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Application of a SECA stack design into a Heavy Duty Truck APU.

12th Annual SECA Workshop

July 28th, 2011

SECA stack design concept utilization in an APU

- Delphi is utilizing the development activity completed on the SECA stack design to be adapted into an APU application.
- The benefits of doing so are:
  - Transfer of technical and stack development activities into a new application.
  - APU application environment and requirements are driven back into the SECA stack design making it a more robust design.
  - As part of the APU the stacks are being subjected to the harsh environment required to operate in a heavy duty truck application.
  - Utilize common test equipment and tooling.
  - Potentially earlier implementation date into a commercial application.

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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

Residential Power

Stationary CHP Power Units

Commercial Power

Stationary Power Units

Heavy Duty Trucks

Auxiliary Power Units

Military

Auxiliary & Mobile Power Units

Clean Coal Power Plant

Advanced Power Systems

Recreational Vehicles

Auxiliary Power Units

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Delphi Has Chosen Three Main Markets for SOFC

- Heavy Duty Truck Auxiliary Power Units (APU) (3-5kW)
  - Greater than 50% of the states have regulations that limit HD truck idling.
  - DOE / EERE sponsored programs used for vehicle development and validation in 2010 to 2012.
  - Development with heavy duty truck OEM's.
  - Delphi maintains a market leading position.
- SECA Stationary Power
  - Partnered with United Technologies in DOE SECA Coal Based Power System.
- Military Applications and Mobile Generators (5-50kW)
  - Testing underway Naval Undersea Warfare Center (NUWC).
  - Potential opportunities with office of Naval Research (ONR)

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Application of a SECA stack design into a Heavy Duty Truck APU.

Delphi Solid Oxide Fuel Cell
SOFC APU's Enable Fuel Savings while Meeting Stringent Emission and Anti-idling Regulations

- Market Drivers/Regulations
  - Greater than 50% of states currently have anti-idling regulations
  - Delphi SOFC APU meets 2012 EPA emissions regulations
- Compared to diesel engine APU's, SOFC APU's are:
  - 40% more efficient than the diesel APU's
  - Able to provide longer maintenance intervals and better durability
  - Very quiet (<60dBA)
  - Significantly lower emissions
- SOFC APU takes advantage of Delphi's engineering/manufacturing capabilities for:
  - » Controllers
  - » Power Electronics
  - » Heat Exchangers
  - » Sensors
  - » Ceramics
  - » Fuel Systems

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System Development Activities

Delphi Solid Oxide Fuel Cell Development and Validation Planning Process

- System requirements are developed based on heavy duty truck usage, environmental and vibration profiles with assistance from Truck OE's. These are then translated into system requirements.
  - Usage Profile determines:
    - Number of Thermal Cycles
    - Number of Load Cycles
    - Peak Electrical Load
    - Amount of time operating at all Electrical Loads
  - Environmental Profile determines:
    - Ambient Temperature Requirements
    - Altitude Requirements
    - Fuels
  - Vibration Profile determines:
    - Accelerated Vibration test
    - Shock and impact that the Unit must withstand

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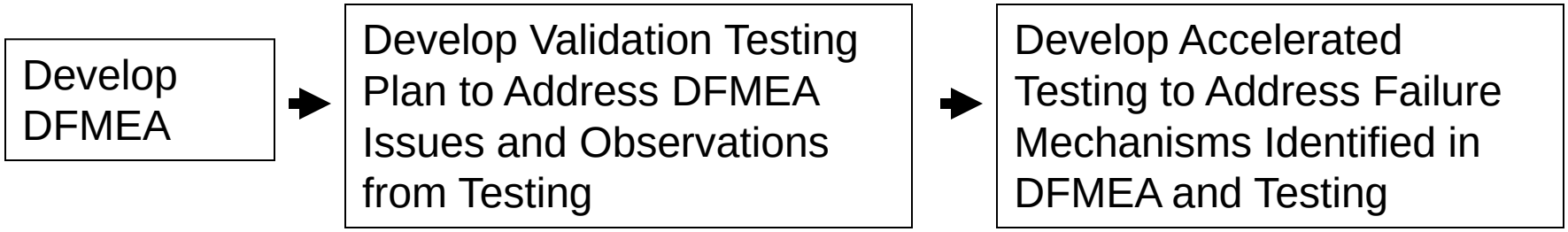
Delphi Solid Oxide Fuel Cell System Acceleration Factors



- System test acceleration factors for SOFC
  - Time
  - Load Cycling
  - Thermal Cycle Acceleration
  - Vibration Energy
- Results from accelerated tests are then compared to baseline durability.
- As data set/population increases>>> accelerated tests are further refined.

