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

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DELPHI
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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

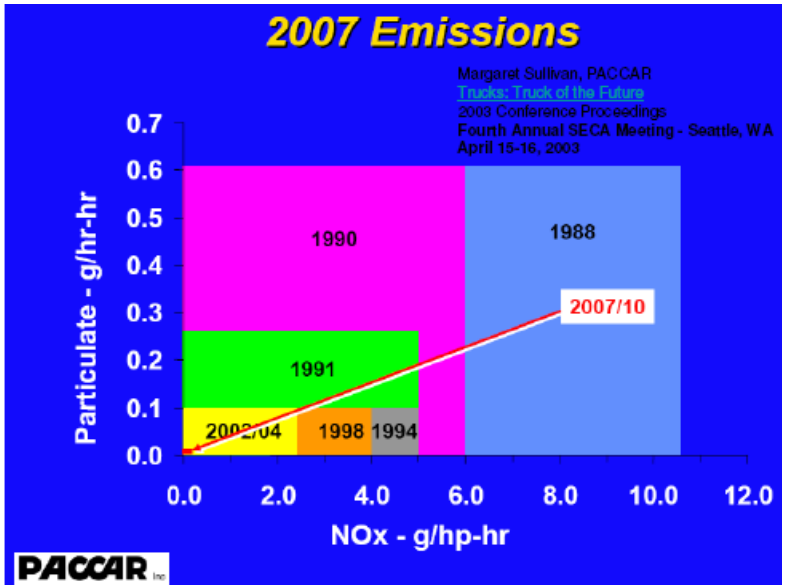
FutureGen Powerplant
Coal Gas

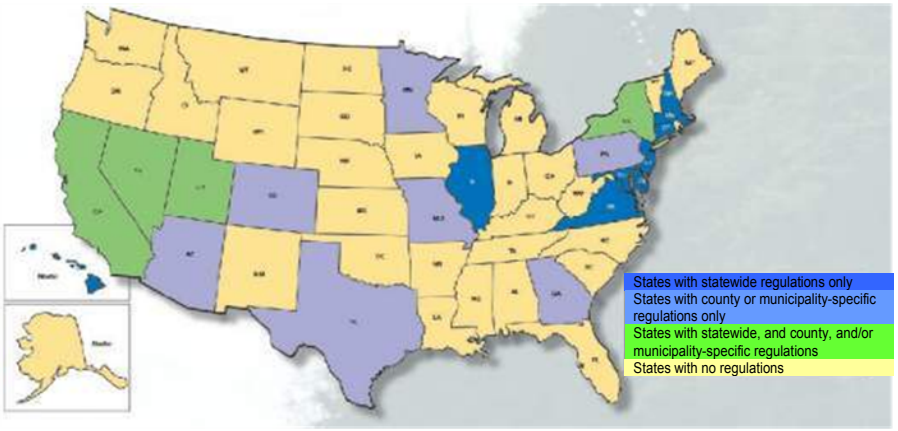
Heavy Duty Truck represents Delphi's target initial development & application

