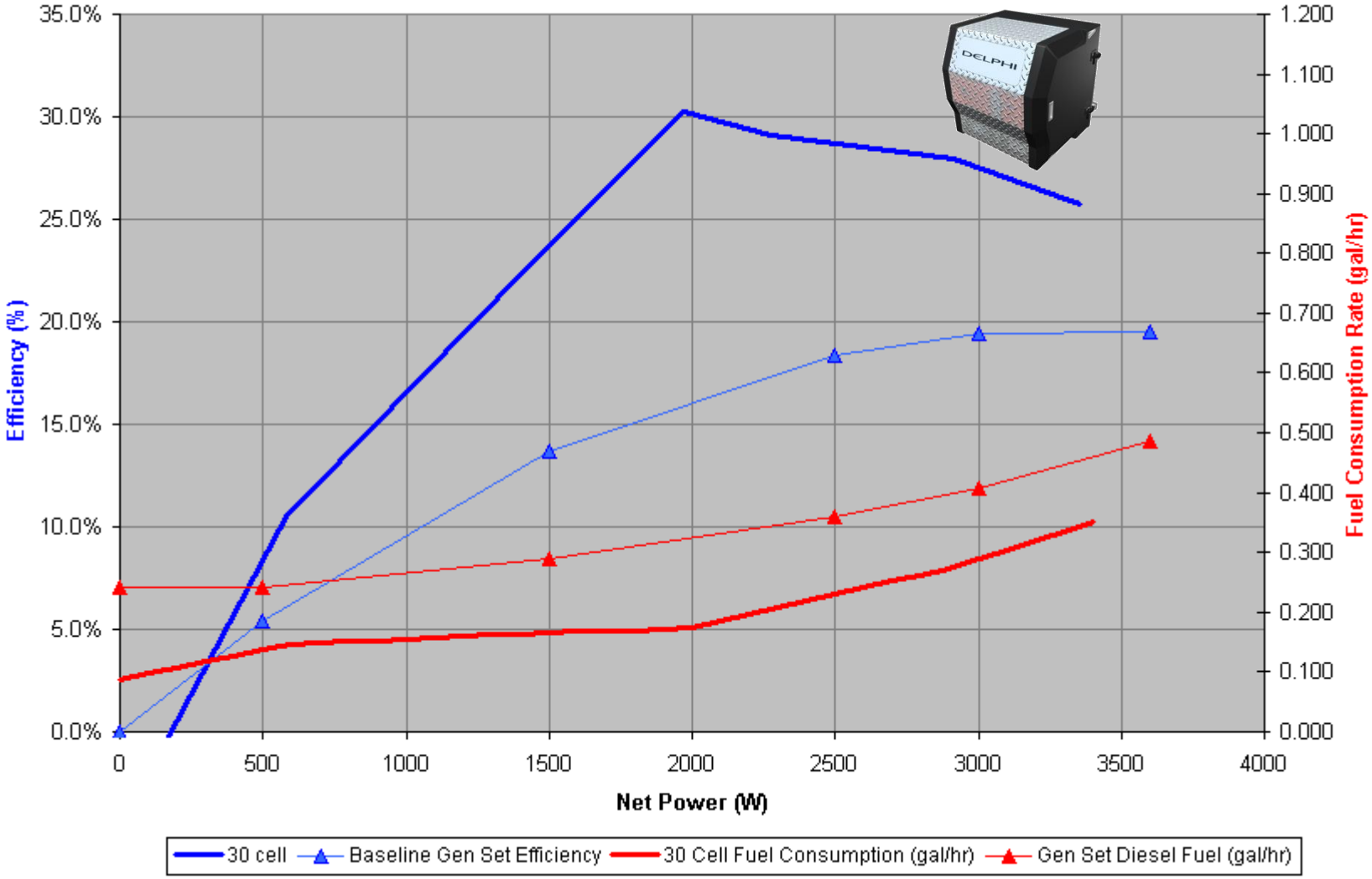
Projected Performance Comparison



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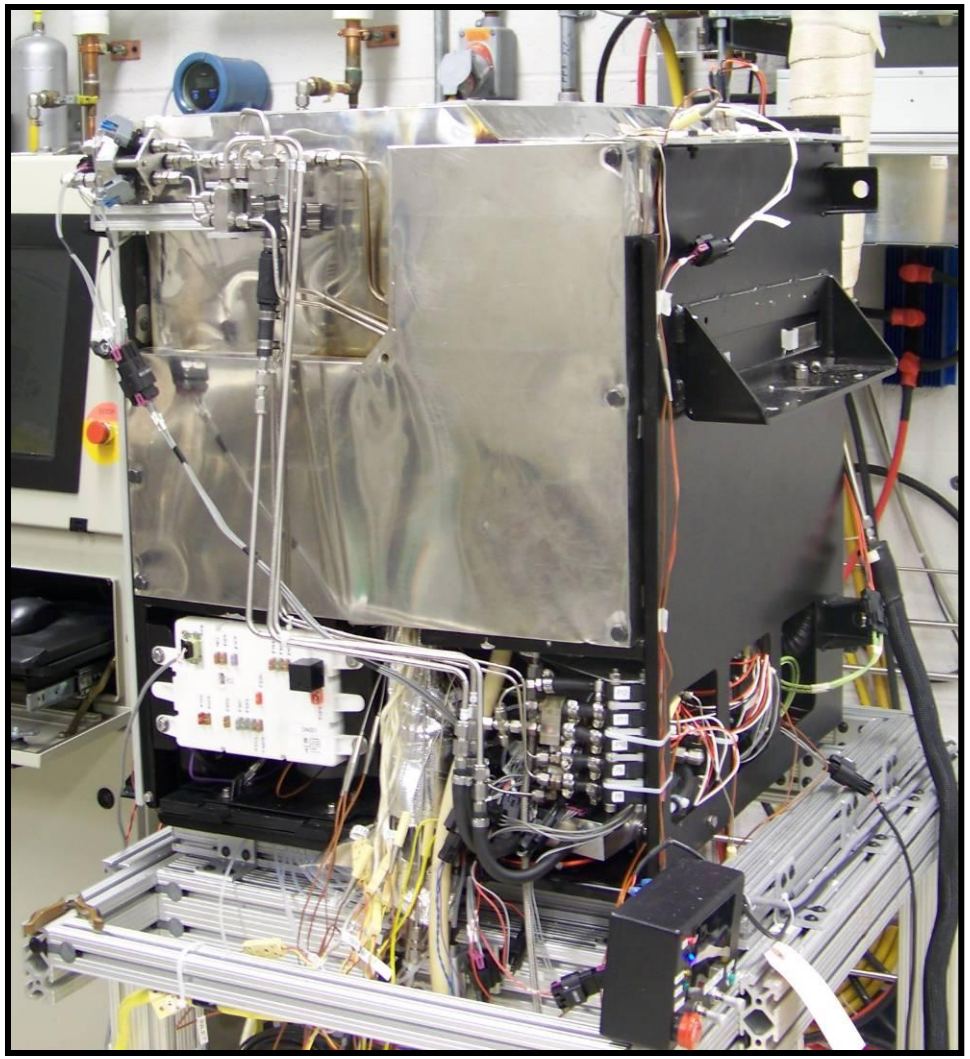
DPS3000 D Initial Builds

- First design engineered specifically as a truck APU
- Internal desulfurizer for ULSD
- ULSD cold-start capable



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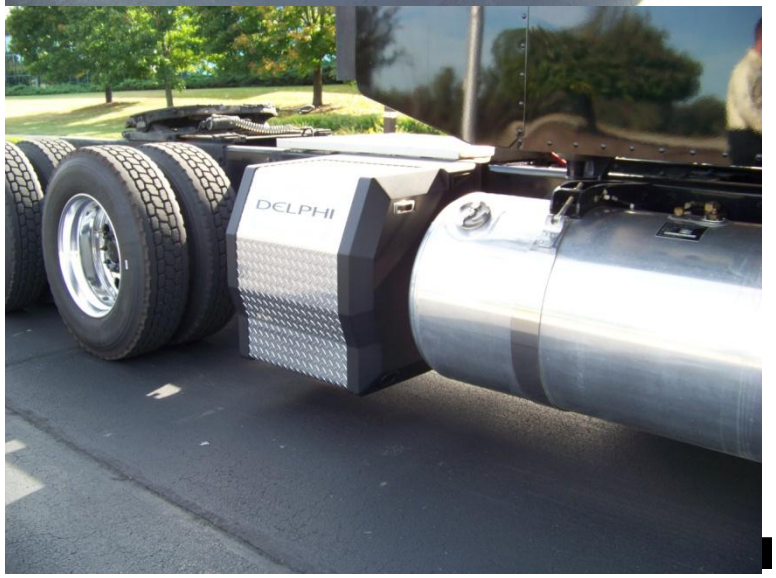
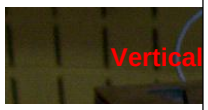
Peterbilt Development Truck

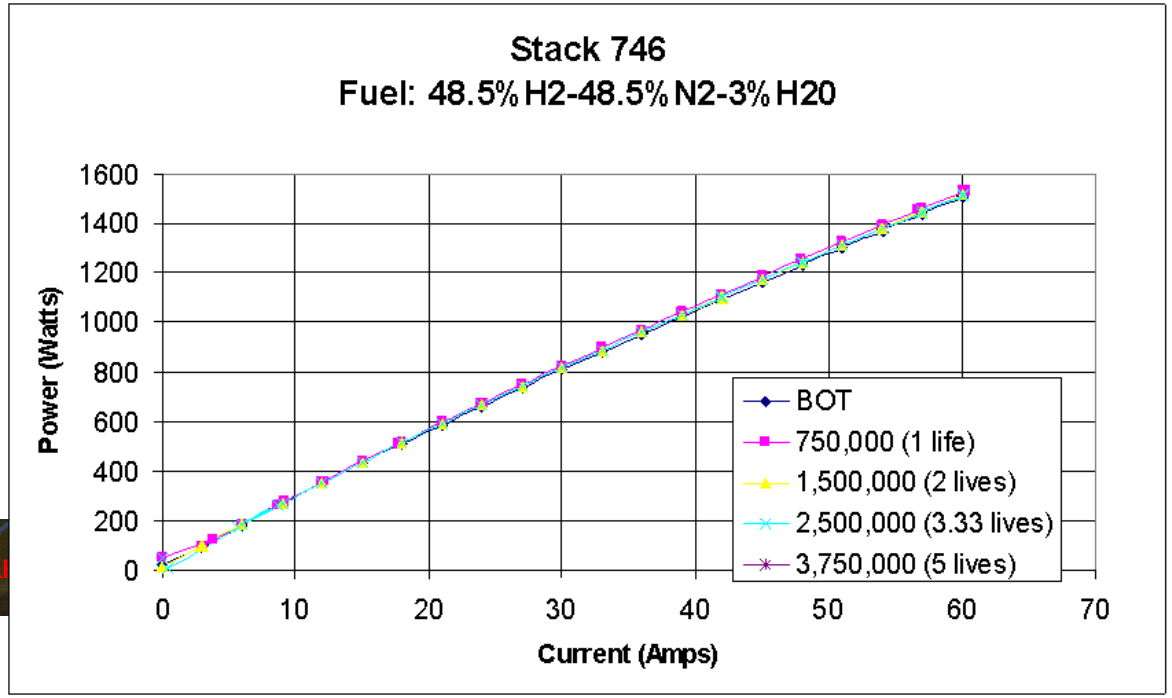
- Model 386 Peterbilt vehicle received at TCR on 8/28/09
- Vehicle provided to Delphi as part of DOE EERE Truck APU Demo project
- Vehicle prepped for SOFC APU
  - Fuel and electrical interface
  - Mounting Hardware for APU enclosure
  - AC inverter
  - Refrigerator



Delphi Solid Oxide Fuel Cell
Gen 3 30-Cell Stack Vibration Testing

- Test to Failure using Step Over Stress strategy to assess stack reliability
  - Mil Std 810G Method 514.6 Annex C, “Truck and Transportation Over US Highways”
  - Ambient temperature random vibration in 3 distinct axes
  - Performance evaluated after each axis of testing
- Successfully completed 3.75 million miles equiv. of vibration





Systems Vibration Testing

- DPS 3000D SOFC System on shaker table

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Delphi SOFC APU Recent Accomplishments

- Delphi/Peterbilt Awarded DOE Program for a 1 year vehicle demonstration
- Stack durability testing
  - 200 Thermal Cycles
  - Completed 5 lives accelerated vibration testing
- Engineered and Built First Truck APU
  - Designed to operate on Diesel
  - Integrated Desulfurizer operational
- First APU installed on Peterbilt Truck
  - Operational by December 2009

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Acknowledgements

SECA

NETL

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Battelle

Pacific Northwest National Laboratory
...delivering breakthrough science and technology

UTC Power
A United Technologies Company

PACCAR

UNITED STATES ARMY
TARDEC
TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

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