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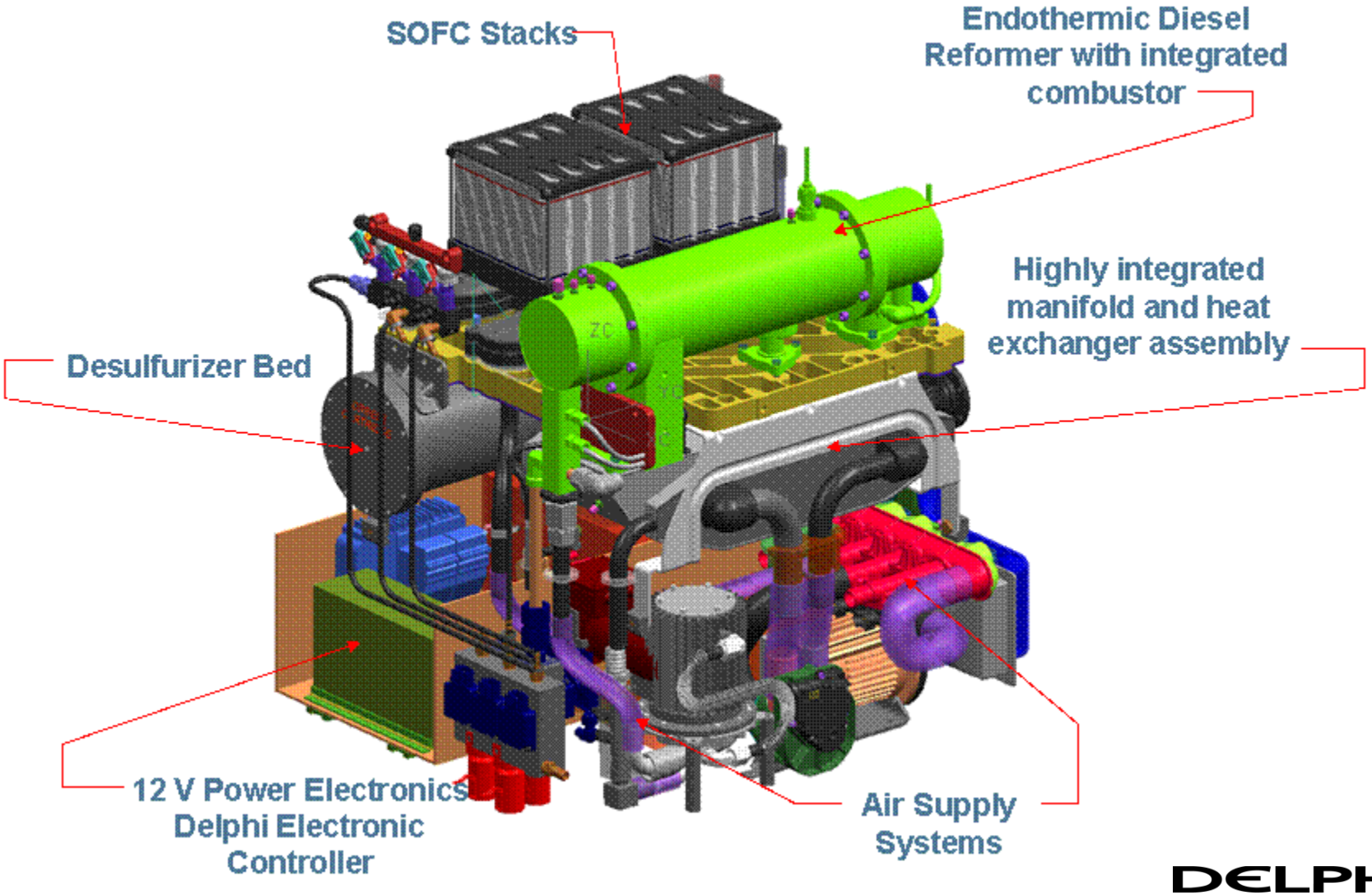
Delphi Solid Oxide Fuel Cell DPS3000D A-Level Layout