Relevance - Heavy Duty Truck Market Drivers

Mission & Anti-idling Regulations

Annually, long-duration truck and locomotive engine idling…

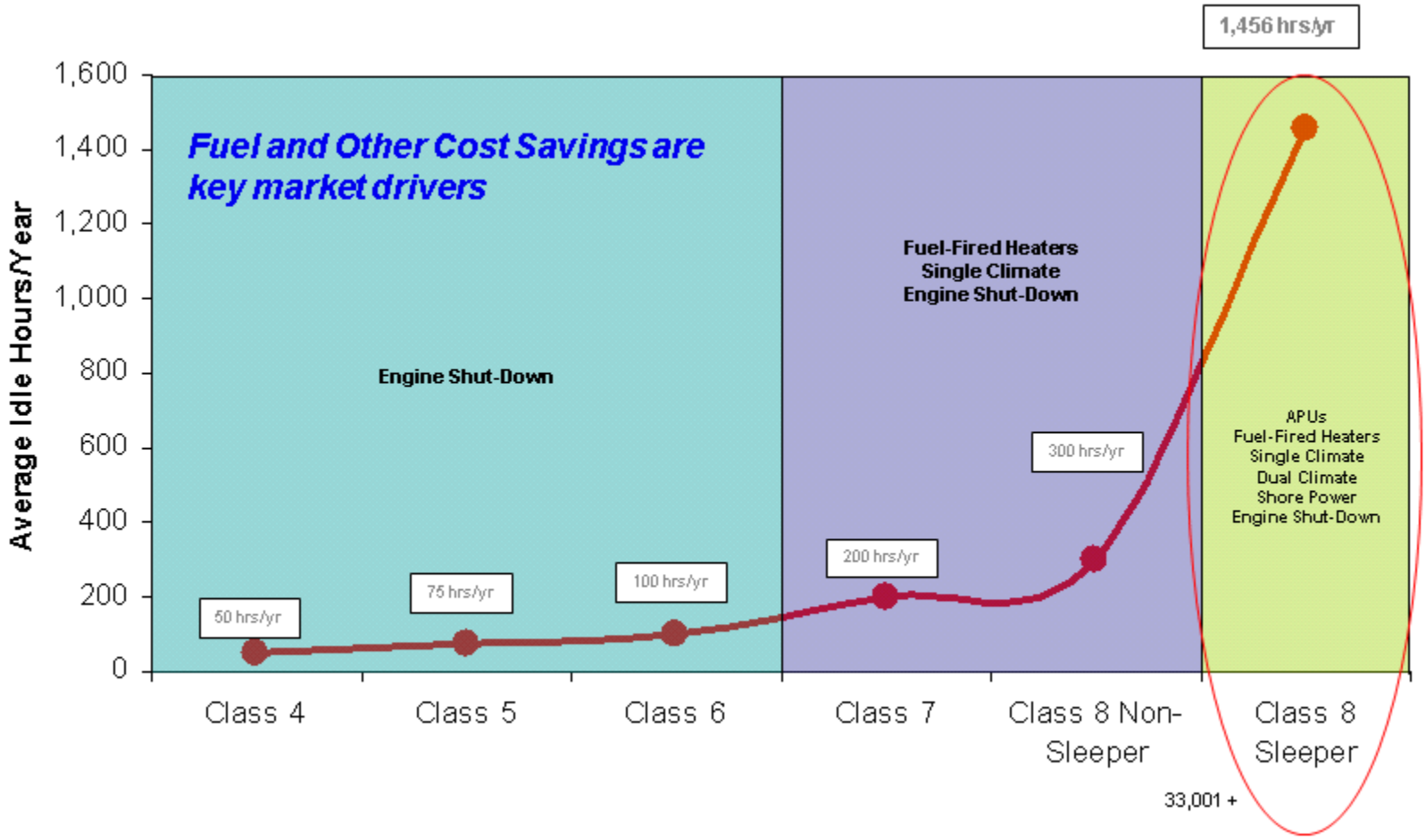




… Emits 11-million tons of CO_2, 200,000 tons of NOx, and 5,000 tons of particulate matter

