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

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Partners: PACCAR, Volvo Trucks North America (VTNA), & Electricore

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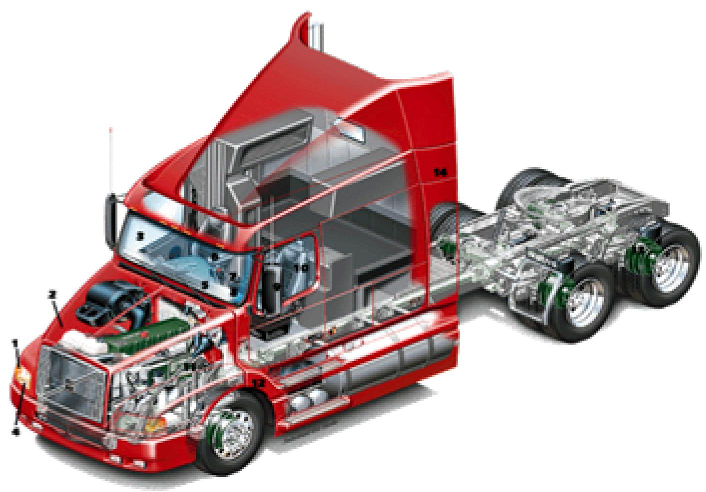
Delphi has teamed with OEM's PACCAR Incorporated and Volvo Trucks North America (VTNA) to define system level requirements for a Fuel Cell (SOFC) based Auxiliary Power Unit (APU) for the commercial trucking industry.

VOLVO



Volvo Trucks North America (VTNA), Greensboro, NC

PACCAR

KENWORTH

DAF

Foden Trucks

Peterbilt

PACCAR, Mt. Vernon, WA

Agenda

- Overview
- Objectives
- Milestones
- Approach
- Technical Progress
- Technical Results
- Future Work
- Summary

Overview

Timeline

- September 2004
- April 2010

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

- 50% Complete

Budget

- Total project funding
  - DOE - $3,000,000
  - Delphi - $1,750,000
- $438,480 received in CY07
- $1,213,274 planned for CY08

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.

