# "Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications"

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**DELPHI**
**May 22nd, 2009**

**Sponsor:** U.S. DOE – Hydrogen, Fuel Cells and Infrastructure Technologies
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**DOE Project Manager:** David Peterson, Ph.D.
**Partners:** PACCAR, Volvo Trucks North America (VTNA), & Electricore

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**Project ID: FC_44_Blake**

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# Agenda

- Overview
- Objectives
- Milestones
- Approach
- Technical Accomplishments and Progress
- Future Work
- Summary

# Overview

## Timeline

- September 2004
- April 2010

(Project was on 18 month hold from 2006-2007)

- 70% Complete

## Budget

- Total project funding
  - DOE - $3,000,000
  - Delphi - $1,750,000
- $1,213,274 received in CY08
- $ 655,653 planned for CY09

## Barriers

- Barriers addressed:
  - Sulfur Remediation
    - Reformer Operation
    - Stack Sensitivity
  - Carbon Issues
    - Catalyst plugging
    - Combustion Start plugging
  - System Pre-combustion
  - System Electrical Integration

## Partners

- Paccar and Volvo Truck
- Electricore Inc.

# Relevance - Solid Oxide Fuel Cells Market Opportunity

**Heavy Duty Truck**
Diesel

**Recreational Vehicles**
Diesel, LPG

**Truck and Trailer Refrigeration**
Diesel

**US Military**
JP-8

***MARKET DERIVATIVES***

**European mCHP & CHCP**
Natural Gas

**US Stationary – APU & CHP**
Natural Gas, LPG

**Commercial Power**
Natural Gas

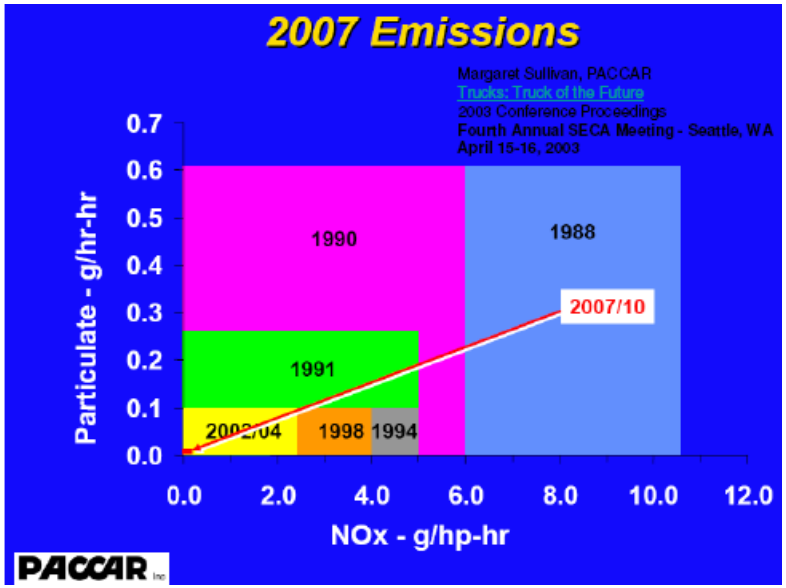
**FutureGen Powerplant**
Coal Gas

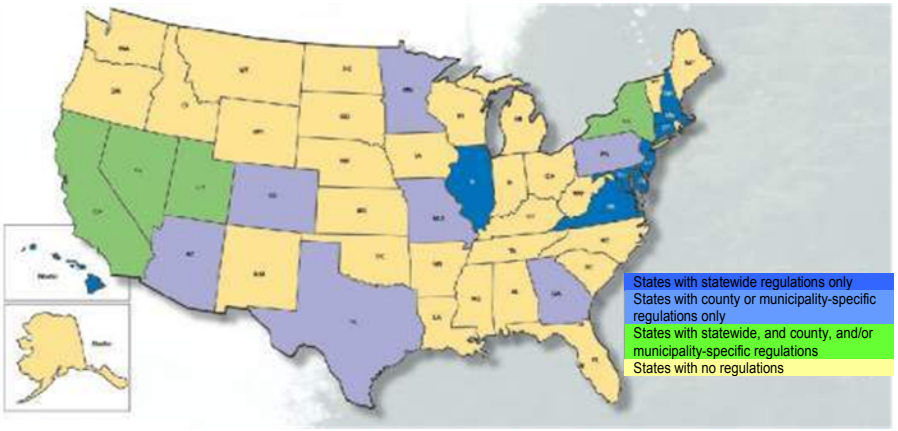
*Heavy Duty Truck represents Delphi's target initial development & application*