… 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

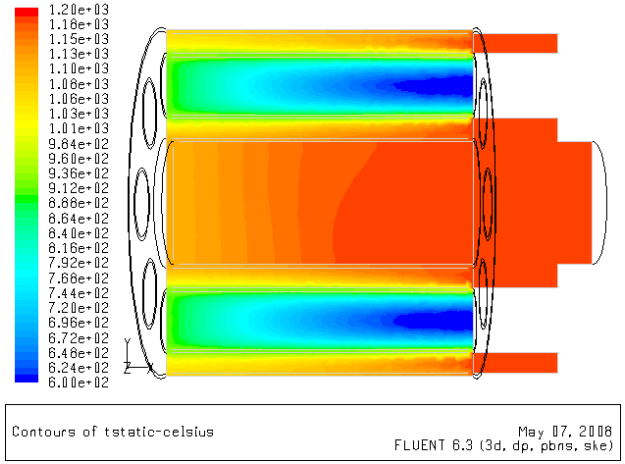
Fuel Reformer Development

- 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

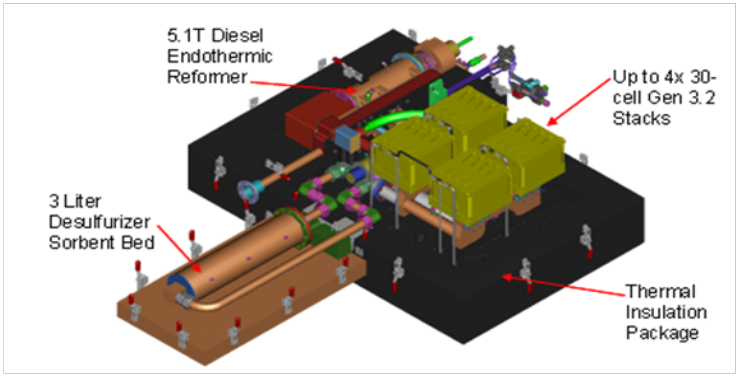
Next Generation Endothermic Reformer

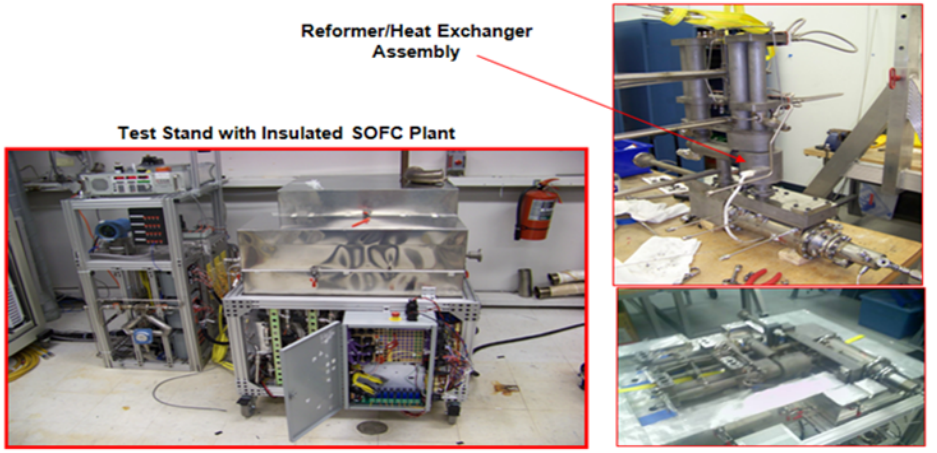
Ceramic has poor HT, not suitable for design intent. Requires Micro-channel design (tubular or planar).

