DELPHI

PACCAR TDA Research

DOE PEER REVIEW
2012

"Solid Oxide Fuel Cell Diesel Auxiliary Power Unit Demonstration"

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DELPHI
May 16, 2012

Partners: PACCAR, TDA Research, Inc

This work is supported in part by the U.S. DOE under Cooperative Agreement
DE-EE0000478

Project ID: H2RA002

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- August 2009
- April 2013
- 80% Complete

Budget

- Total project funding
  - DOE share: $2,400,000
  - Delphi share: $2,400,000

Barriers

- Barriers to address:
  - System Vibration Robustness
  - Packaging / size (Form factor)
  - System Weight
  - System Cost
  - System Manufacturability
  - System durability / reliability

Partners

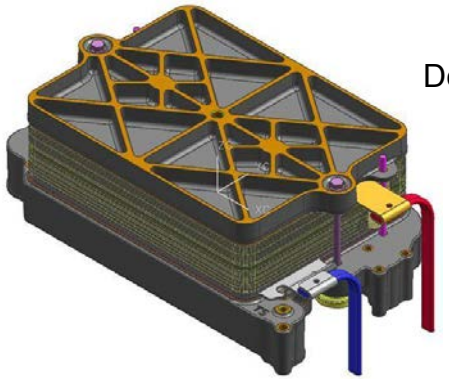
- PACCAR, TDA Research Inc.

Relevance: Objectives

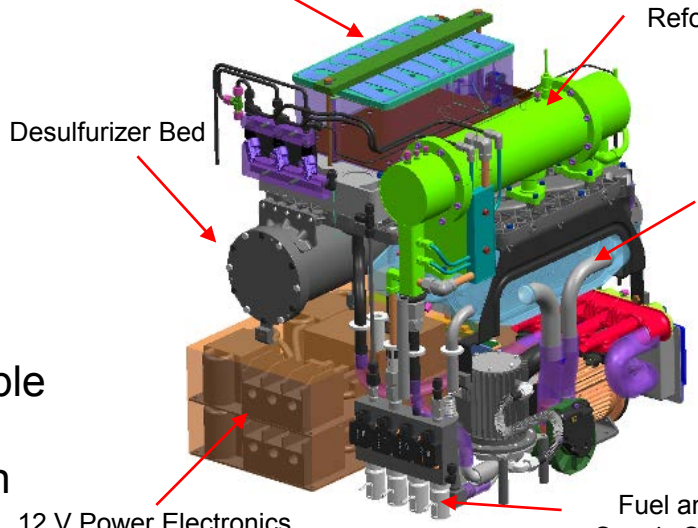
- DOE's support of Solid Oxide Fuel Cells Development will:
  - Support Delphi's continued investment in the Fuel Cell Technology
  - Accelerate the commercialization and high volume manufacture of SOFC Auxiliary Power Unit (APU)Technology
  - Augment the US's long term energy policy by enabling the development and commercialization of alternate energy technology
  - Provide immediate job creation / retention during the Development Phase
    - Jobs created / retained: **9**

Relevance: Objectives

- **Market Drivers**
  - 30-states currently have Anti-Idling Regulations
  - Delphi's SOFC meets 2012 EPA Emissions Regulations and **offers a solution to newly approved 2014-2018 NHTSA/EPA Standards**
- **Benefits Compared to Diesel Engine APUs**
  - Fuel Efficiency: 40-50% higher
  - Emissions: Meets current emission standards with no aftertreatment
  - Noise: Very low noise
  - Durability: Significant improvement expected
- **Delphi is:**
  - Meeting budget forecasts
  - Behind schedule for long term fleet test due to balance of plant components
  - Designing components and subsystems capable of meeting production requirements
  - Committed to developing SOFC and a solution for the heavy duty truck market



Delphi Gen 4 Stack



Relevance - Heavy Duty Truck Market Drivers

Increasing Cab Electrical Loads

Truck load profiles identify potential power requirements of 2.5kW and 4.0kW

In-Cab Appliances Include

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

Approach - Objectives

Complete a 30-month contract with the DOE EERE:

- Define System Specifications and Commercial Requirements
  1. Define Subsystem requirements
  2. Develop subsystem requirements document
- Design, Build and Test the Diesel APU system
  1. Verification testing of APU subsystems
  2. Form and packaging re-design
  3. APU System vibration analysis
- One year vehicle demonstration and data analysis

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

Approach – 2010 Milestones

Month/Year	Milestone and Go/No-Go Decisions (Immediate)	Complete
April 2010	**Milestone Review #1:** Requirements Document complete	**100%**
July 2010	**Milestone Review #2:** SOFC APU System Design Release Go / No Go	**100%**
October 2010	**Milestone #3:** System Integration APU Complete	**100%**
December 2010	**Milestone #4:** In-house Tests Complete Go / No Go .	**90%**
January 2011	**Milestone #5:** Deliver APU to Demonstration Site (**now planned for May 2012**)	**0%**

Approach

Phase 1: OEM input Collection

- Delphi worked with PACCAR to establish the APU Application Specifications and specific Commercial requirements.
- Information was compiled into Delphi's "House of Quality" that then established the various Subsystem Requirements

Phase 2: Design/Build/Test

- 2010 Phase 2 effort is design and component verification period
- Late Phase 2 work will include system testing: both bench top and vehicle.
- Additional Desulfurizer development will be performed during this phase.