# Relevance - Heavy Duty Truck Market Drivers

## Mission & Anti-idling Regulations

*Annually, long-duration truck and locomotive engine idling…*

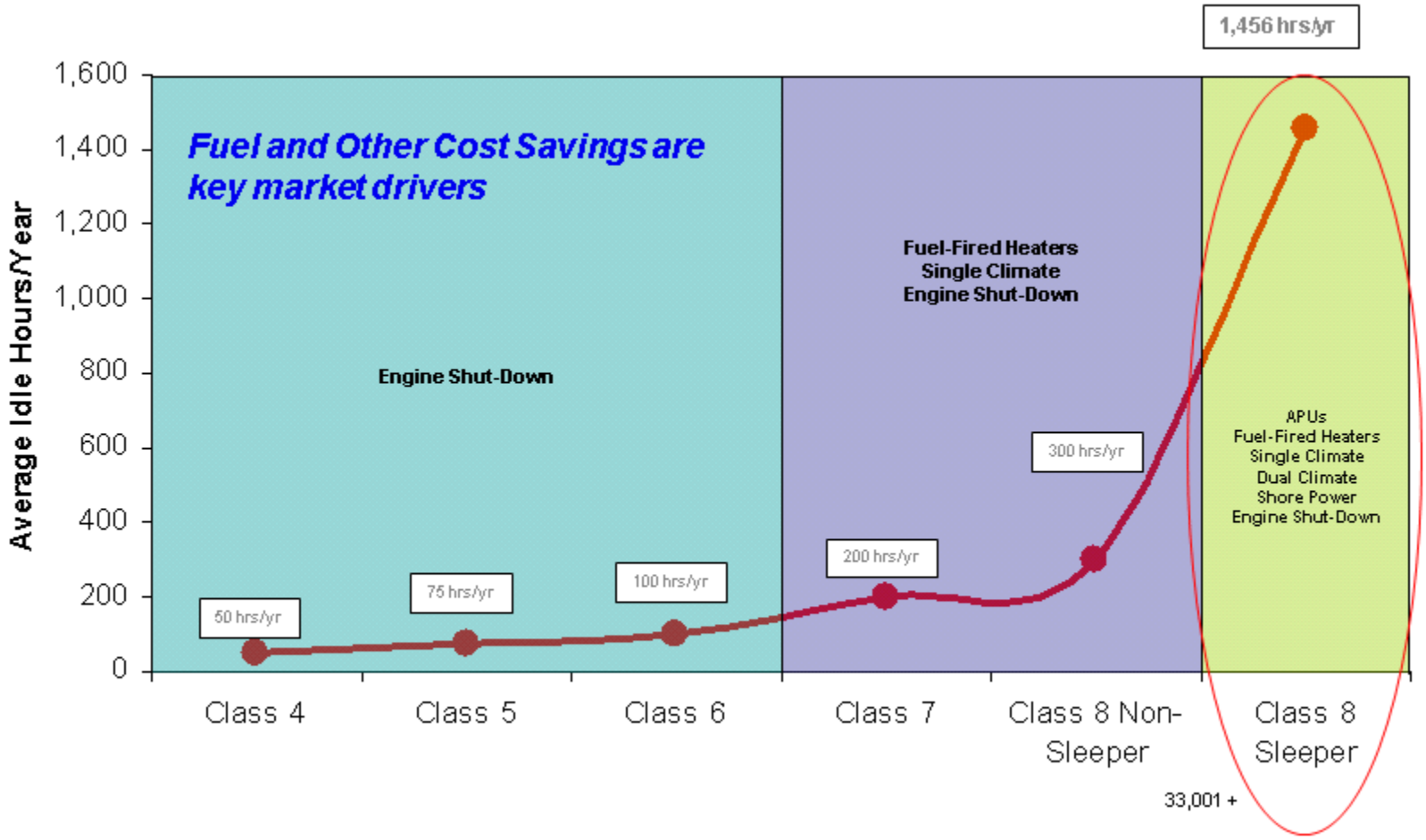



*… Emits 11-million tons of $CO_2$, 200,000 tons of NOx, and 5,000 tons of particulate matter*