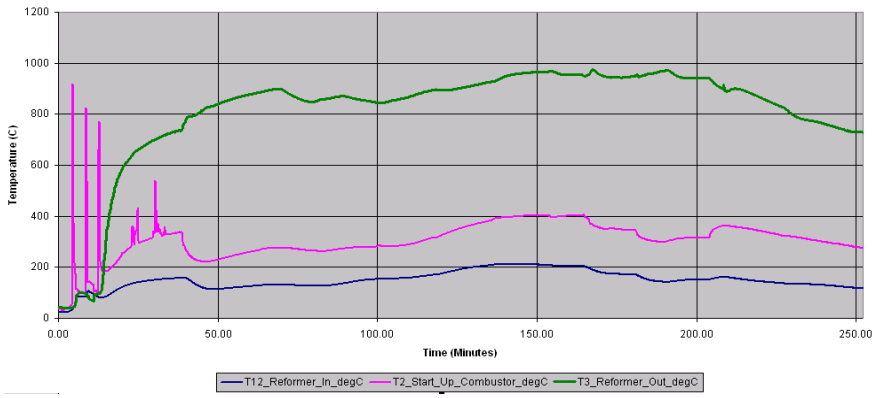


Technical Accomplishments and Progress

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

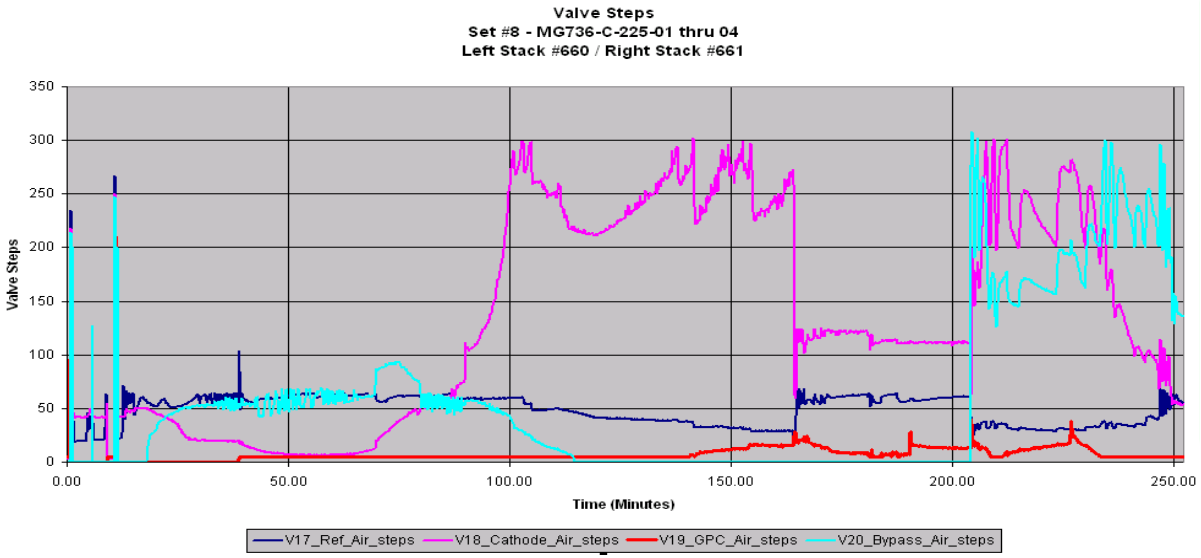
- Next Generation Stack Design with increase active area
- Enhanced Thermal Energy Management Controls
- Endothermic Reformer Integration
- Integrated Reformate Desulfurizer with Serviceability Enhancements
- Next Generation 12v Blower Design
- Multi-function Heat Exchanger
- Fully integrated turnkey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