Delphi Solid Oxide Fuel Cells Market Opportunity

Heavy Duty Truck
Diesel

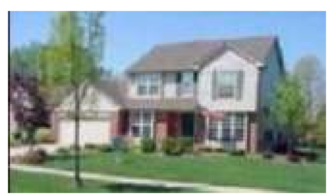
Recreational Vehicles
Diesel, LPG

Truck and Trailer Refrigeration
Diesel

US Military
JP-8

MARKET DERIVATIVES

European mCHP & CHCP
Natural Gas



US Stationary – APU & CHP
Natural Gas, LPG

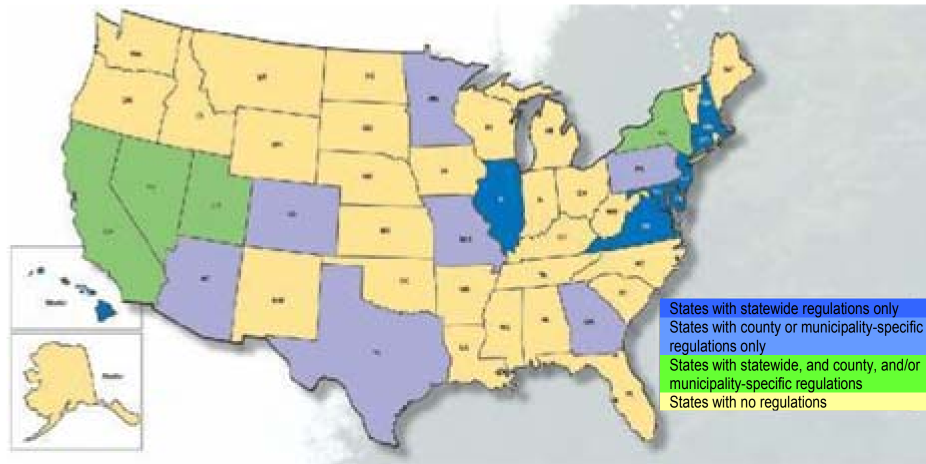
Commercial Power
Natural Gas

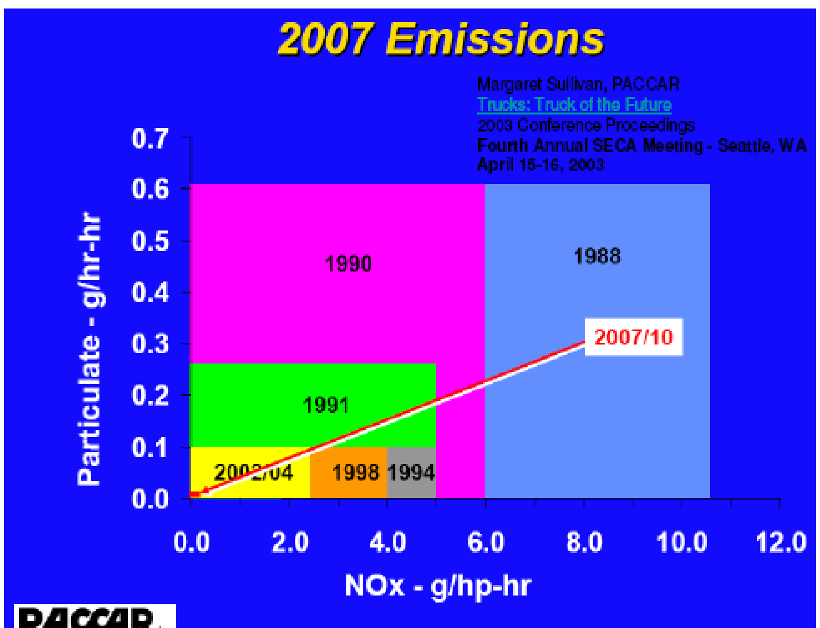
FutureGen Powerplant
Coal Gas

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

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

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

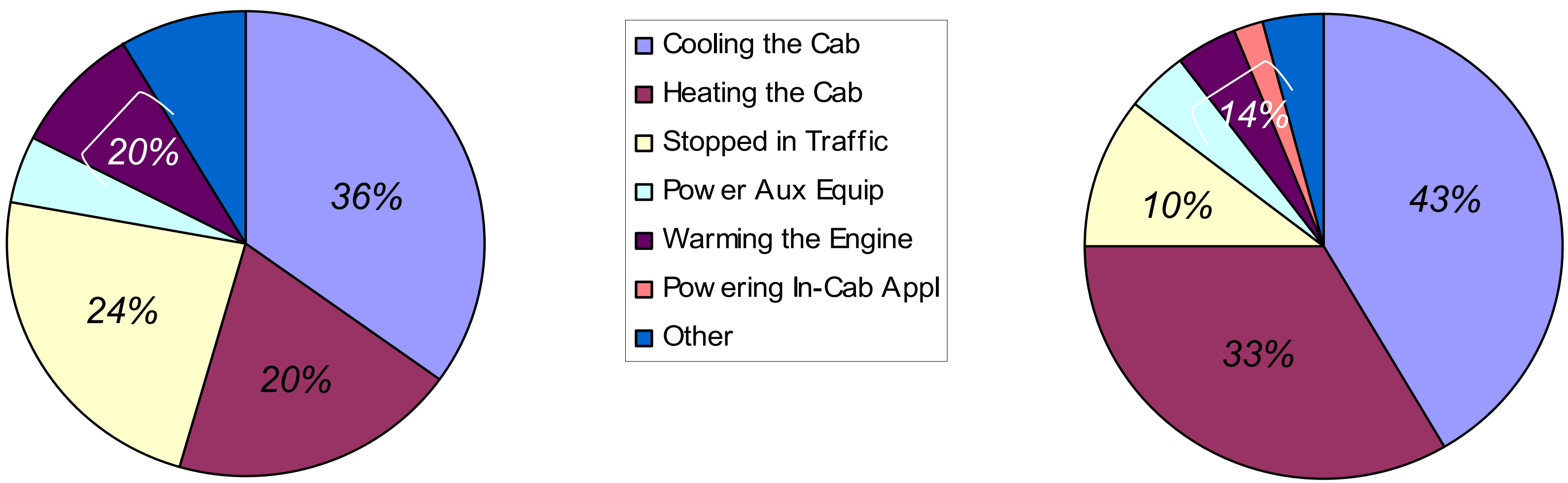
OEM load profiles identify potential power requirements of 2.5kW and 4.0kW respectively