*… Consumes >1-billion gallons of diesel fuel*

# Relevance - Heavy Duty Truck Market Idling Time



# Relevance - Heavy Duty Truck Market Drivers

## Increasing Cab Electrical Loads


*In-Cab Appliances Include*

- CB Radios
- Cell Phones
- Televisions
- Refrigerators
- Stereos
- Lamps
- DVD / VCR Player
- Computer
- Microwave
- Coffee Maker
- Electric Blankets
- Electric AC / Heater

*OEM load profiles identify potential power requirements of 2.5kW and 4.0kW respectively*

# Relevance - Objectives

## Complete a 48-month contract with the DOE EERE:

✓1.Develop APU system requirements and concepts with major truck OEMs input

2.Design, develop and test the needed subsystems for the approved concept
   1. Verification testing of brass-board APU system
   2. Form and packaging design
   3. Review Phase 2 system specification

3.Build and demonstrate a diesel fueled truck APU system to the DOE

| | DOE 2010 APU Technical Targets | DOE 2015 APU Technical Targets | Delphi Proposed SOFC APU Targets |
|---|---|---|---|
| System cycles # | 150 | 250 | 150 |
| Net System Power (kW) | ≤ 5 | ≤ 5 | 3 |
| Specific Power (W/kg) | 25 | 25 | 25 |
| Power Density (W/L) | 25 | 25 | 25 |
| Net System Efficiency | 35.0% | 40.0% | 38.0% |
| Durability (hrs) | 20,000 | 35,000 | 20,000 |
| Start Up Time (min) | 15-30 | 15-30 | 60 |
| Factory Cost ($/kWe) | $1,000 | $500 | $1,000 |
| Fuel | US '07 Diesel | US '07 Diesel | US '07 Diesel |

DOE/Delphi SOFC Key Performance Metrics

Meeting these objectives will dramatically increase both the technical and commercial viability of fuel cell APU technology

# Approach - Milestones

| Month/Year | Milestone and Go/No-Go Decisions | Complete |
|---|---|---|
| **April 2008** | **Sub-Milestone Review #2:** This milestone focused on the APU design and layout; and Developing the subsystem requirements document and development plan. | **100%** |
| **Sep. 2008** | **Sub-Milestone Review #3:** This milestone focused on the SOFC APU hardware design and build; Subsystem test fixture hardware development. | **100%** |
| **April 2009** (As of March 20th) | **Phase 2: Critical Milestone #3 Hardware Design & Development** This milestone focused on completion of the SOFC APU hardware build and procurement; Initiation of subsystem hardware testing and design iterations. | **80%** |
| **August 2009** (As of March 20th) | **Phase 2 Milestone #4 System & Subsystem Design Progress** This milestone includes subsystem testing and controls development; Initial SOFC APU system brass board integration and design iteration. | **25%** |

# Approach

**Phase 1: OEM input Collection**

- Delphi works with PACCAR and VTNA to understand the APU demands from the OEM point of view
- Information has been collected and is compiled into Delphi Requirements

**Phase 2: Design/Build/Development**

- 2008 Phase 2 effort is design and component verification period
- Late Phase 2 work will include a brass-board system build and test (2009)
- OEM involvement will be reduced until Phase 3

**Phase 3: System Integration & Test**

- In 2010, system development will use OEM input for test planning
- Conduct bench top testing
- Add in “real-world” profiles from the changing APU marketplace