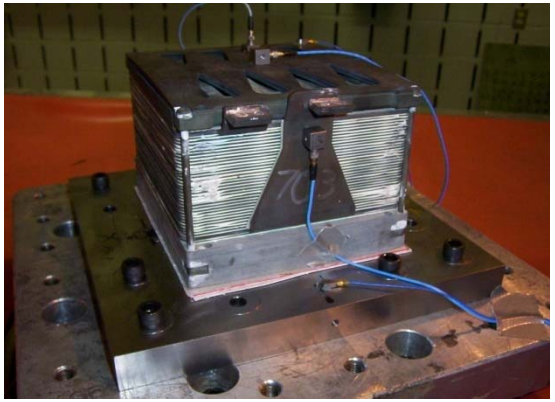


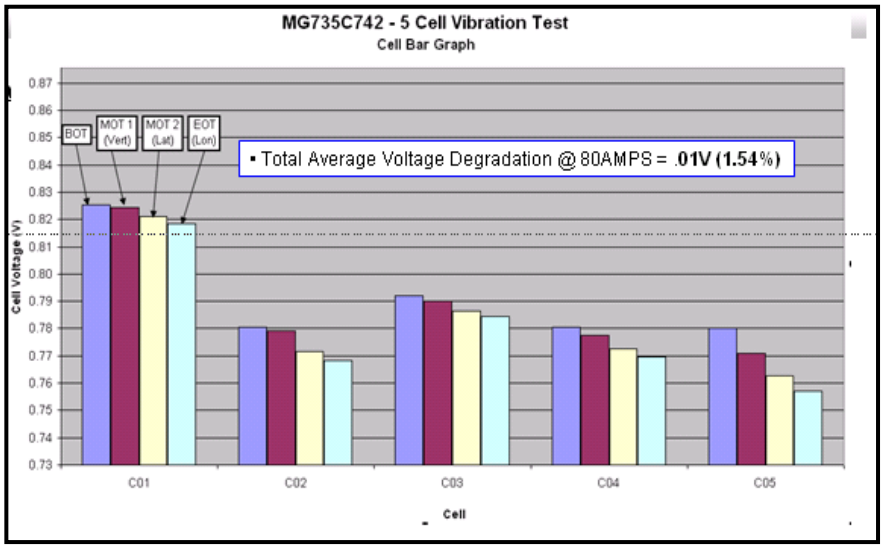
Technical Accomplishments and Progress

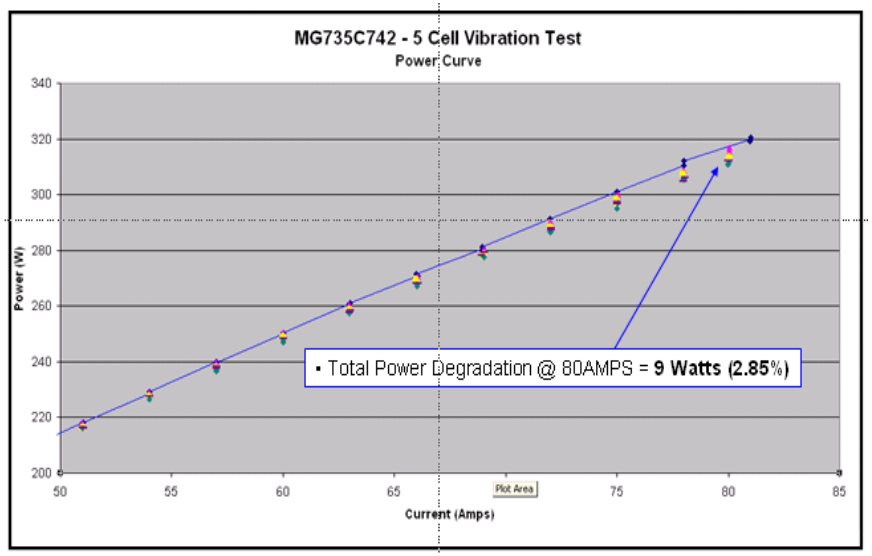
Perform Accelerated Vibration Durability Test

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

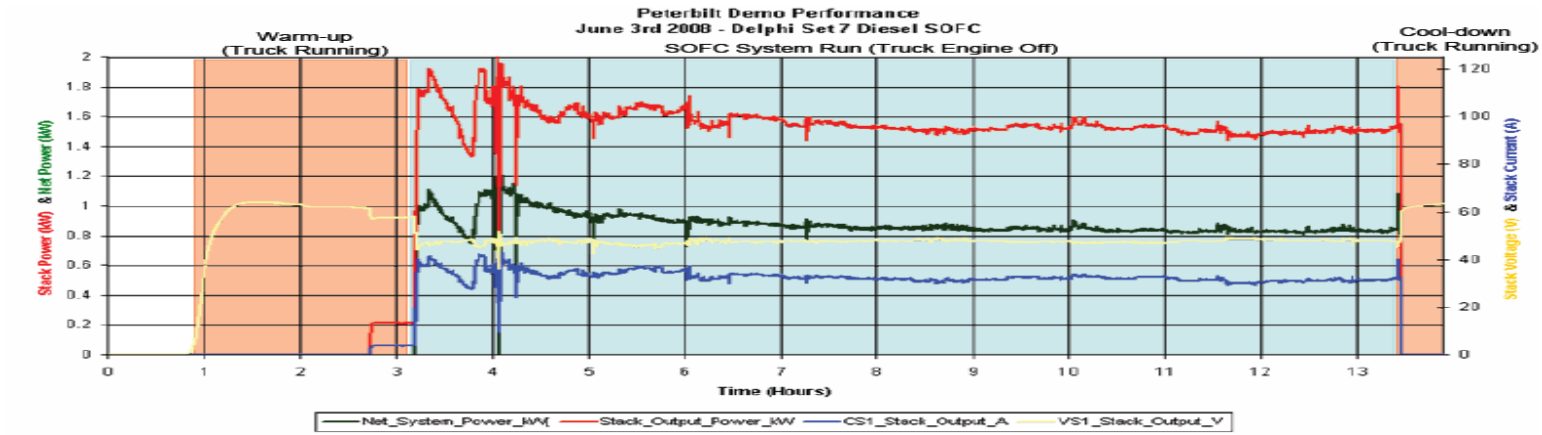
June 2008
Denton, Texas

Daimler / Freightliner

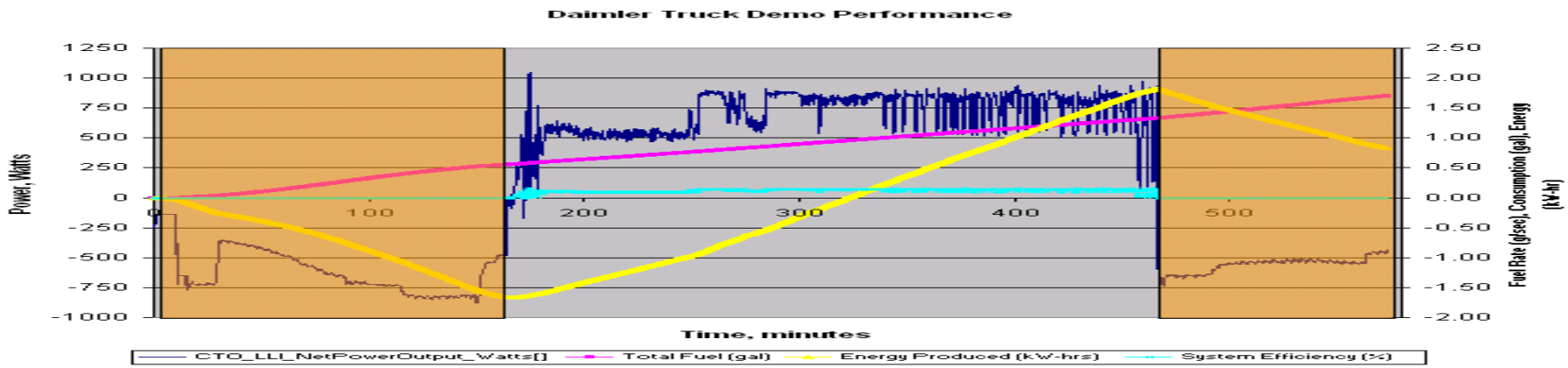
November 2008
Portland, Oregon

Technical Accomplishments and Progress

Steady State Performance



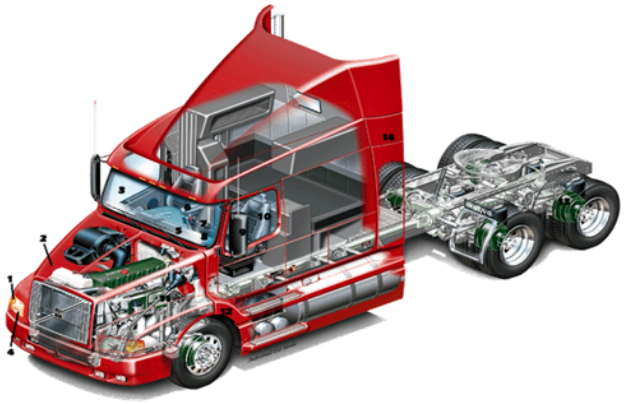
Transient Performance



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**