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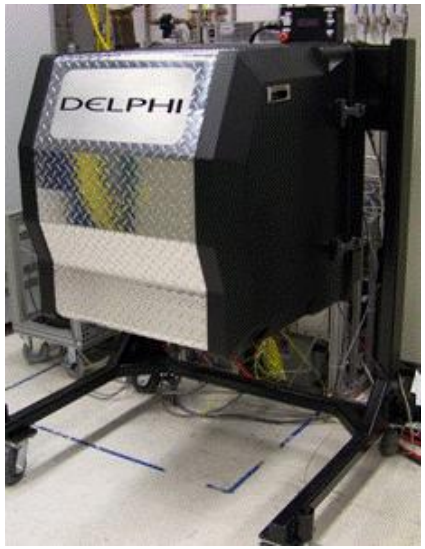
Delphi Solid Oxide Fuel Cell A-Level System Testing

Accomplishments

- 1.5 kW net peak load
- 25 % system efficiency
- 440 hrs, 2200 miles operation on truck

Next Steps

- Continue to use as a test bed as B level APU design testing is initiated.



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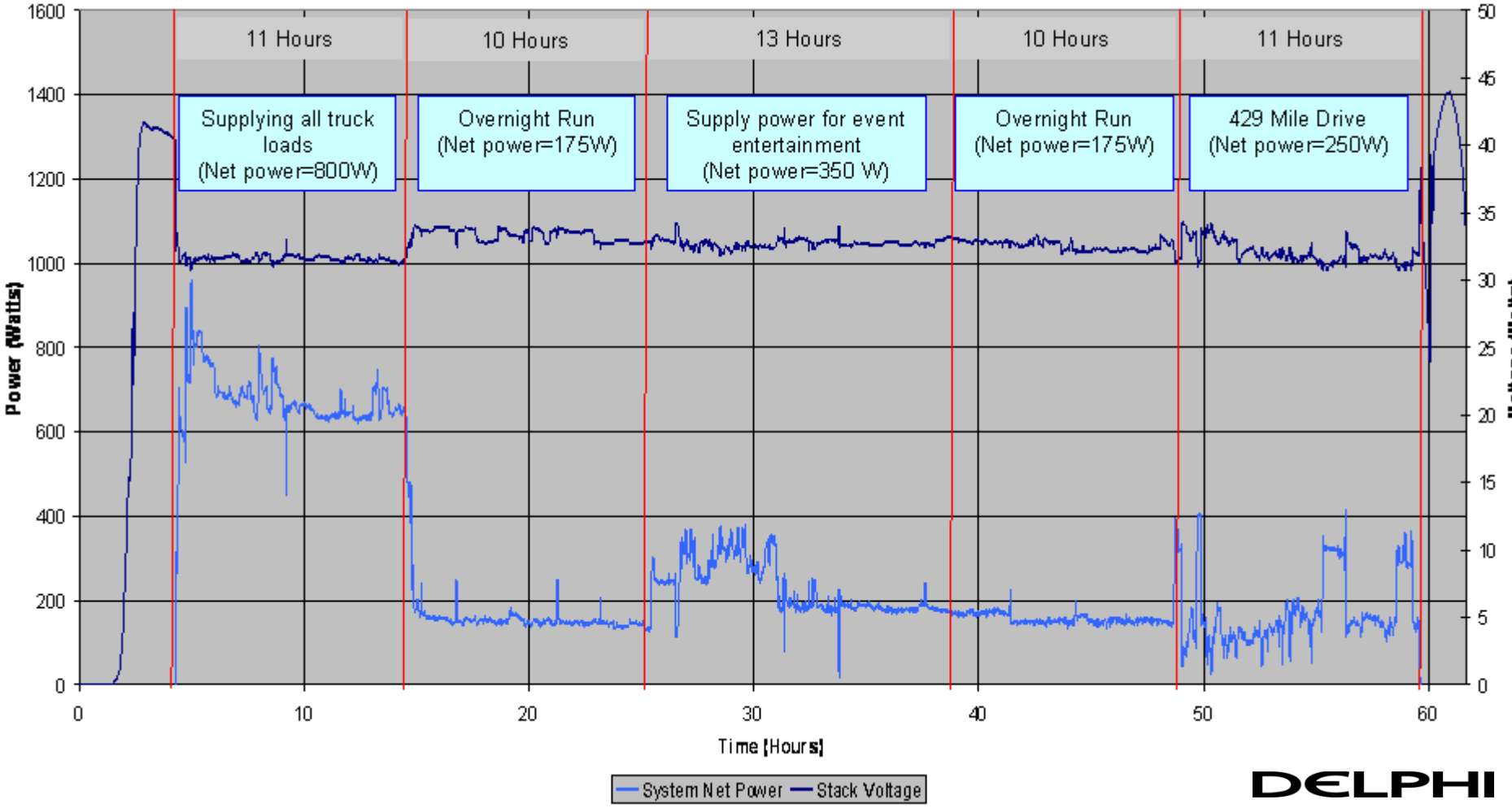
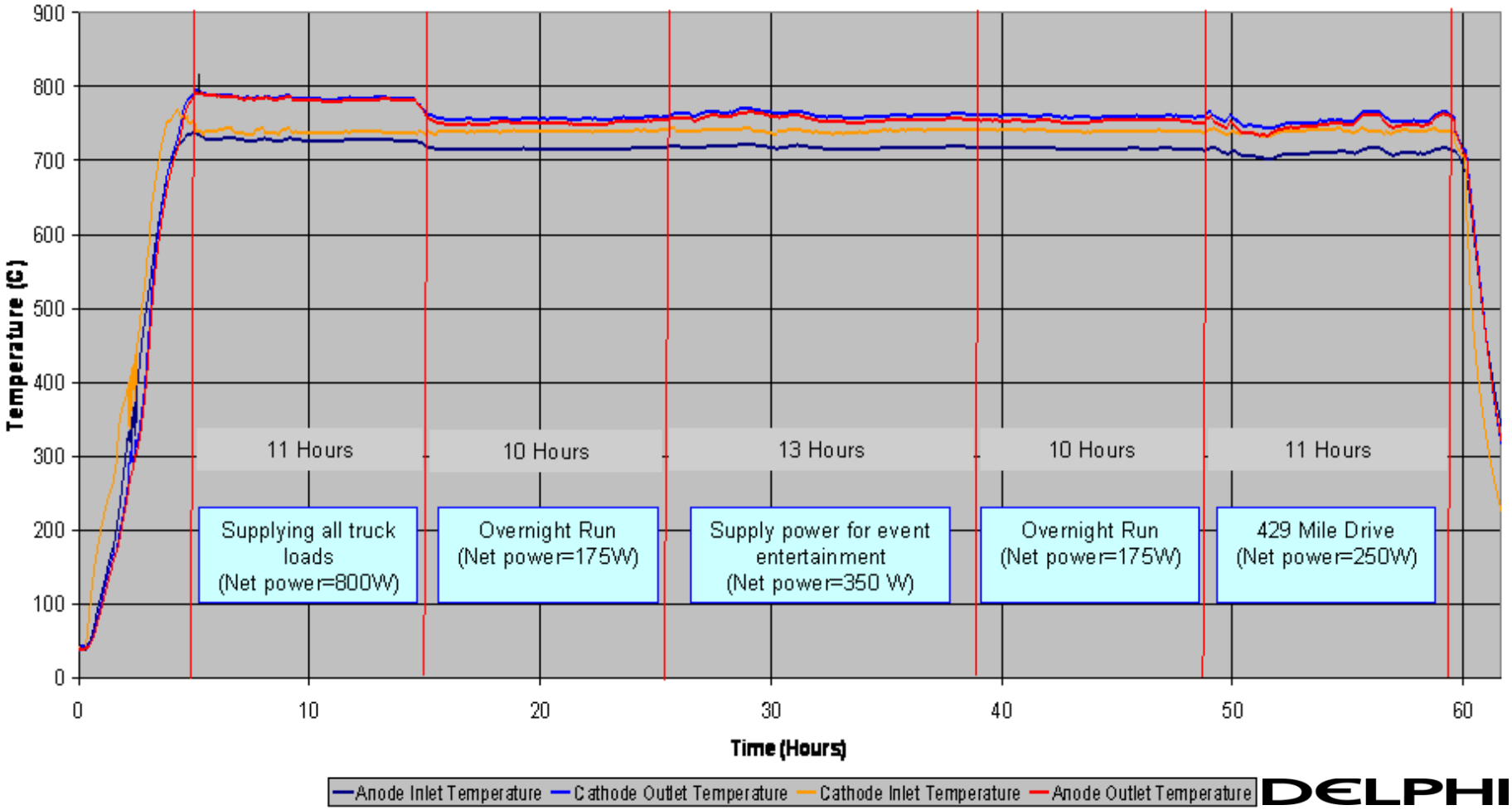
Delphi Solid Oxide Fuel Cell
A-Level Testing On Vehicle-SOFC System Power