# Technical Accomplishments and Progress

## System Performance Design Analysis

| | | SPU 1E GAP | DPS 3000 ENHANCEMENT |
|---|---|---|---|
| Power | Power Level (3 kW net) | 60 cells (105 $cm^2$) - 1-1.5 kW Stack cooling limited | 40 cells (270 $cm^2$) - 3-4 kW Improved cooling environment around stacks |
| System Efficiency | Parasitic power losses | High parasitic loads due to high-pressure drop components and high stack cooling airflow required | Opportunities for reduced pressure drop and improved stack cooling. |
| | Fuel Processing Efficiency | Lower efficiency with CPOx reformer with low recycle flow | Improved efficiency with "Endothermic" reformer and high recycle flow |
| | Heat Loss | High heat loss due to thin insulation and high internal thermal communication (undesirable) | Increased insulation thickness and thermal component compartmentalization |
| Sulfur | Fuel Compatibility | Zero sulfur Diesel fuel restricted (no reformate desulfurizer) | US 07 Ultra-Low-Sulfur Diesel compatible (internal, integrated reformate desulfurizer) |

# Technical Accomplishments and Progress

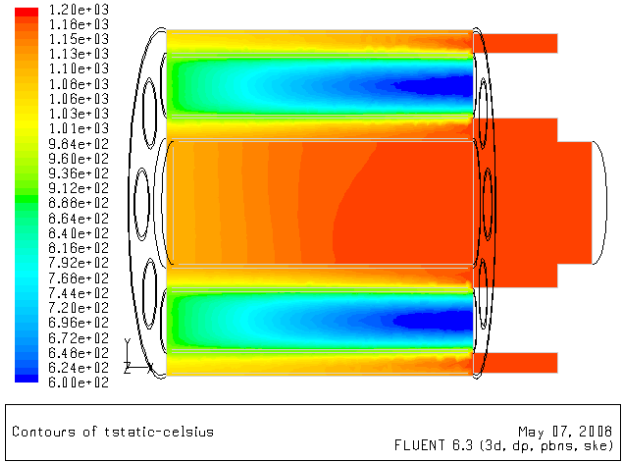
## Fuel Reformer Development

- Delphi is developing reforming technology for Diesel/JP-8 SOFC applications, by modifying our existing Natural Gas reformer
- The Next Generation design is a Recycle Based Endothermic Reformer:

Current Generation Reformer

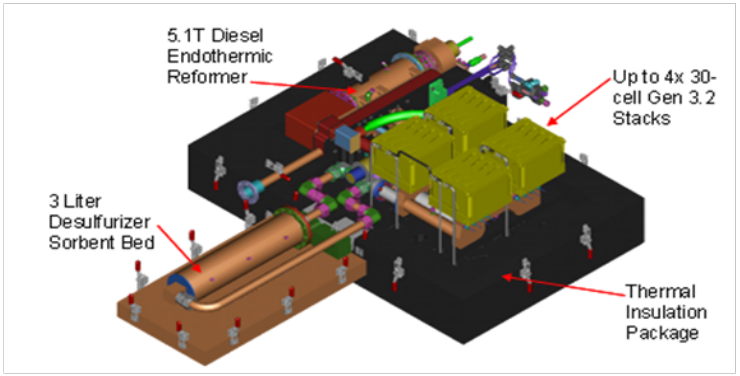
Next Generation Endothermic Reformer

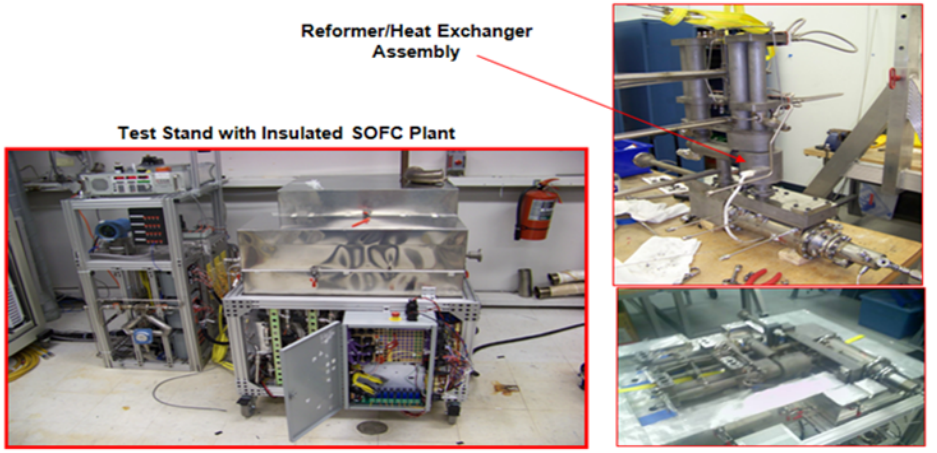
**Ceramic has poor HT, not suitable for design intent. Requires Micro-channel design (tubular or planar).**