Heavy Duty Truck Market Idling Time

Time Idling by Activity

Day Cabs

Sleeper Cabs



Average Idle Time (Day Cabs)
6 hr/wk
312 hr/yr

Average Idle Time (Sleeper Cabs)
28 hr/wk
1,456 hr/yr

Source : “Idle Reduction Technology: Fleet Preferences Survey” ,American Transportation Research Institute, February 2006

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

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

Milestones

Month/Year	Milestone
October 2007	**Sub-Milestone Review #1:** This milestone focused on the development of vehicle and APU system mechanization concepts; and the Development of the APU system requirements document.
April 2008	**Sub-Milestone Review #2:** This milestone focused on the APU design and layout; and Developing the subsystem requirements document and development plan.
September 2008	**Sub-Milestone Review #3:** This milestone will focus on the SOFC APU hardware design and build; Subsystem test fixture hardware development; and Subsystem testing and development iterations.

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

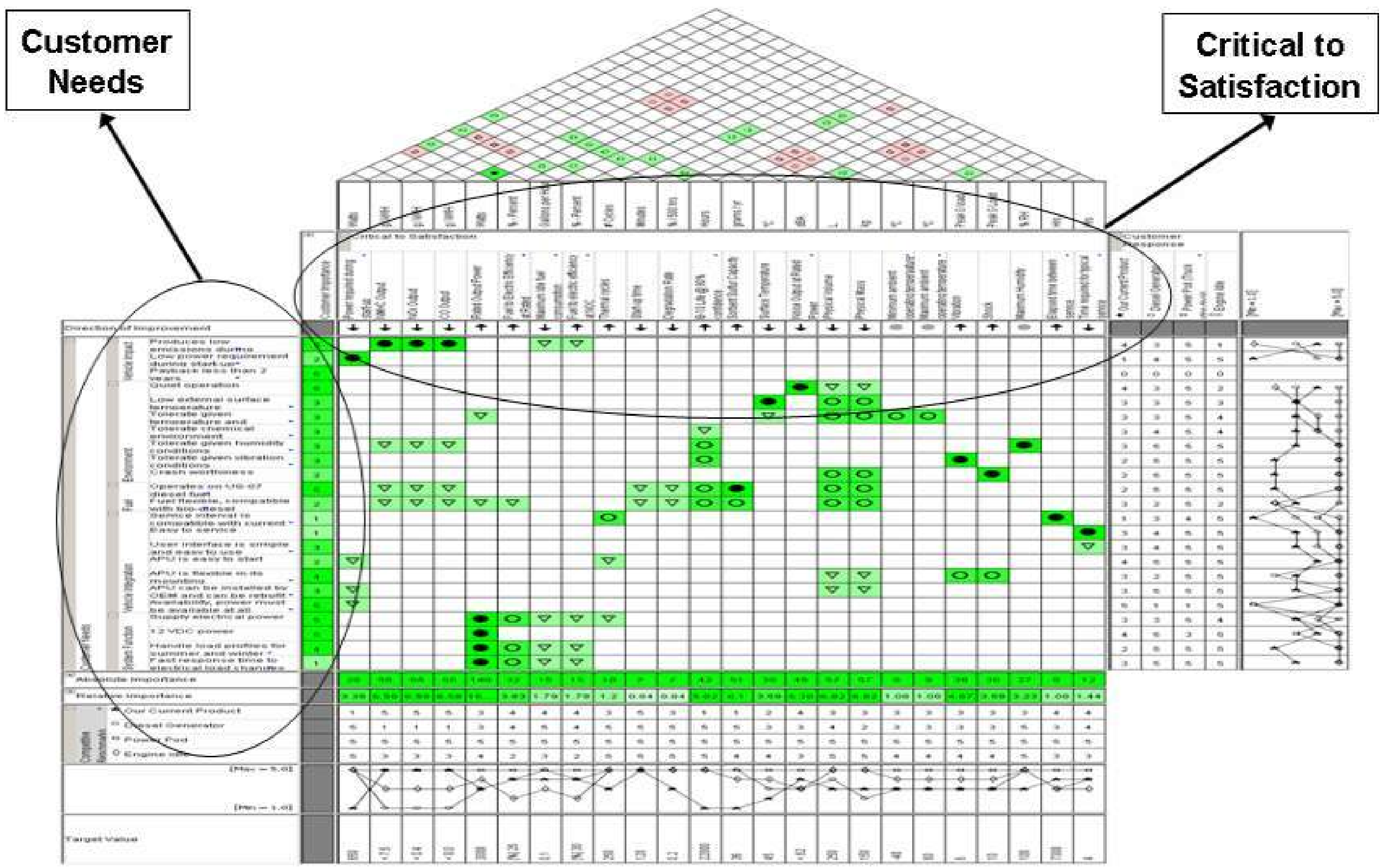
Phase 2: Design/Build/Development

- 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

Customer System Requirements
House of Quality



System Requirements

Critical to Satisfaction	Value	Units	Rationale
Rated Output Power	3.5	kWatts	Net power out - based on truck usage profile, and volume & mass constraints
Fuel to electric efficiency at rated power	25	%	Need to be better than current Diesel GenSet
Thermal Cycles	250	# cycles	1 cycle/week, 50 wks/yr, for 5 yr 1 cycle equals going from ambient temp to operating temp and then back to ambient
Sulfur Tolerance	15	PPM	ASTM D975, Grade No. 2-D, S-15 Sulfur content < 15 ppm
Emissions – NO_x CO NMHC	0.4 8.0 7.5	g/KWH	Per Tier 4 Emissions Standards for Non-Road Diesel Engines

System Requirements

Critical to Satisfaction	Value	Units	Rationale
Min Ambient Operating Temperature	-40	ºC	Per Customer Requirements
Max Ambient Operating Temperature	60	ºC	Per Customer Requirements
Surface Temperature	45 or 11 above ambient	ºC	The greater of the two, per OEM requirements document
Physical Mass	150	kg	Need to be better than current Diesel GenSet
Physical Volume	250	Liters	Based on Current Diesel GenSet Dimensions of L686 x D584 x H660
Economic Payback	< 2	years	Per OEM requirement

Technical Results

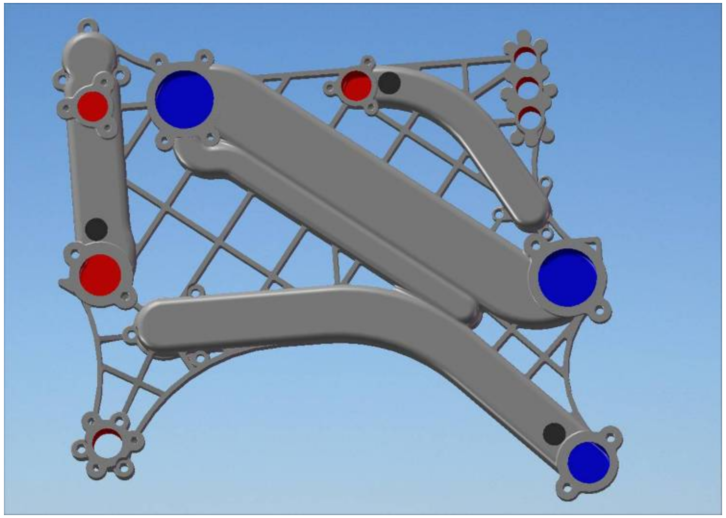
Balance of Plant

New manifold design

- Single flow layer; one casting
- Simplified geometry
- Smaller footprint/ package size
- Round c-ring seals vs. oval

Current Generation

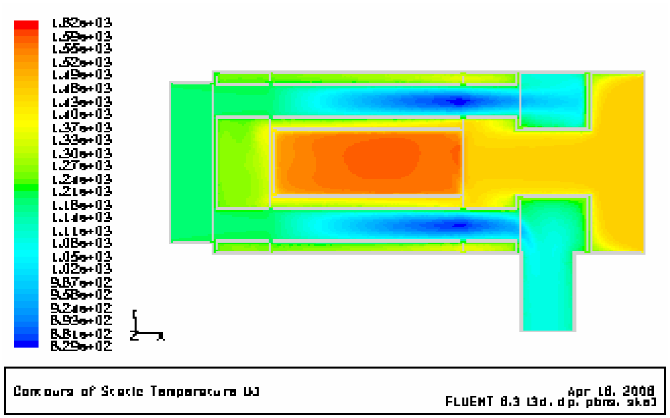
Next Generation



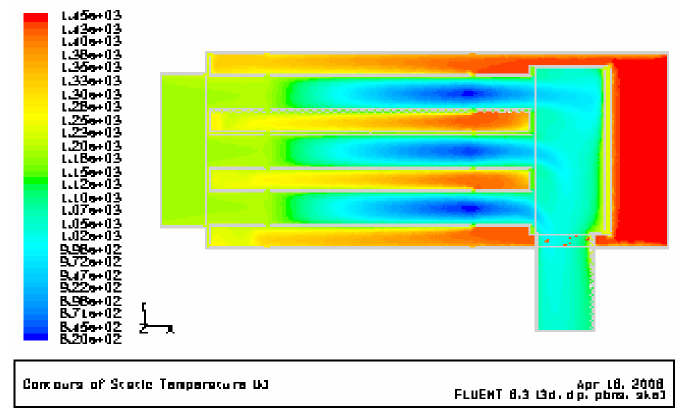
Fuel Reformer Development

- Delphi is developing reforming technology for Diesel/JP-8 SOFC applications, by modifying our existing Natural Gas reformer
- Two main designs are being developed:
  - **CPOx Reformer**
    - Moderate efficiency
    - Simplicity of design
    - Not recycle capable
  - **Recycle Based (Endothermic) Reformer**
    - High efficiency
    - Use of water in anode tailgas to accommodate steam reforming
    - Recycle capable

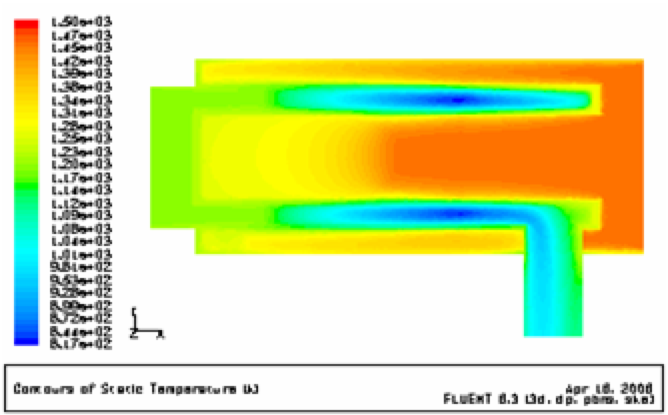
Reactor Modeling –Temperature Results



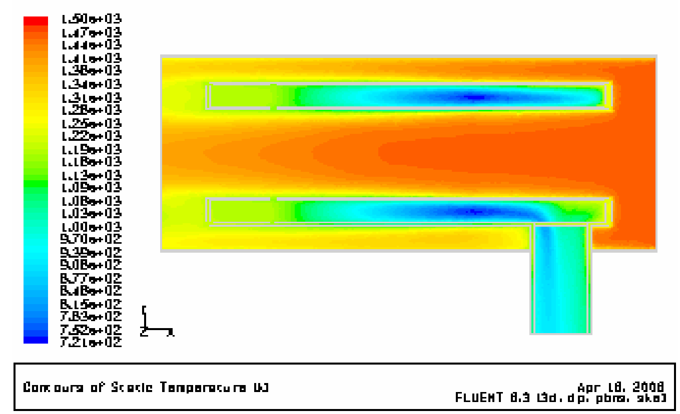
Concept A1



Concept B1



Concept C1



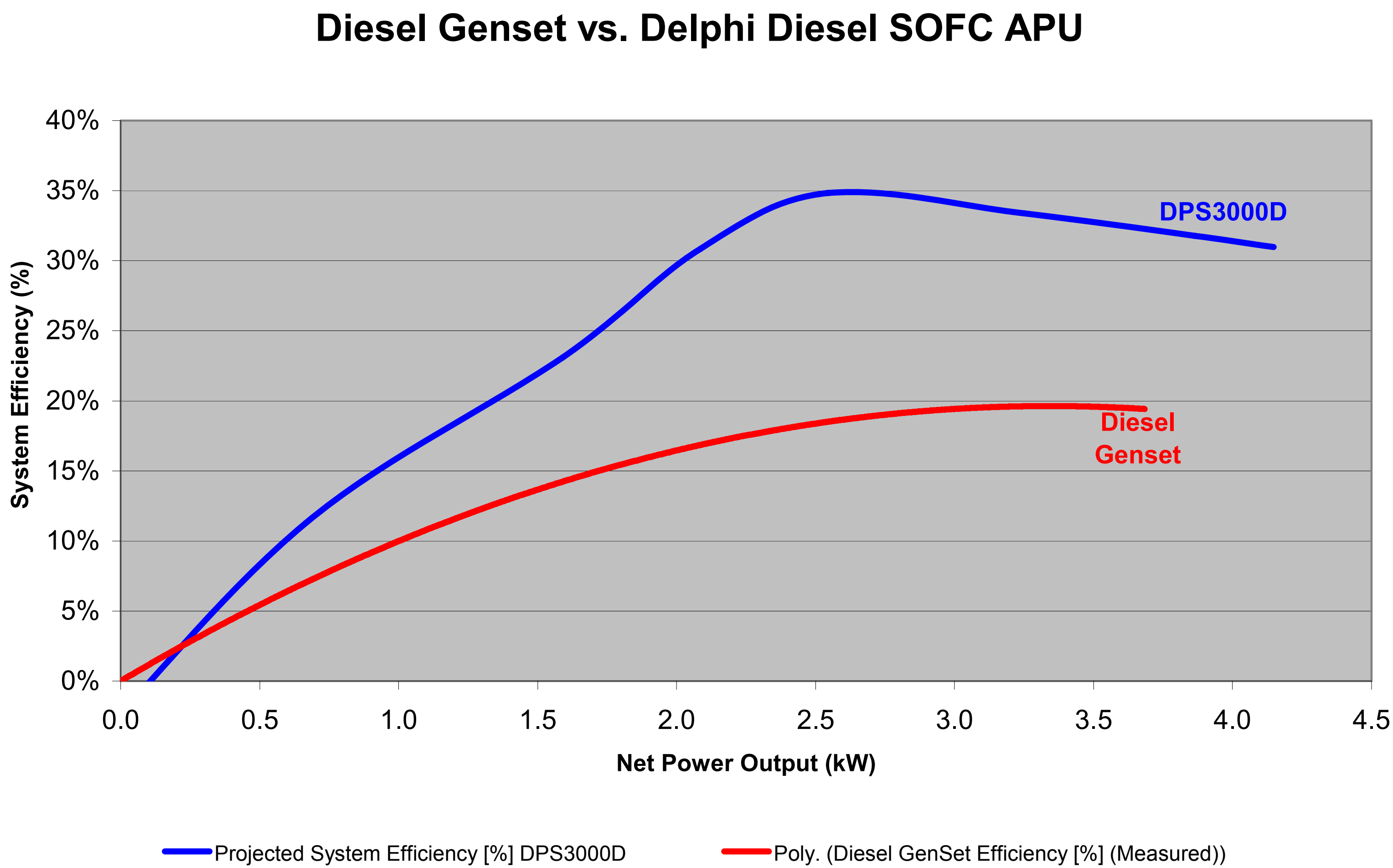
Concept D1

Technical Results

System Performance Design Analysis

		SPU 1E Gap	DPS 3000 Enhancement
	Power Level (3.5kW net)	1 - 1.5 kW Stack Cooling Limited	3 - 3.5 kW Stack Cooling Limited
System Efficiency	Parasitic Power Losses	High parasitic loads due to high pressure drop components and high stack cooling airflow required	Opportunities for reduce pressure drop and improved stack cooling
System Efficiency	Fuel Processing Efficiency	Lower efficiency with CPOx reformer with low recycle flow	Improved efficiency with "Endothermic" reformer and high recycle flow
System Efficiency	Heat Loss	High heat loss due to thin insulation and high internal thermal communication (undesirable)	Increased inisulation thickness and thermal component compartmentalization

Technical Results – Truck Demonstrator

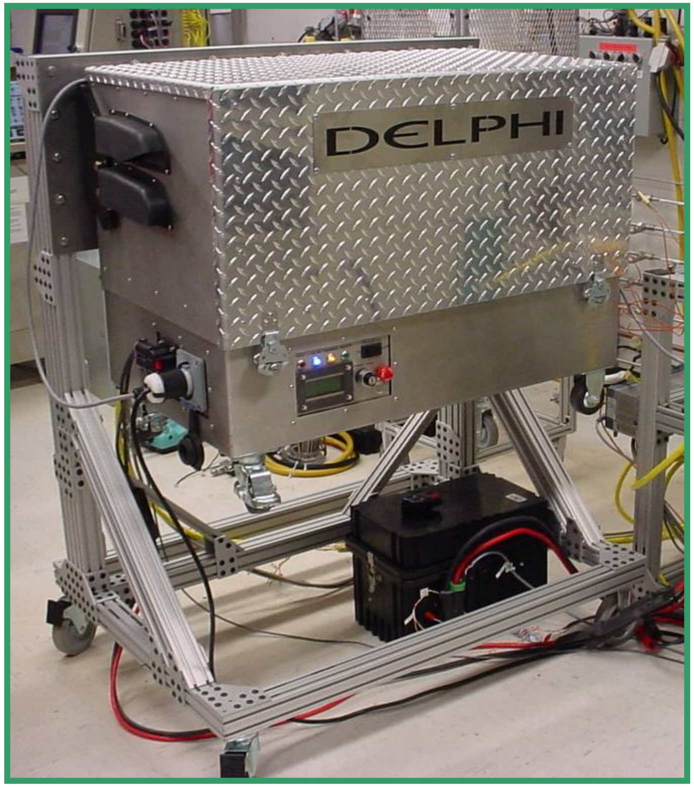


Technical Progress

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 Progress – DPS3000D

Major Design Efforts in Diesel APU Development

- 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

DPS3000-D (244 Liters)

(25 in long x 22 in wide x 27 in tall)

Future Work

2008

- Finalize the Subsystem Requirements Document and Development Plan
- Complete the SOFC APU Hardware Design and Build
- Design Subsystem Test Fixture Hardware
- Begin Subsystem Testing and Development Iterations

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 (September 2009)
- Begin Full SOFC APU System Testing

Summary

- **Primary Market Drivers**
  - Anti-Idling Legislation
  - Emissions Legislation
  - Increasing Heavy Duty Truck Cab Electrical Loads
  - Transportation Fuel Cost
- **Preparing 2nd / 3rd Quarter On Truck Installation to Continue Developing APU Requirements**
  - Using a modified Natural Gas APU in an Integration Enclosure
- **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**