- System capable of responding to load transients
- Operating on road diesel (ULSD)



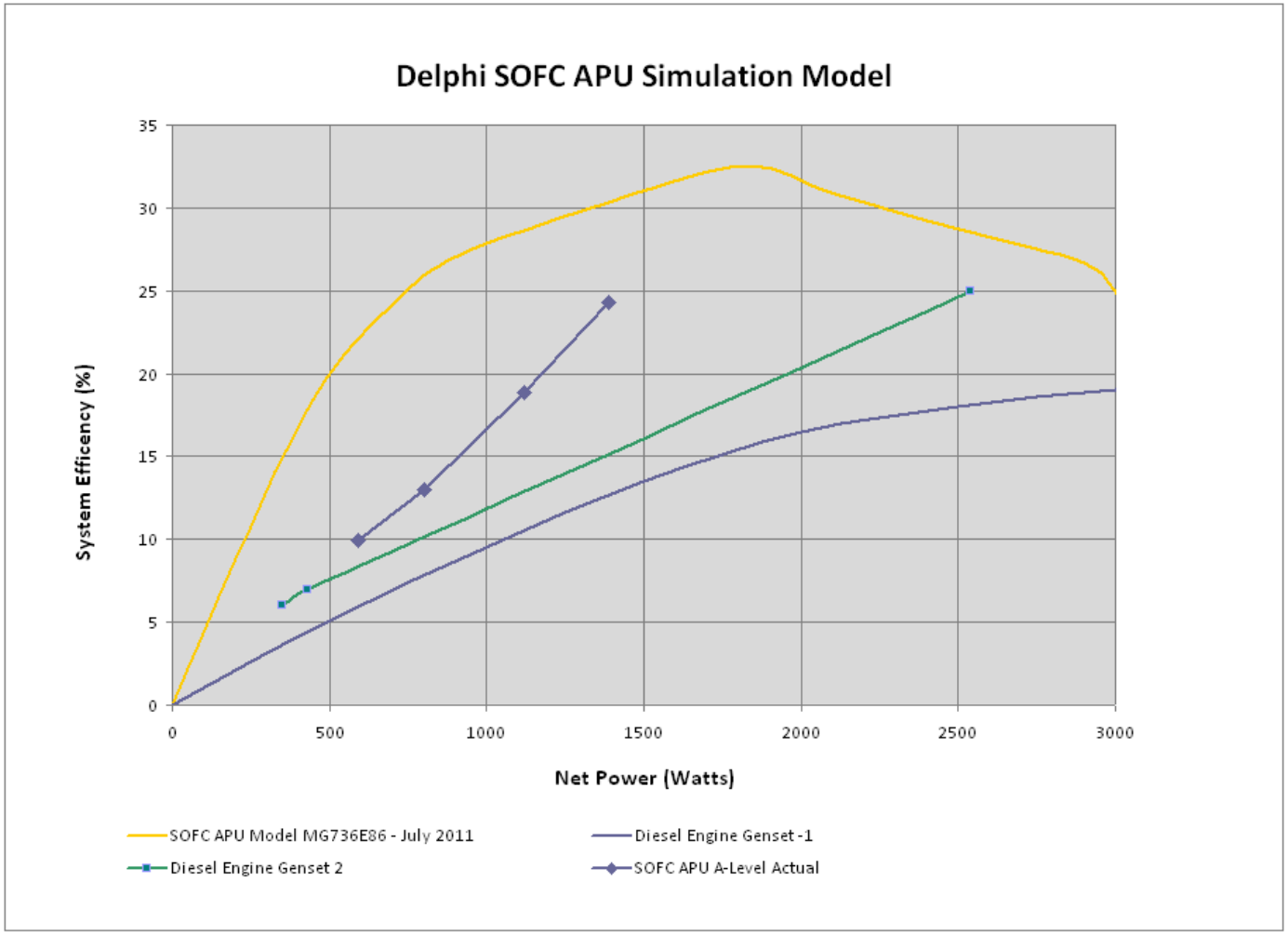
Delphi Solid Oxide Fuel Cell
A-Level Testing On Vehicle- SOFC Stack Temperatures

- System capable of maintaining desired stack temperatures during load transients



Delphi Solid Oxide Fuel Cell Performance Comparison: Efficiency vs Power

- Delphi's SOFC APU has higher efficiency compared to a diesel engine gen set.



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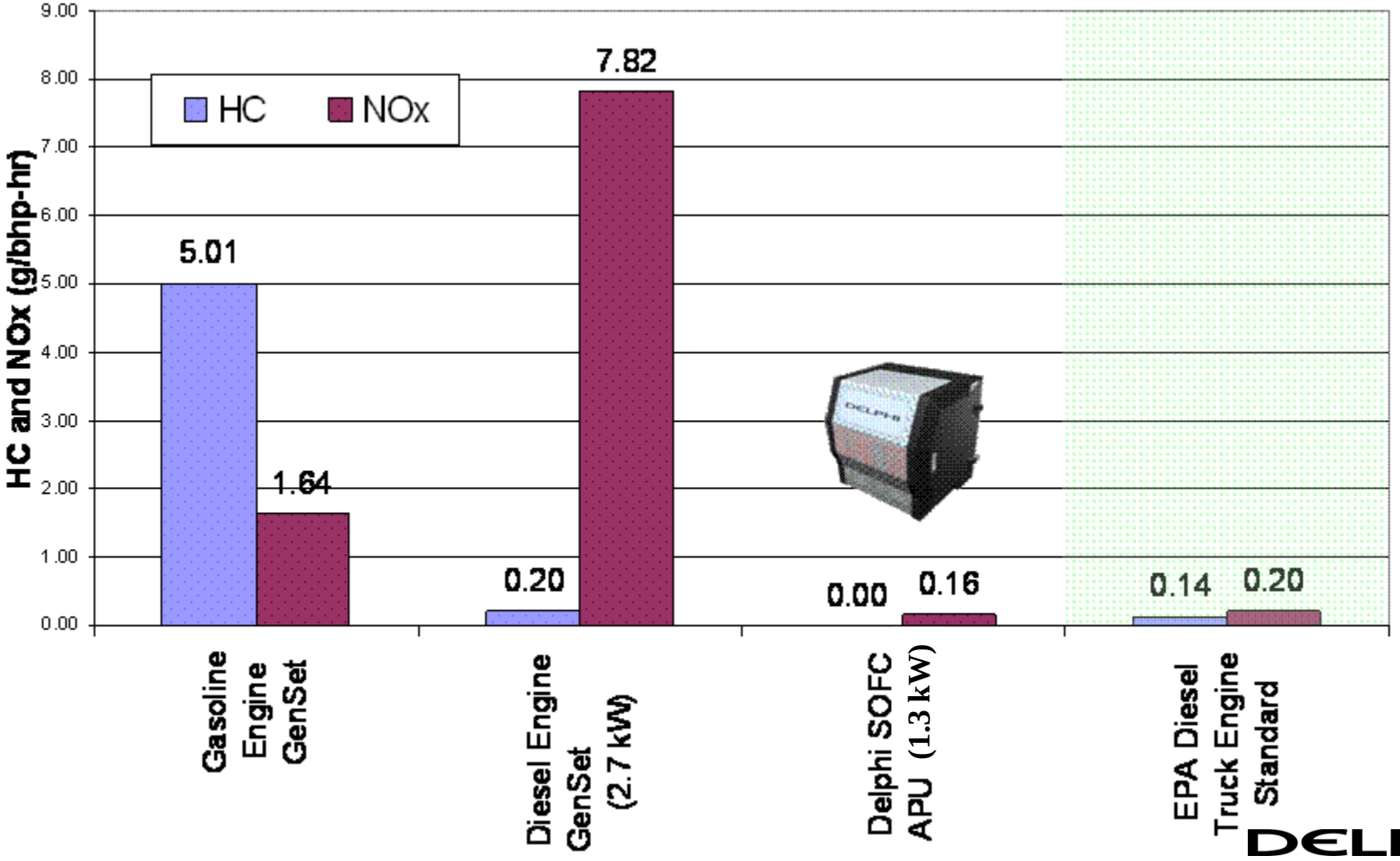
Delphi Solid Oxide Fuel Cell System Emissions

- Delphi's SOFC APU meets current EPA emissions standards



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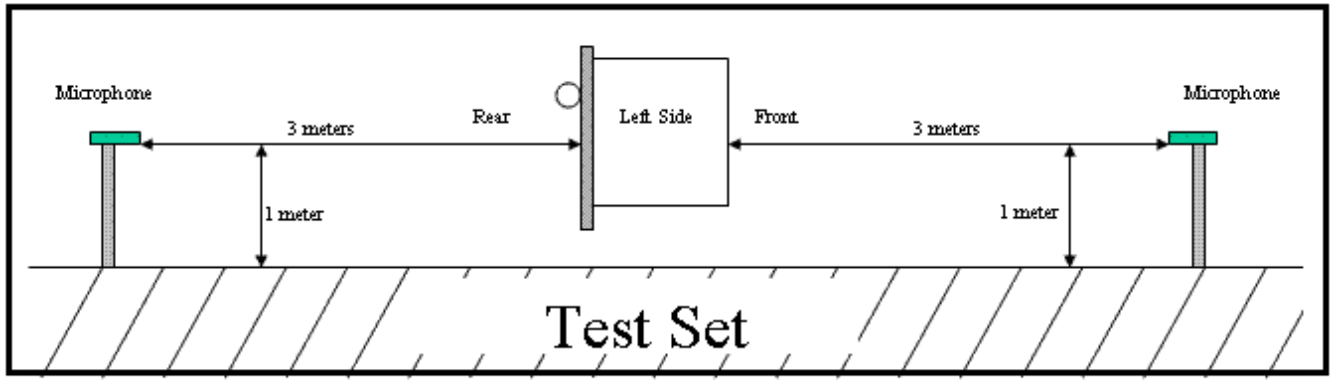
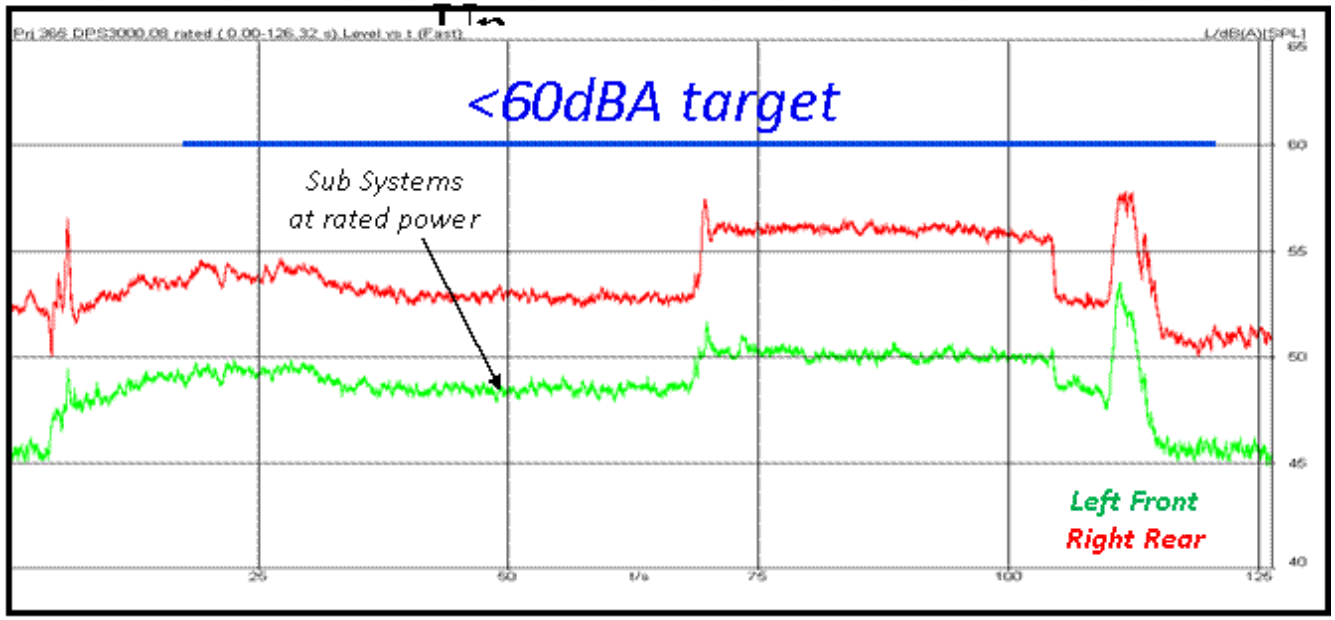
Delphi Solid Oxide Fuel Cell Noise Evaluation

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





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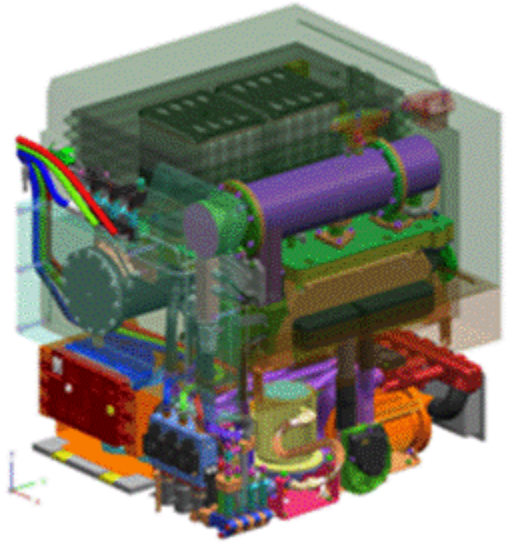
Delphi Solid Oxide Fuel Cell
A –Level to B-Level System Features

- 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

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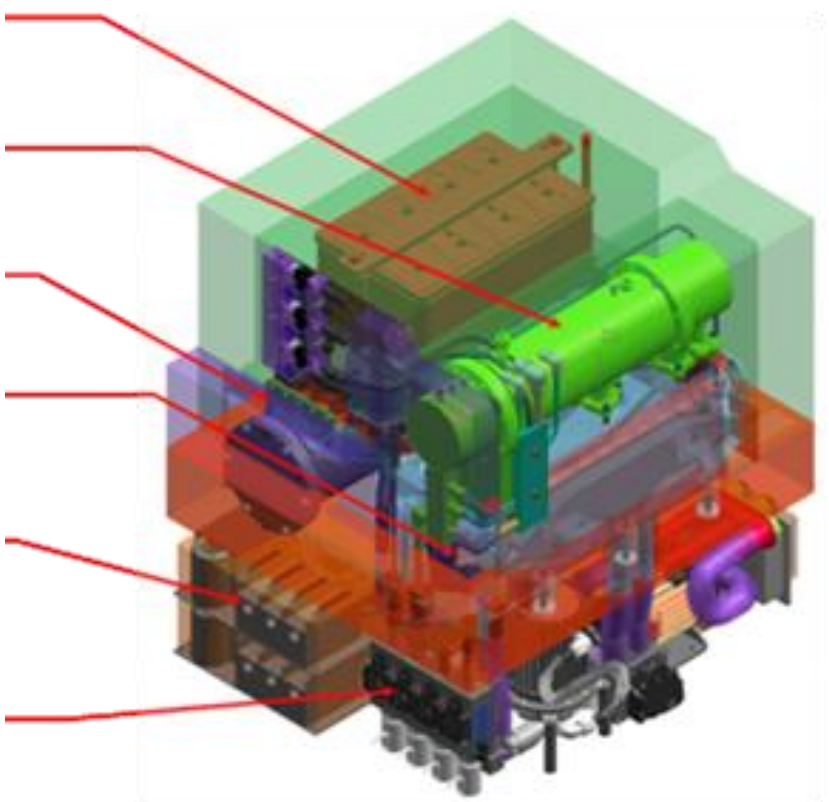
Delphi Solid Oxide Fuel Cell Current System Layout



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Delphi Solid Oxide Fuel Cell Summary

- Delphi's SOFC Stack developed for SECA meets many market needs:
  - Auxiliary Power Units
  - Military applications
  - Residential & Commercial stationary power
  - Coal-based, stationary power generation
- Delphi SOFC APUs have demonstrated:
  - 25% efficiency
  - Ability to meet 2012 EPA emission regulations
  - Low noise (<60dBA)
- Compared to diesel engine APUs, SOFC APUs are:
  - 40% more efficient
  - Have significantly lower emissions
  - Very Quiet
  - Able to provide longer maintenance intervals and better durability
- Delphi is focused on the commercial viability of its SOFC
  - Manufacturability and cost reduction
  - System level durability and validation

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