Phase 3: Site Demonstration / Analysis

- During 2012 and 2013, the APU System will be demonstrated on a Class 8 vehicle, as part of a controlled vehicle fleet.
- The data gathered during the demonstration will be analyzed and reported.

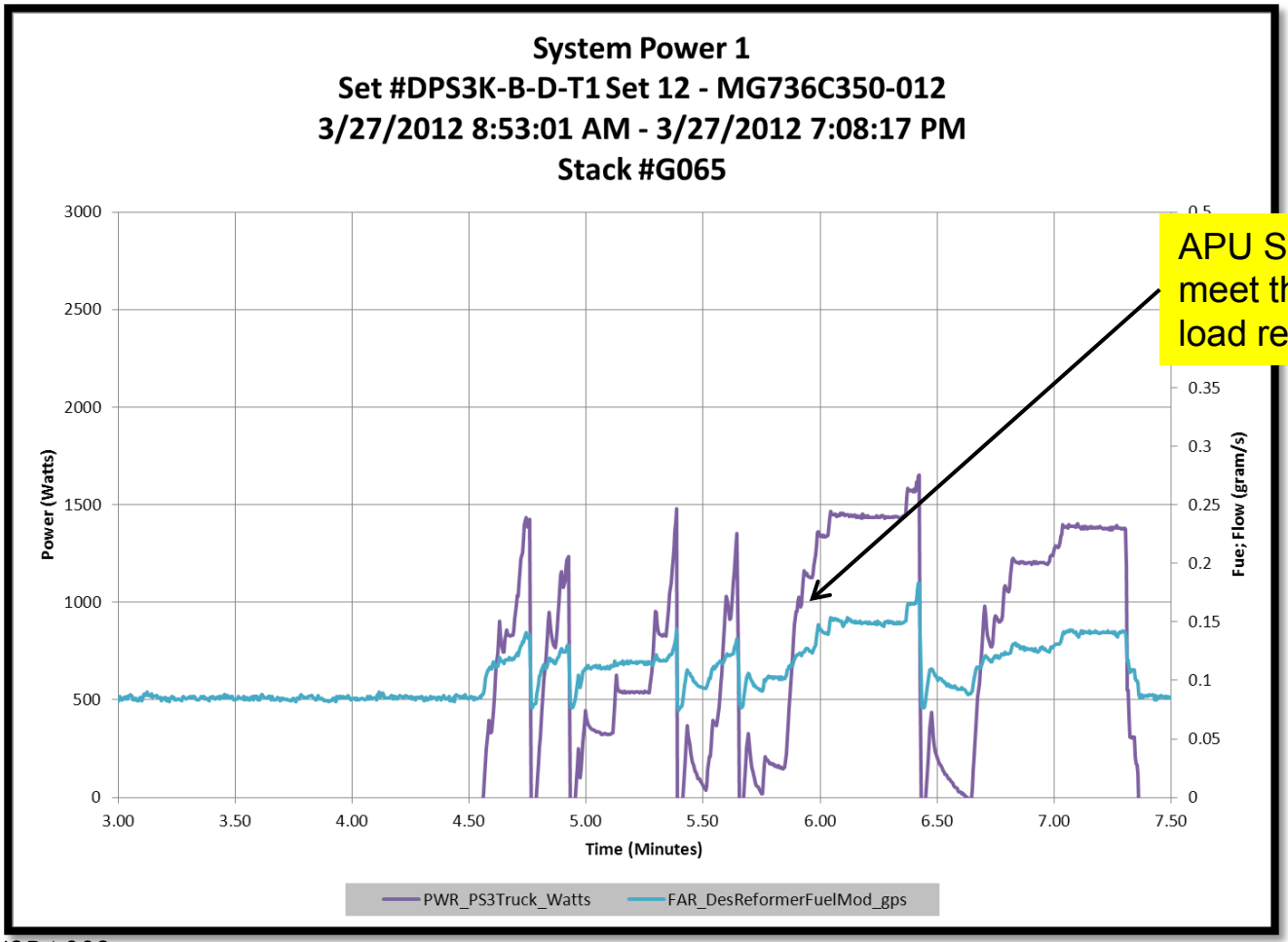
Technical Accomplishments and Progress

Major Design Efforts in APU Development

- B Level Vehicle Testing
  - B Level SOFC APU has been installed and operated on a Peterbilt Class 8 Truck.
  - Start up and shut down functions supported with truck electrical system
  - Hotel loads supported by APU when main engine is turned off
- B Level Laboratory Testing
  - Load cycle functionality and durability testing in process
  - System Efficiency Testing
  - Fuel Consumption at APU idle development
    - Demonstrated <.085 gal/hour
  - Delivers 2kW for Hotel Loads

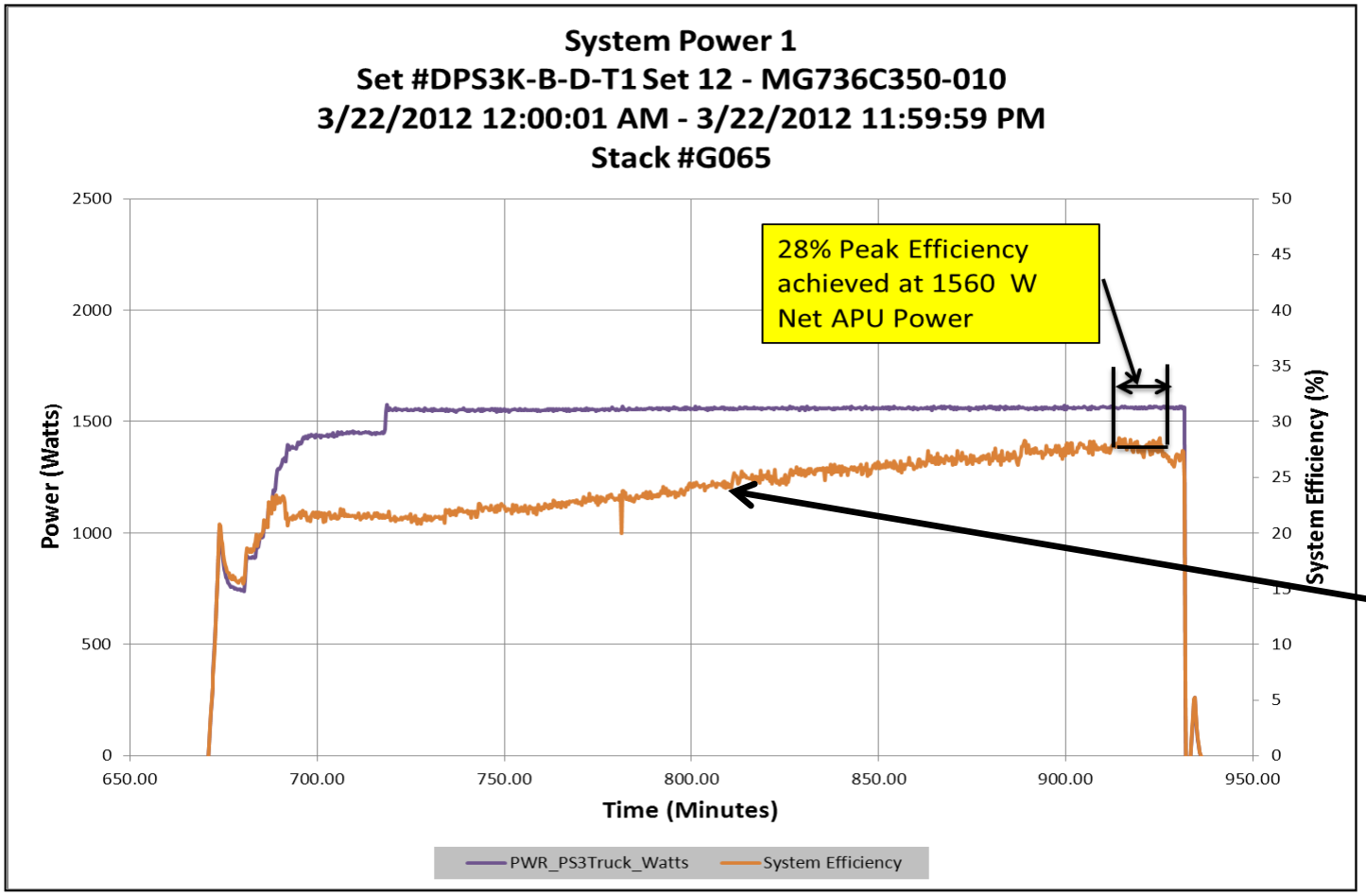
Technical Accomplishments and Progress

Load Cycle Test

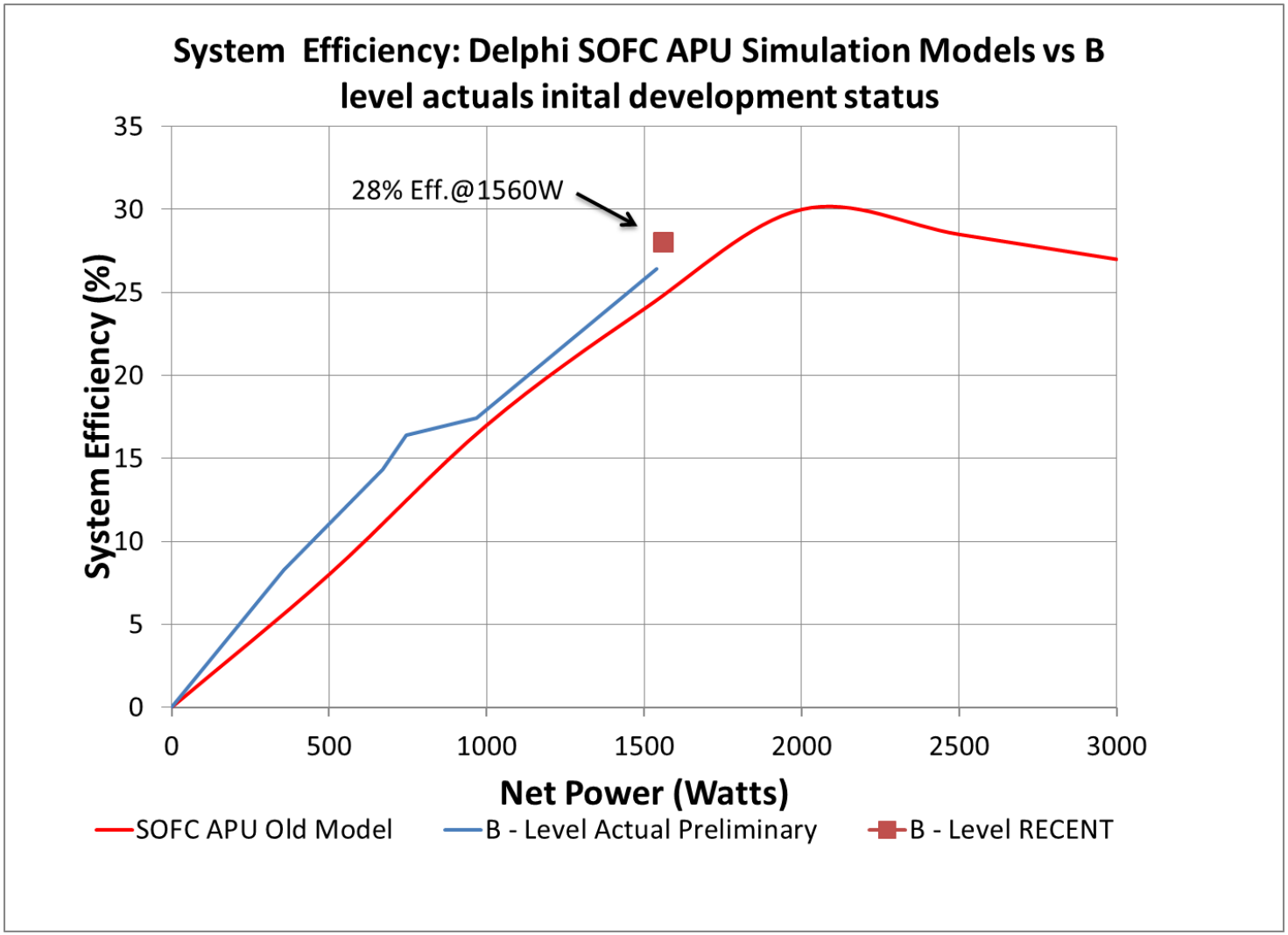


Technical Accomplishments and Progress

SOFC APU Development – System Efficiency



Accomplished through calibration optimization


System Efficiency: Delphi SOFC APU Simulation Models vs B level actuals inital development status
28% Eff.@1560W
System Efficiency (%)
0
5
10
15
20
25
30
35
0
500
1000
1500
2000
2500
3000
Net Power (Watts)
SOFC APU Old Model
B - Level Actual Preliminary
B - Level RECENT

Technical Accomplishments and Progress

SOFC APU Development – Vehicle Integration

Preparation for Road Test

We have had Great Partner Cooperation to Develop Schedule

1. Operator Instructions and Training
   a. Manual Prepared
   b. Driver will be trained before starting use
2. Service Plan
   a. Frequency of checks by Delphi Engineers
   b. Training of technicians on site
3. