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Solid Oxide Fuel Cell Development for Transportation and Stationary Applications: Overview & Status Update

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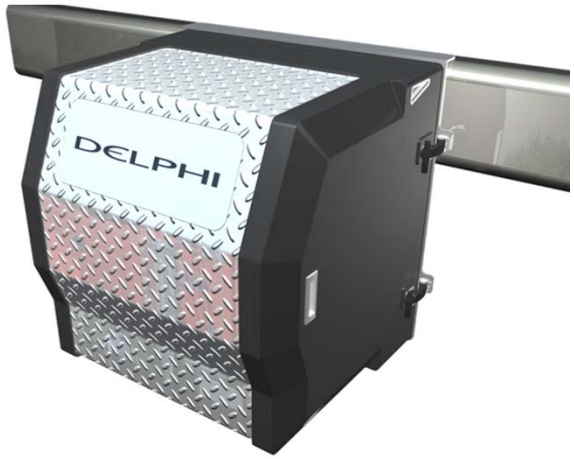

Topics

- SOFC 101
- Technology Evolution
- A Level System
  - Design Overview
  - Accomplishments
- B Level System
  - Design Overview
  - Gen 4 Stack
- Recent Accomplishments
- Acknowledgements

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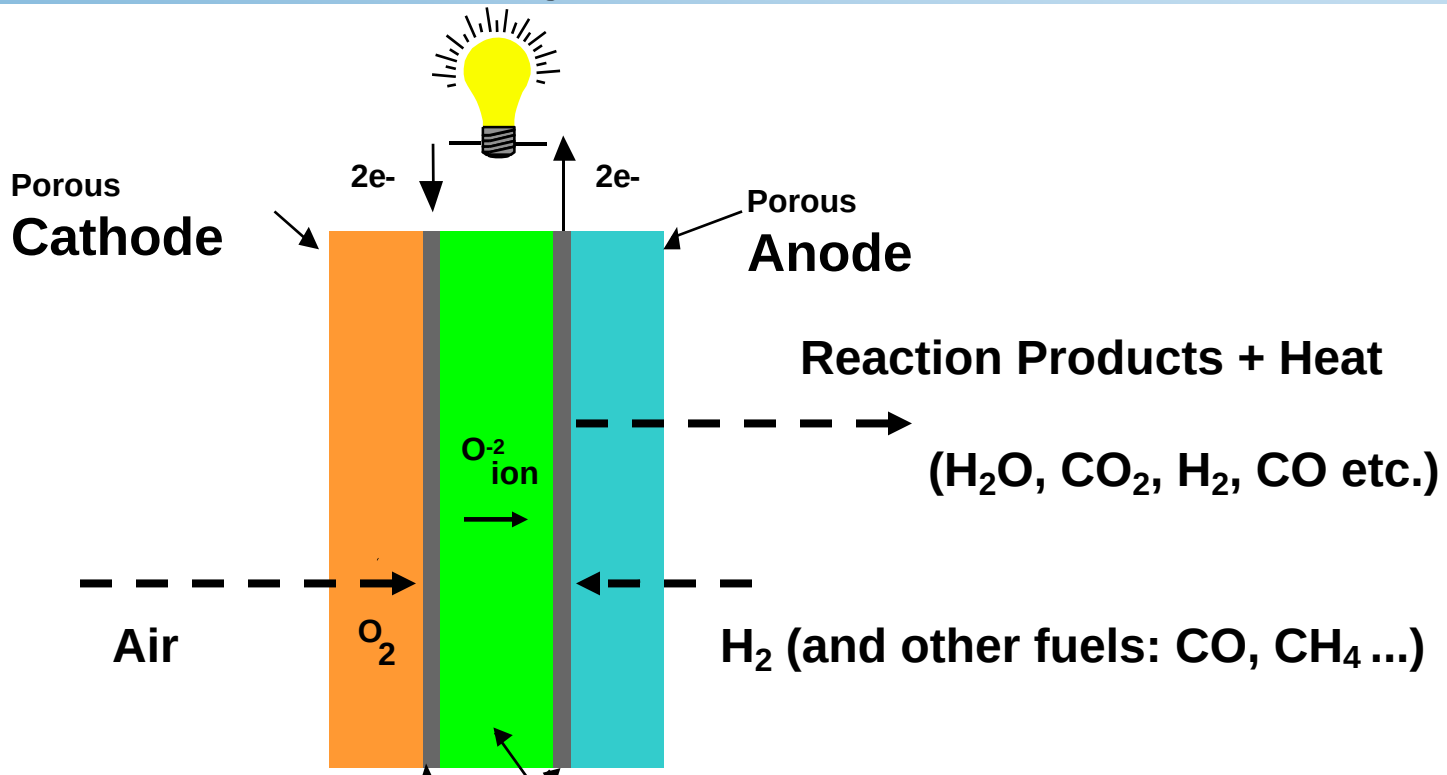
Solid Oxide Fuel Cell Physics



SOFC = High temperature (700 to 1000 C) solid state fuel cell with ceramic, oxygen ion conducting electrolyte

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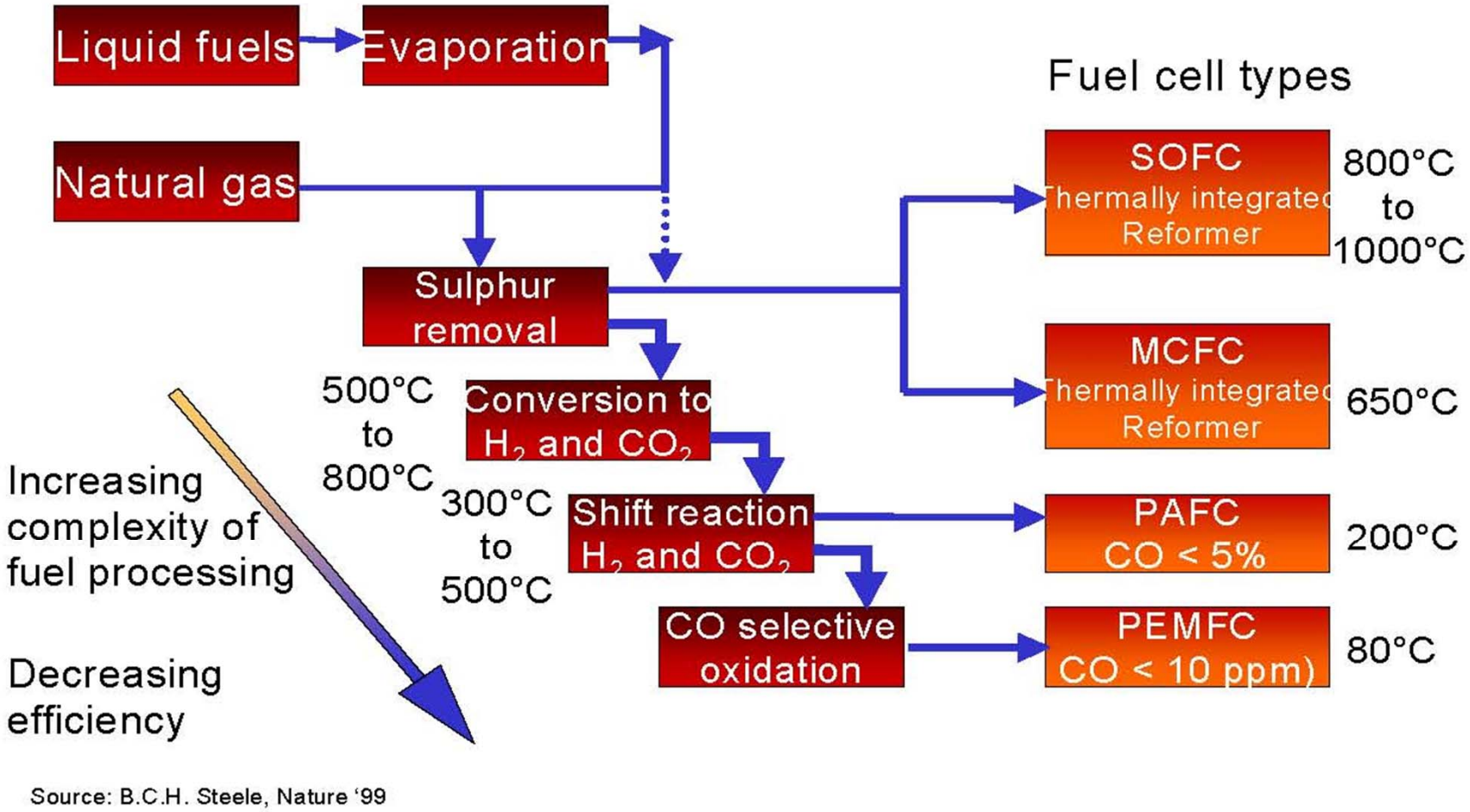
Required Reforming and Cleaning Steps For Different Fuel Cell Types



Source: B.C.H. Steele, Nature '99

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Market Opportunities

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

Residential Power

Stationary CHP Power Units

Commercial Power

Stationary Power Units

Heavy Duty Trucks

Auxiliary Power Units

Recreational Vehicles

Auxiliary Power Units

Military

Auxiliary & Mobile Power Units

Clean Coal Power Plant

Advanced Power Systems

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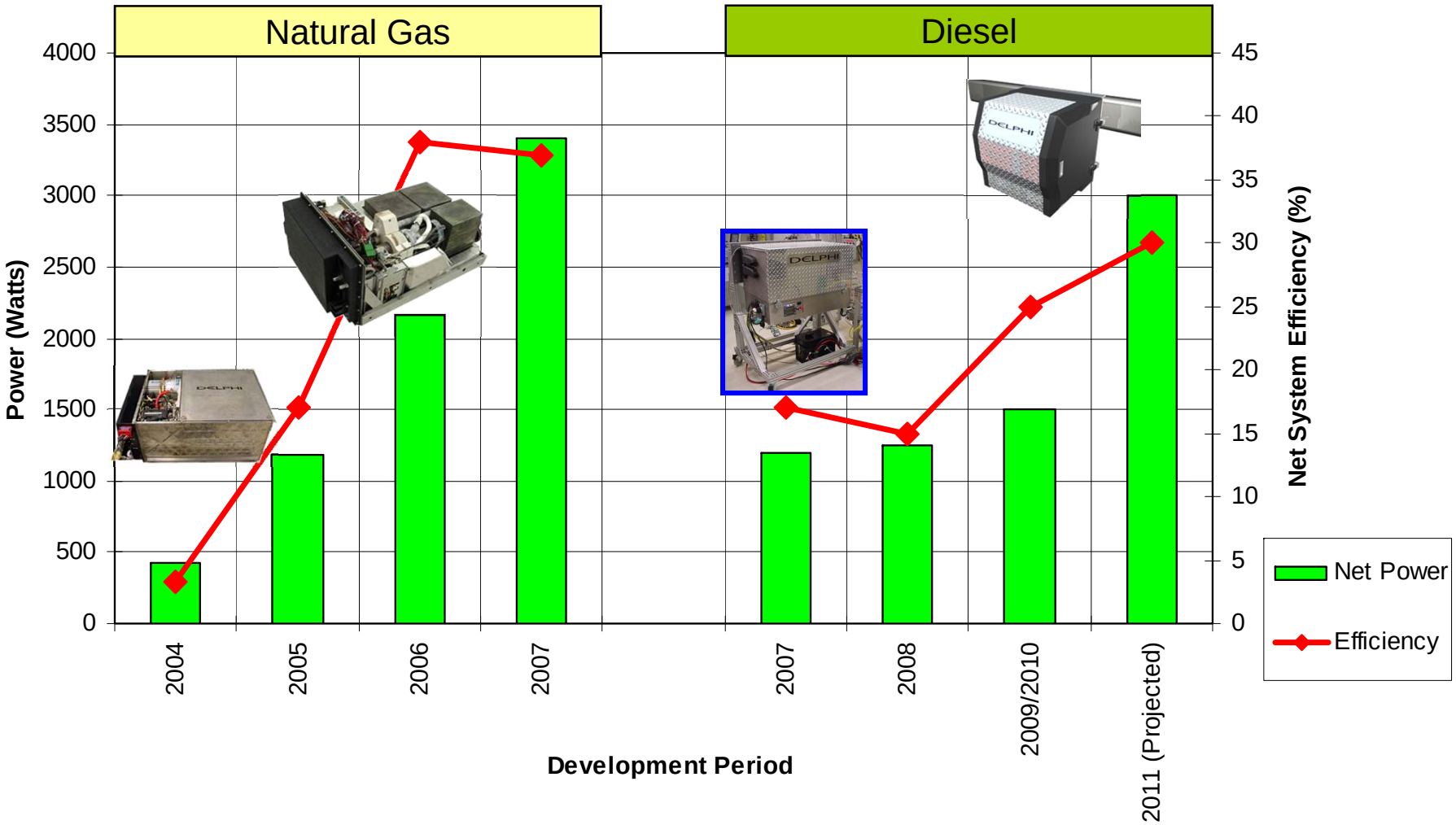
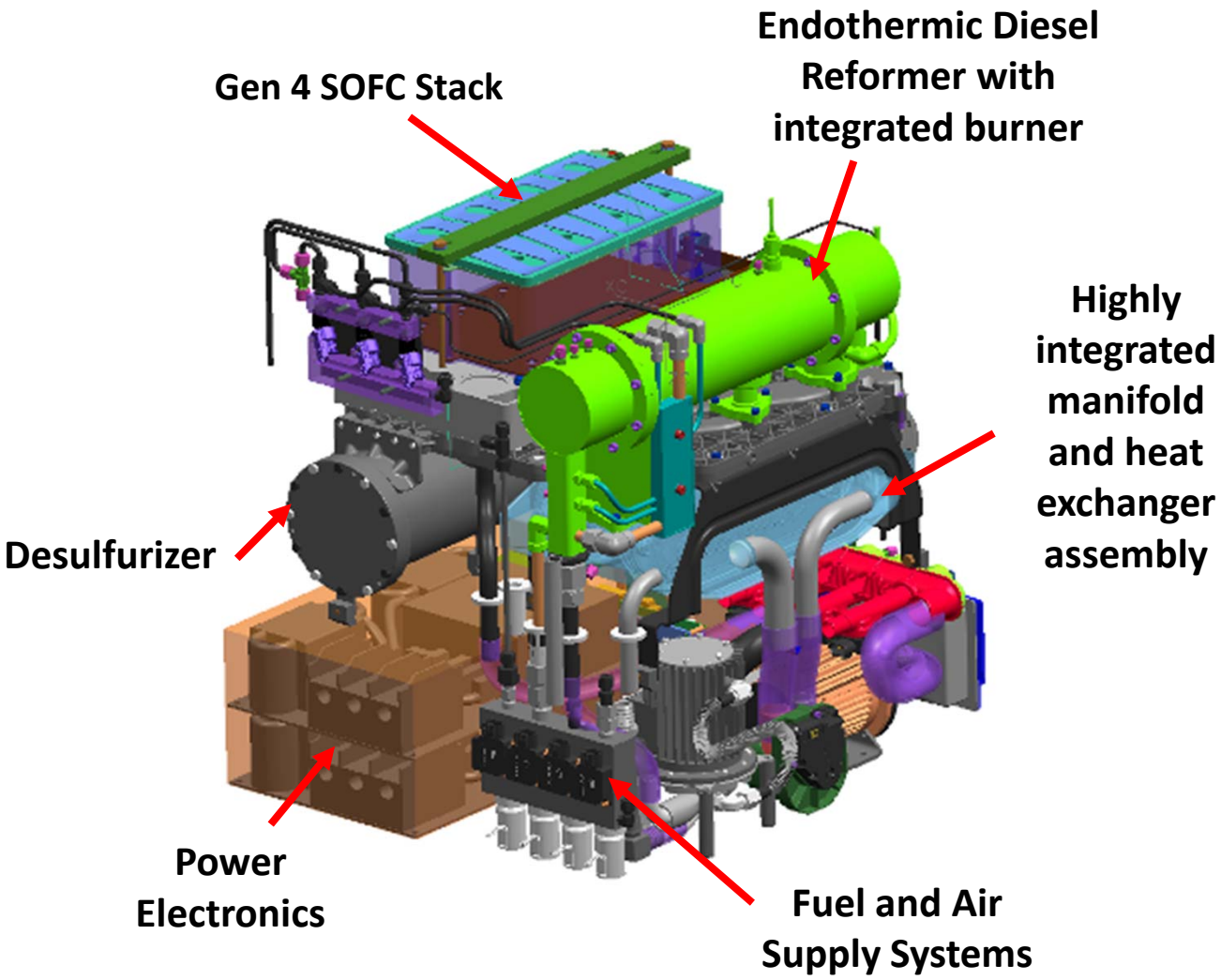
Delphi Solid Oxide Fuel Cells
System Power & Efficiency Progress



Level A Hardware Overview



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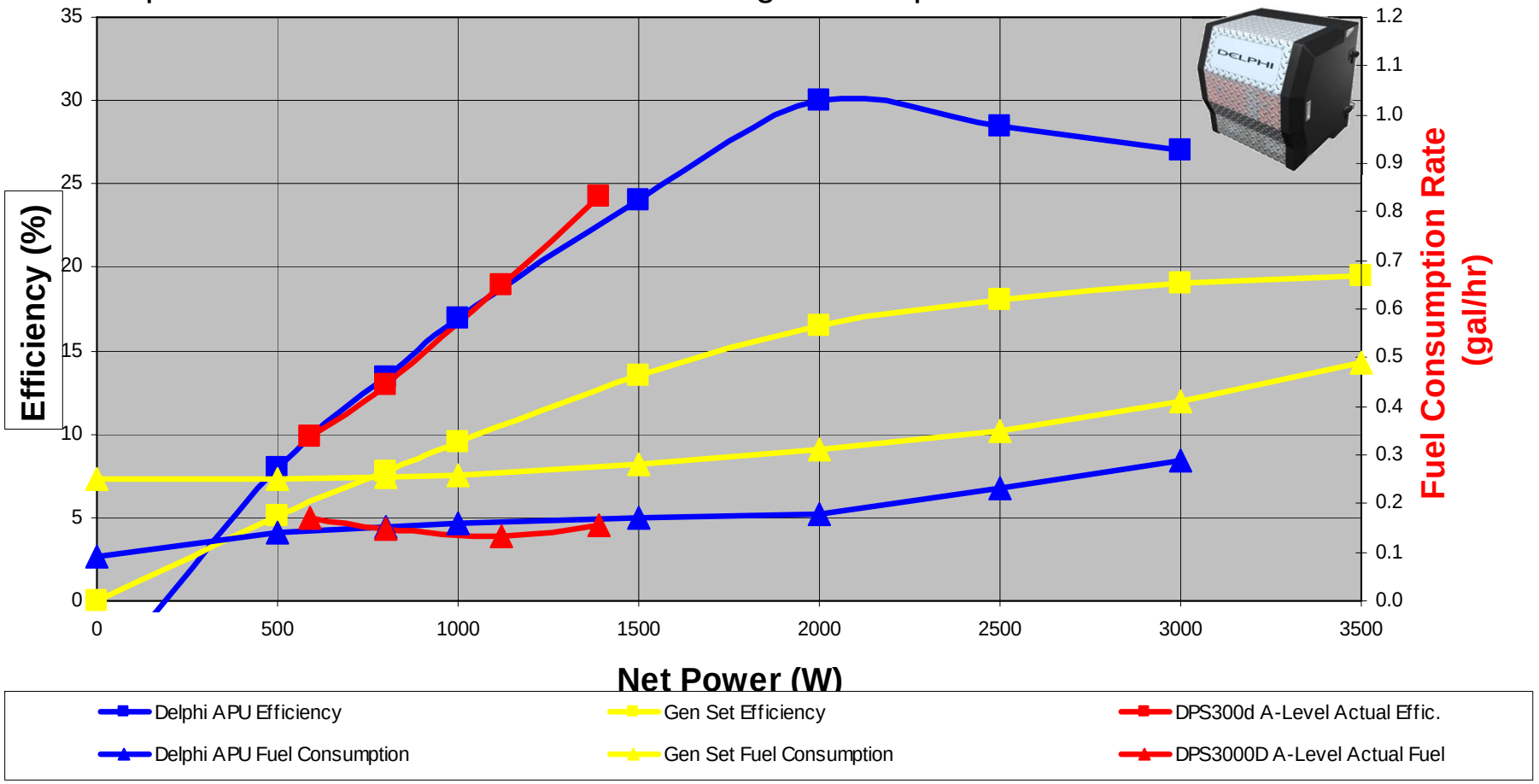
Delphi Solid Oxide Fuel Cell Performance Comparison – Actual vs Predicted

- Delphi's SOFC APU has higher efficiency and lower fuel usage compared to a diesel engine gen set
- Delphi's A-level hardware actual results agree with predicted values for B-level hardware



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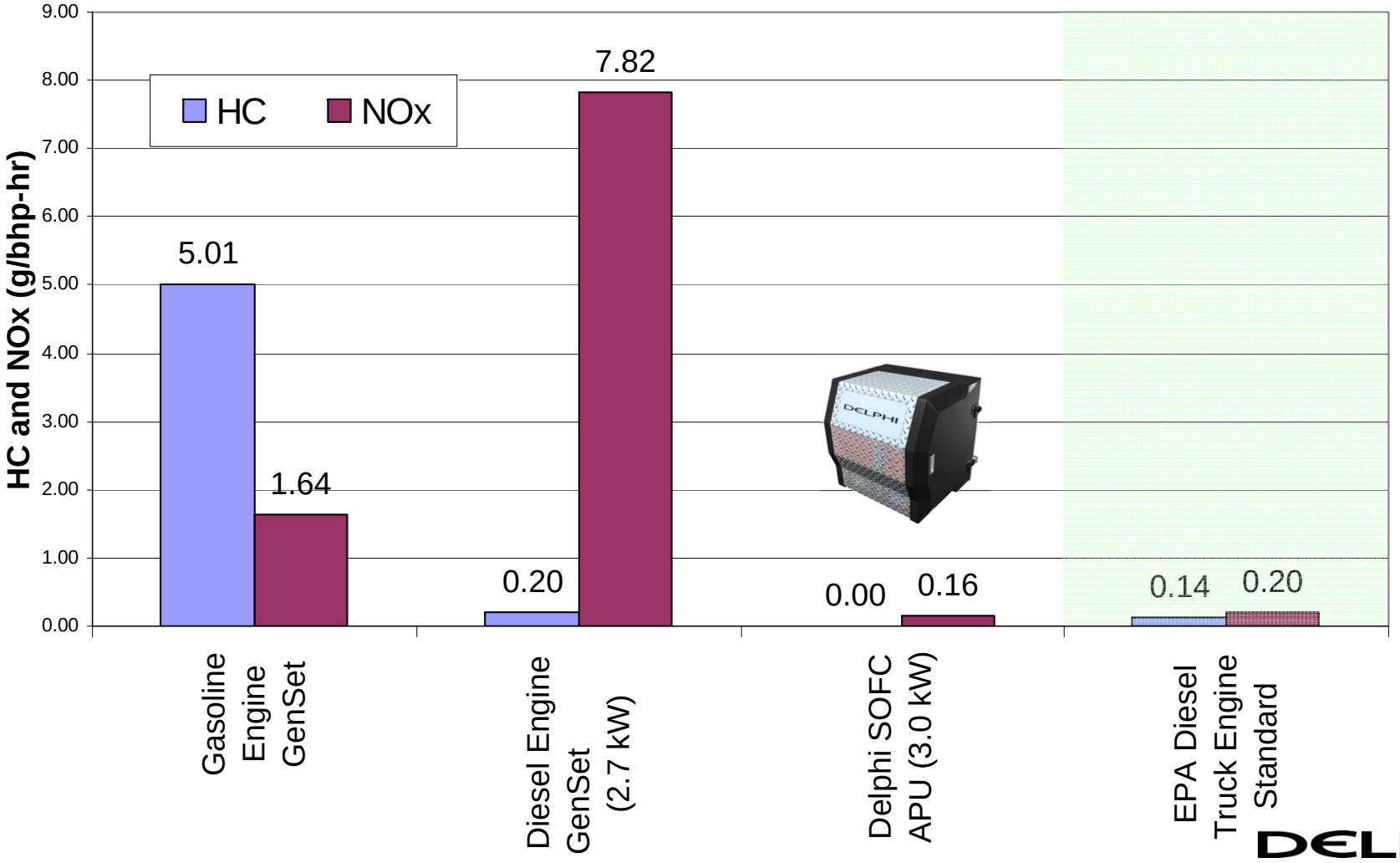
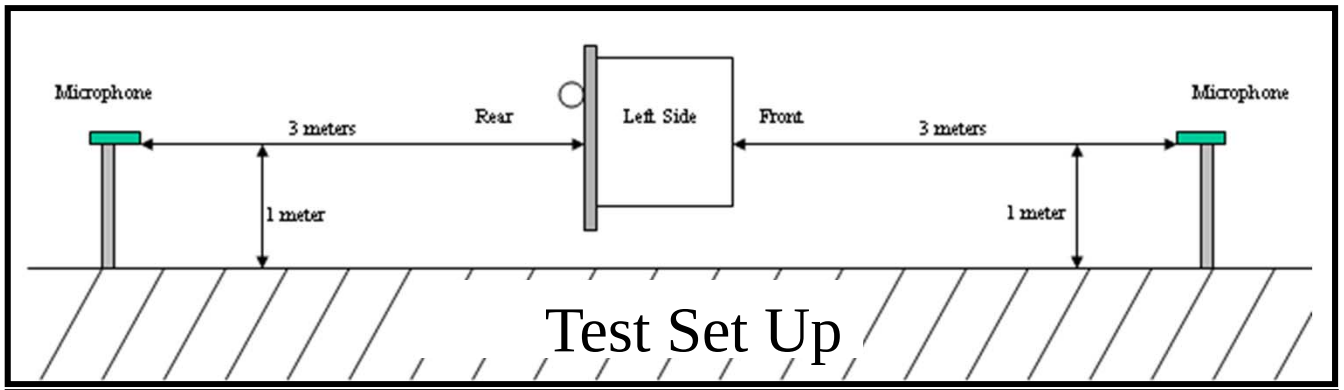
Delphi Solid Oxide Fuel Cell System Emissions

- Delphi's SOFC APU meets current EPA emissions standards

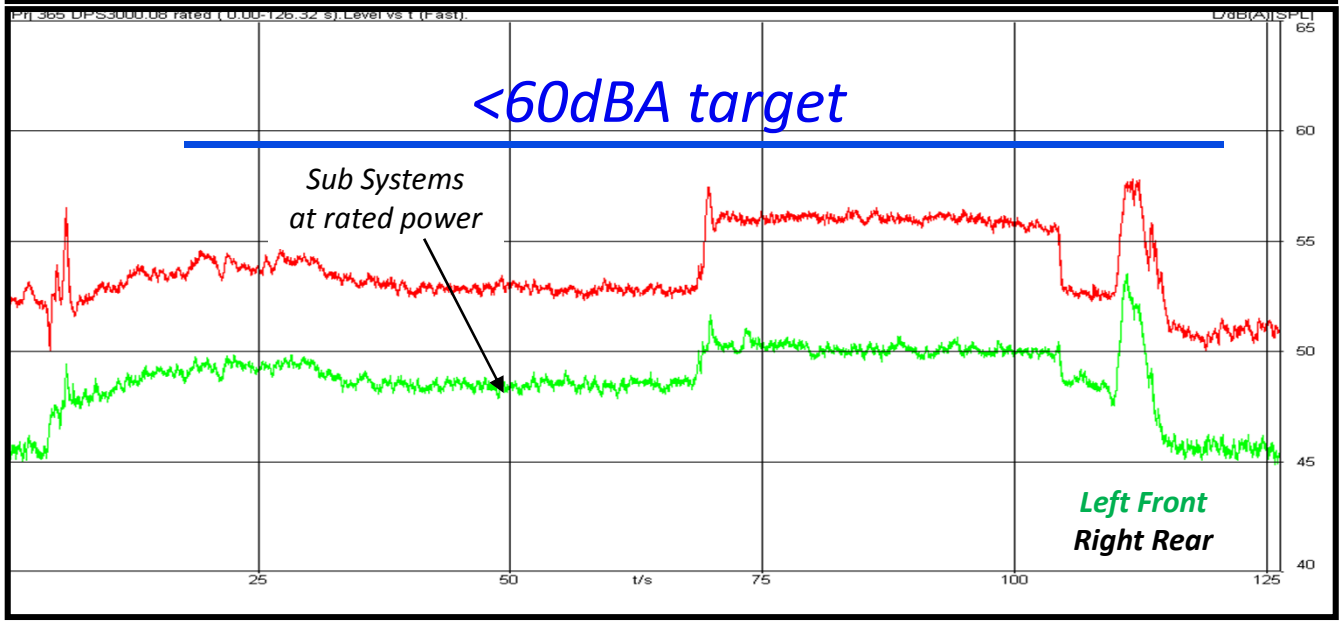


Delphi Solid Oxide Fuel Cell Noise Evaluation

- Delphi's SOFC APU is quieter than current diesel gensets



Test Set Up



Relative Noise Levels

- Snowmobile (100dBA)
- Telephone Dial Tone (80dBA)
- Current Diesel Gen Set APU (75-80dBA)
- Normal Conversation (60-70dBA)
- ***Delphi SOFC APU (60dBA)***
- Whisper Quiet Library (30dBA)

Increasing Noise Level

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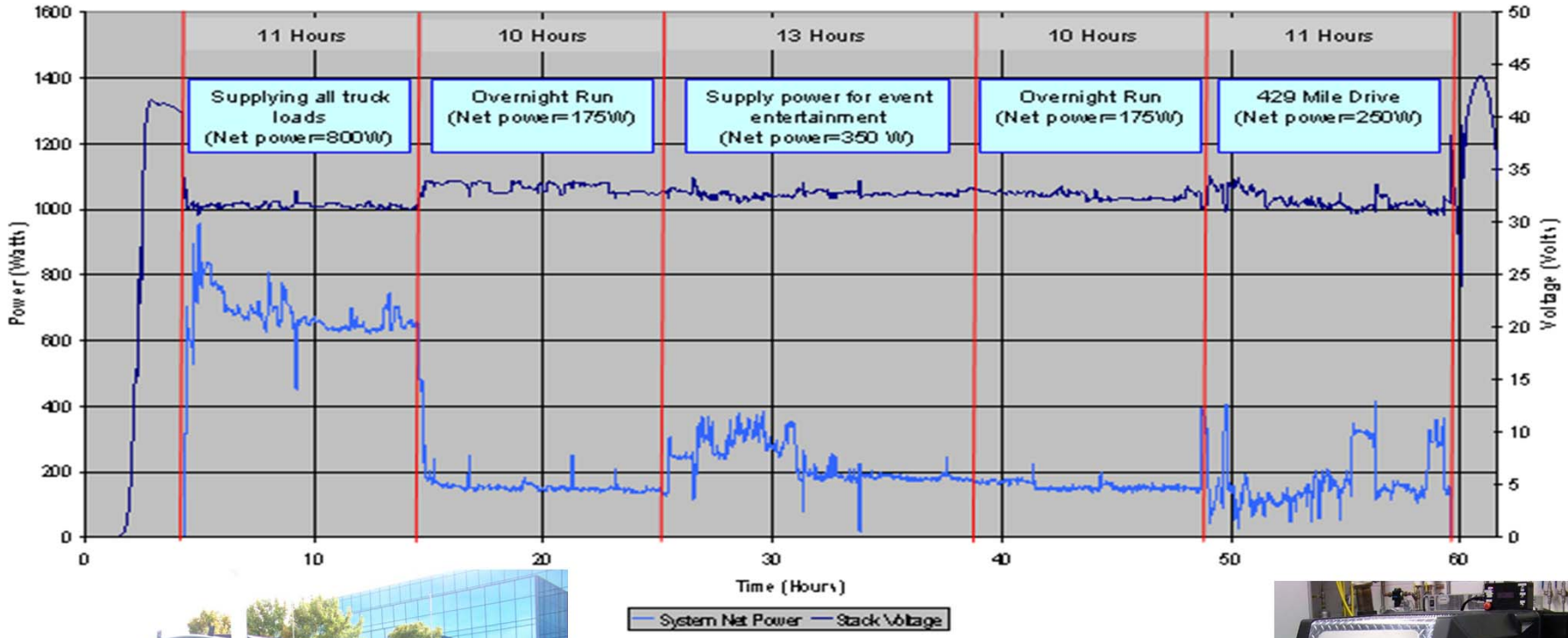
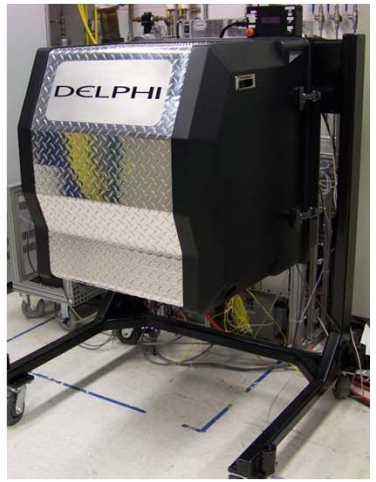
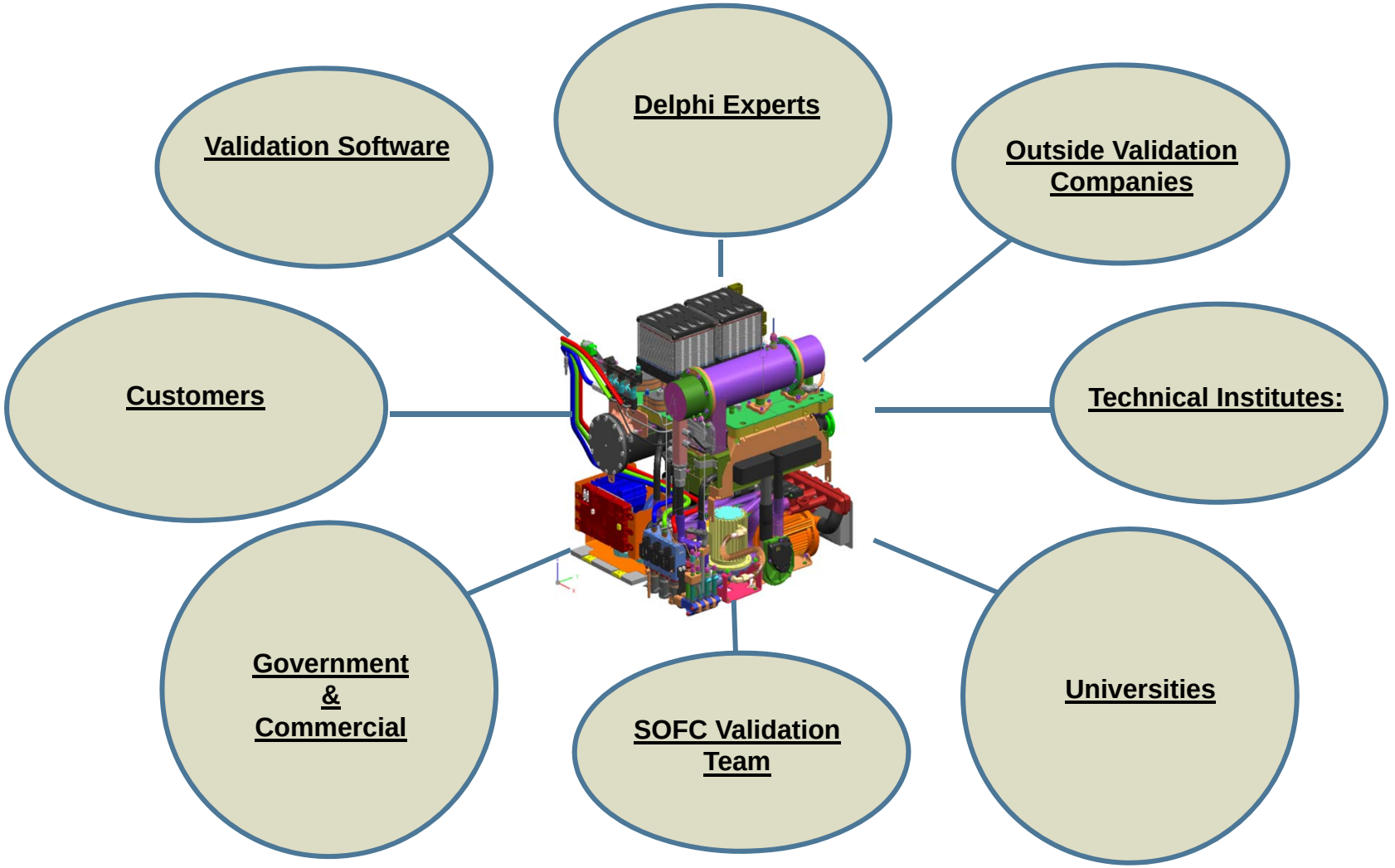
DPS3000D A-Level Testing On Vehicle
SOFC System Power - Operating on Road Diesel (ULSD)



Showing SOFC System capable of responding to load transients



SOFC Validation Plan is Being Developed by Leveraging Product Development & Testing Expertise



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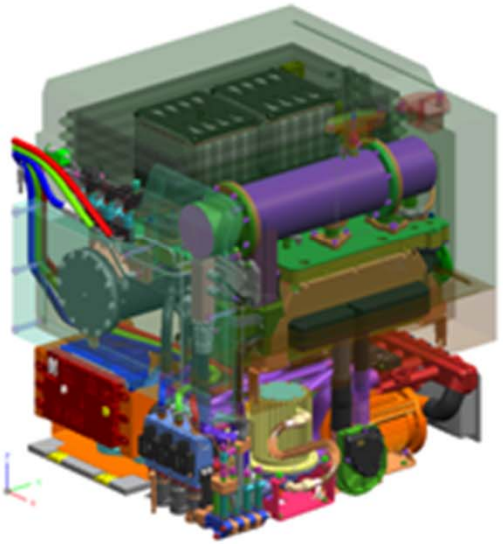
Delphi Solid Oxide Fuel Cell
A –Level to B-Level System Features

- Increased net power output
- Smaller package size
- Reduced mass
- Anode Oxidation Protection System included
- Reduced sensor requirements
- High volume manufacturable sub-systems

A –Level System

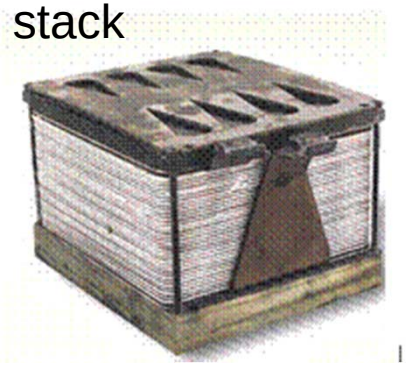


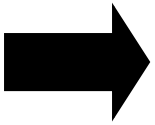
B –Level System

GEN 4 STACK

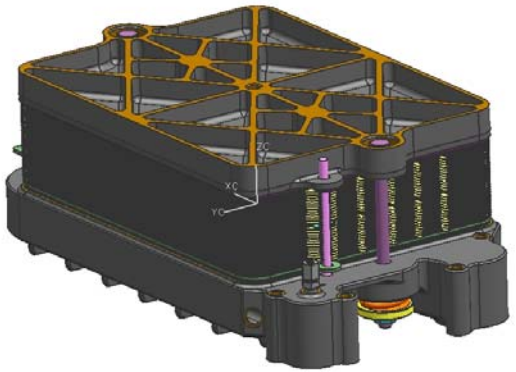
- Key stack features are:
  - 4x active area increase
  - Very low pressure drop (less than 4kPa, anode and cathode)
  - Laser welded cassette repeating unit configuration
  - Stamped metallic cassette components including interconnects
  - Reduced part count
  - Low cost, conventionally processed balance of stack components
  - Improved sealing features
  - Low cost castings
  - Low cost loading mechanism

Gen 3 stack





Gen 4 stack



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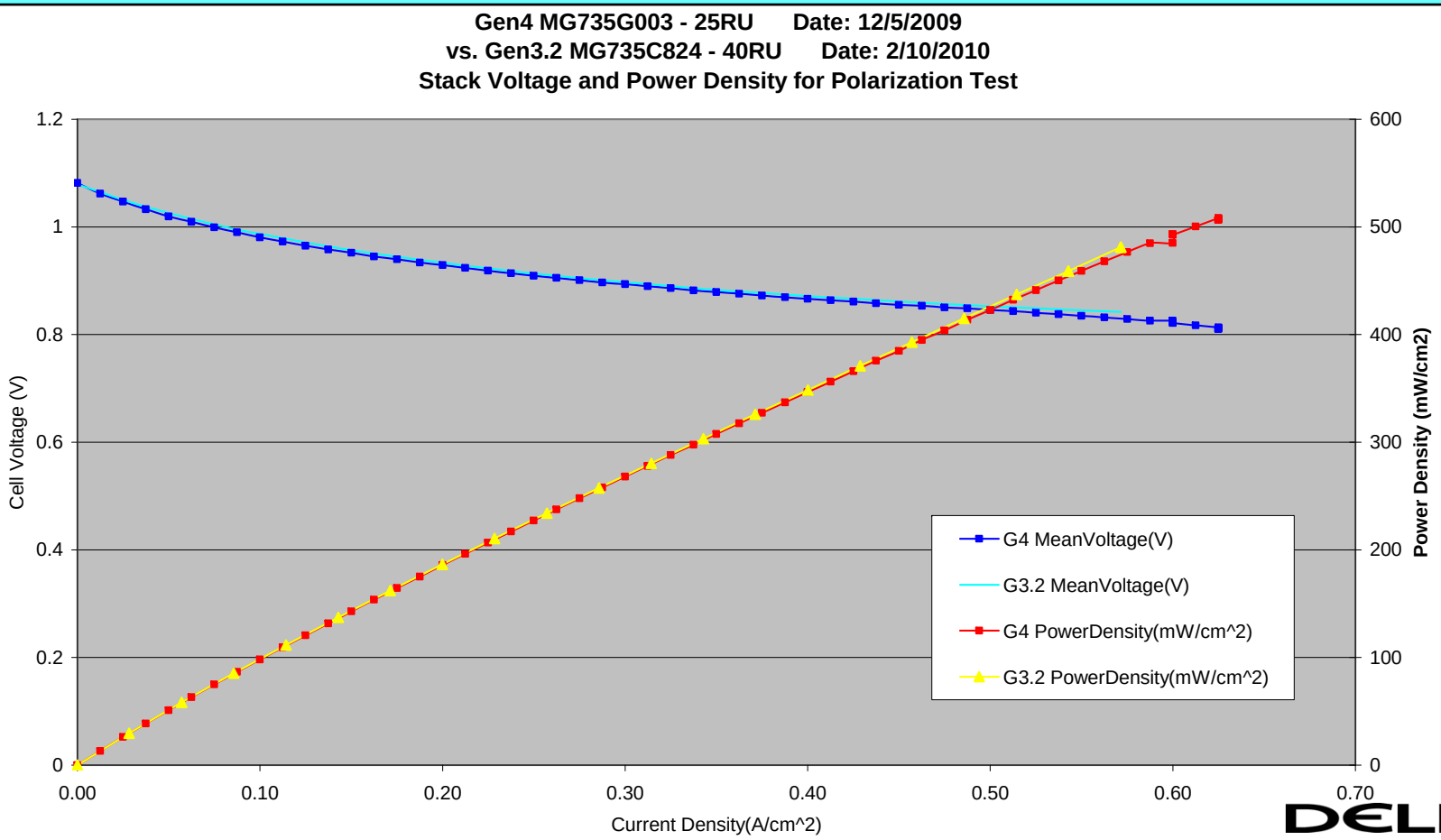
GEN 4 STACK PERFORMANCE

- 25-cell Gen 4 stack power density
  - Produced 5064 Watts (506 mW per cm^2) @ 0.81 Volts per cell with 48.5% H_2, 3% H_2O, rest N_2
  - Data shows comparison of Gen 3 and Gen 4 electrochemical performance



Delphi Solid Oxide Fuel Cell Recent Accomplishments

- **Installed first Delphi diesel SOFC APU on a Heavy Duty Truck for operation on the road**
  - Operates on road diesel (ULSD) using internal desulfurization and reforming devices
  - Completing APU level Vibration testing in Lab based on truck vibration profile from Customer vehicle testing
  - Recently complete first every SOFC 430 mile over-the-road trip
- **DPS 3000D B-Level system design complete and first units built by end of year**
- **Stack Build**
  - Built first larger footprint Cells and Stacks (403cm2).
  - Gen 4 40-cell stack produced 7.5 kW at average cell voltage of 0.8 volts on 50% H_2 / 47% N_2 / 3% H_2O
- **Stack durability testing**
  - >10,000 hours of continuous operation with no measurable performance degradation over the last 8,500 hours
  - Successfully passed 3.5M mile equivalent vibration test
- **Delphi/Peterbilt awarded DOE program for 1 year on vehicle demonstration**

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Acknowledgements

SECA

NETL

UTC Power
A United Technologies Company

Battelle

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

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

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