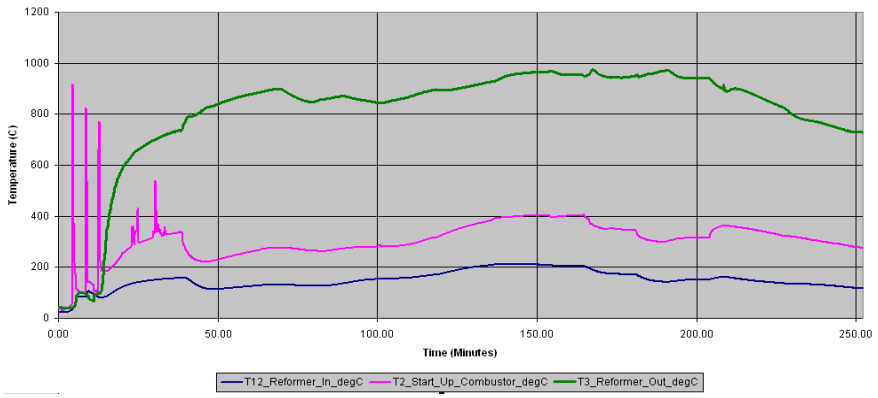


# Technical Accomplishments and Progress

## DPS3000D Development Test Chassis




- Integration of Development Endothermic Reformer
- Integration of gaseous Desulfurizer
- Initial debug of updated APU Software
- Testing of SOFC APU running on US07 Diesel

# Technical Accomplishments and Progress

## Major Design Efforts in Diesel APU Development – DPS3000D

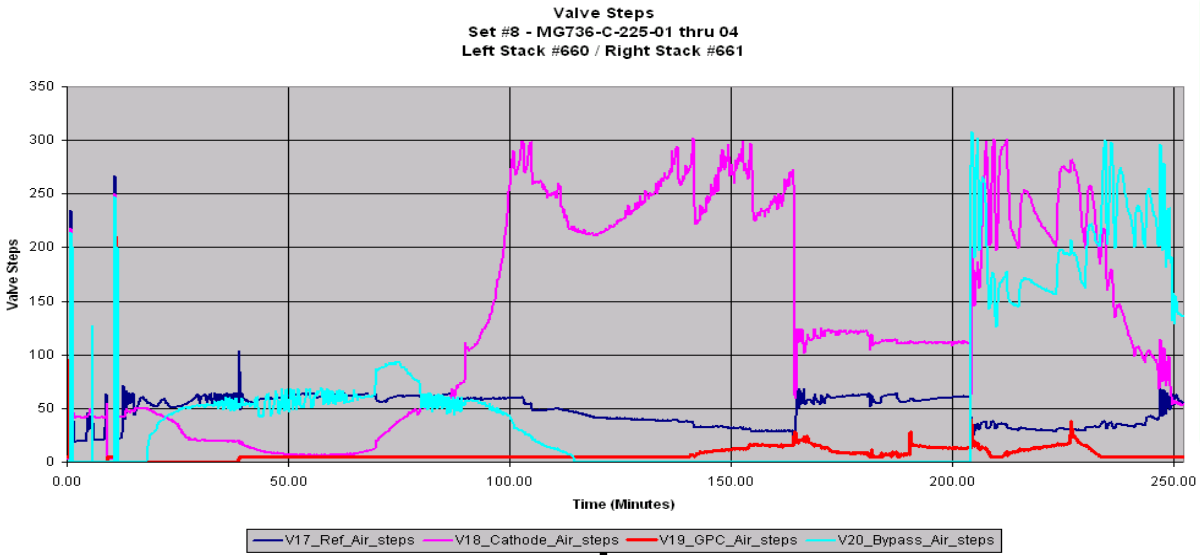

- Next Generation Stack Design with increase active area
- Enhanced Thermal Energy Management Controls
- Endothermic Reformer Integration
- Integrated Reformate Desulfurizer with Serviceability Enhancements
- Next Generation 12v Blower Design
- Multi-function Heat Exchanger
- Fully integrated turnkey system
- Simplified Integrated Component Manifold

# Technical Accomplishments and Progress

## Truck Demo Chassis Test

### Modified Natural Gas Platform to operate on Diesel Fuel

- Introduction of SOFC subsystem to OEM
- Better understand packaging and vehicle integration issues
- Initial Testing of basic operational parameters
- First testing of SOFC in a 'non-lab' environment
- Identify system Safety and Diagnostic concerns
- Better understand possible vehicle interface

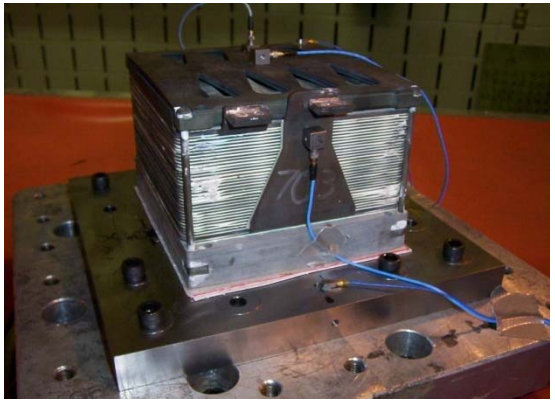


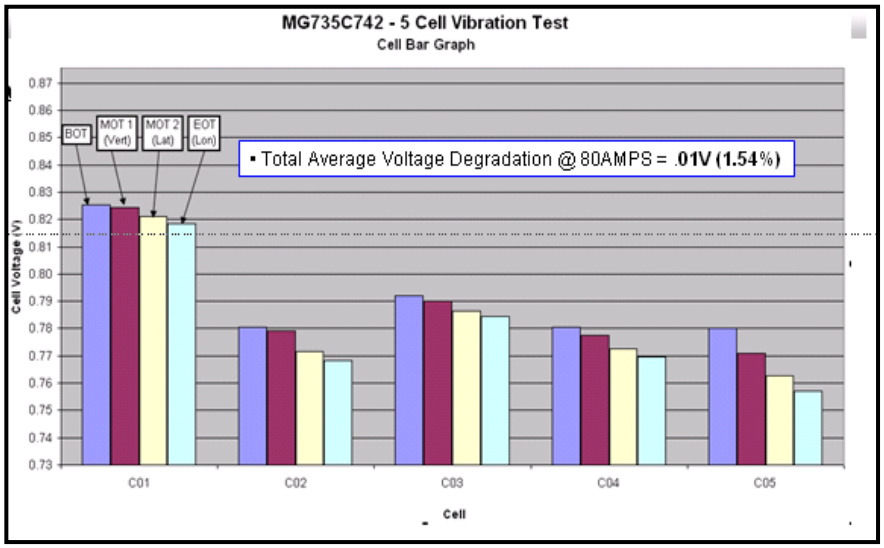

# Technical Accomplishments and Progress

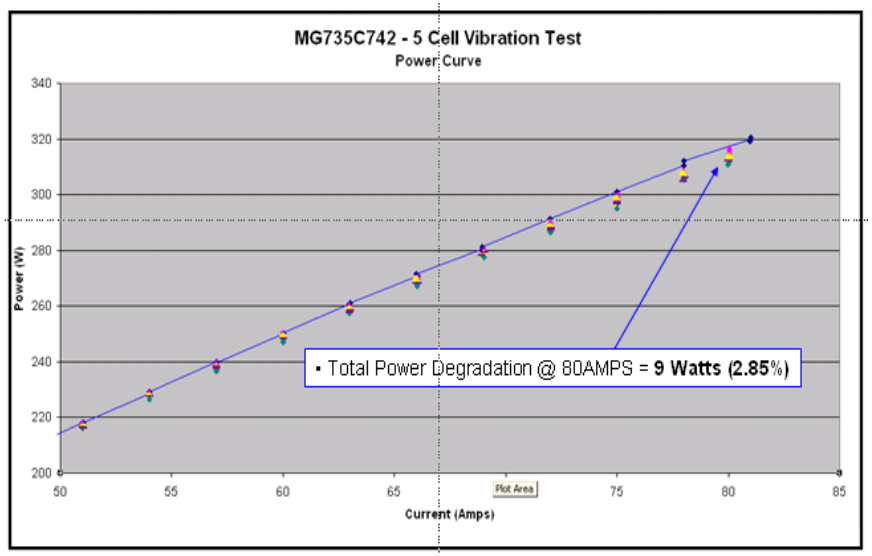
## Perform Accelerated Vibration Durability Test

### Stack Vibration Testing:

- Test Performed was a 3 mode Longitudinal, Lateral, Vertical, 2 hr per mode random vibration test, total test time was 6 hrs. Test acceleration is equal to 100k vehicle miles.
- 93% high usage class 8 truck driver accumulates ~ 250k miles/year (ATRI survey results)
- Validation Milestone ~ 750k miles in 3 years of operation





# Technical Accomplishments and Progress

**PACCAR / Peterbilt**

June 2008
Denton, Texas

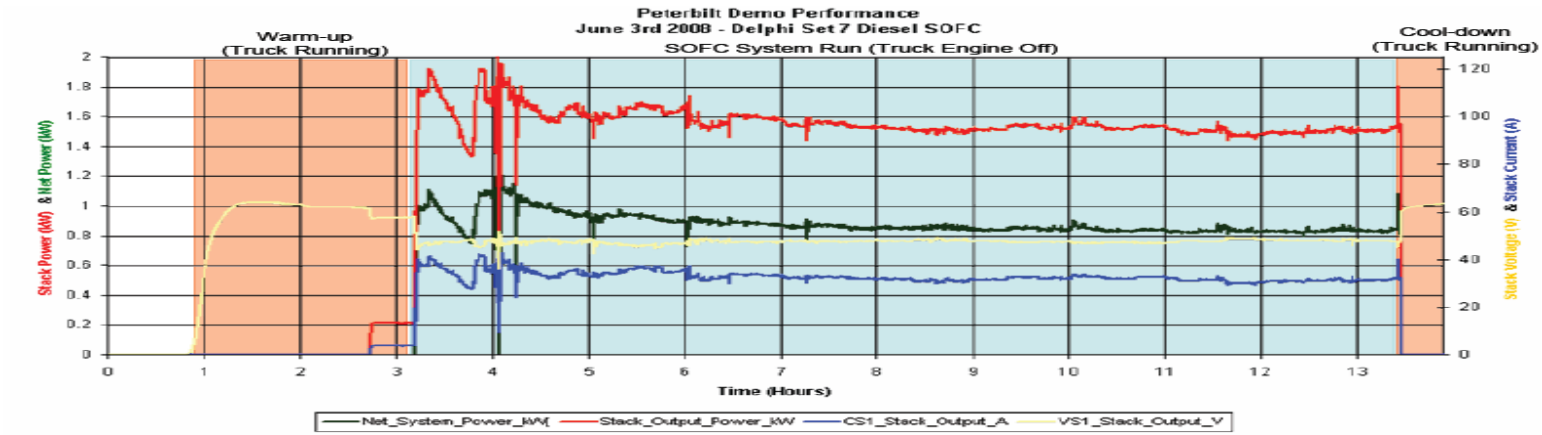


**Daimler / Freightliner**

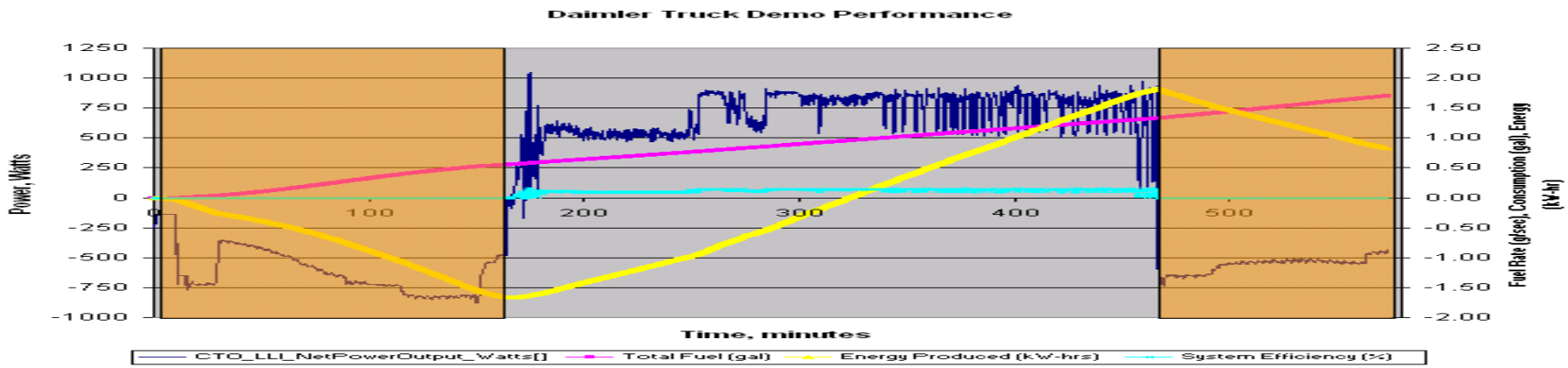
November 2008
Portland, Oregon

# Technical Accomplishments and Progress

## Steady State Performance



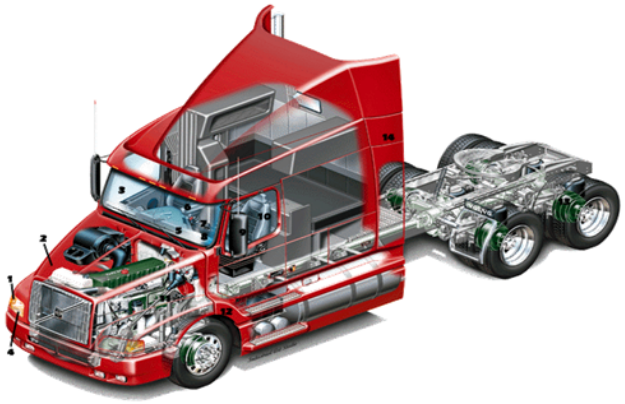

## Transient Performance



# Collaborations

***Delphi has teamed with OEM's PACCAR Incorporated and Volvo Trucks North America (VTNA) to define system level requirements for a Fuel Cell (SOFC) based Auxiliary Power Unit (APU) for the commercial trucking industry. As well as Electricore Inc, to help with the overall program management***

VOLVO



***Volvo Trucks North America (VTNA), Greensboro, NC***

PACCAR

KENWORTH Peterbilt DAF Foden Trucks

***PACCAR, Mt. Vernon, WA***

ELECTRICORE
POWERING THE FUTURE

**Electricore Inc, Valencia, CA**

# Future Work

## 2009

- Finish Subsystem Testing and Development Iterations
- Conduct 24 Month Critical Decision Milestone Review (April 2009)
- Complete System Module Testing and Development
- Phase 2 complete – Conduct Milestone Review (August 2009)
- Begin Full SOFC APU System Testing

## 2010

- Build Commercial Packaged SOFC APU
- Demo Test, 24 hour truck user profile using battery interface and vehicle simulation

# Summary

- **Primary Market Drivers**
  - Anti-Idling Legislation
  - Emissions Legislation
  - Increasing Heavy Duty Truck Cab Electrical Loads
  - Transportation Fuel Cost
- **Completed 3rd and 4th Quarter On-Truck Installation / Demonstration for Continued Development of APU Requirements**
  - Using a modified Natural Gas APU in an Integration Enclosure
- **Initiated Component Build and Testing of SOFC DPS3000D subsystems**
- **We are on Target for Meeting Timing and Budget**
- **Delphi is Committed to Introducing SOFC Diesel Technology in Full Scale Production for Heavy Duty Truck Applications**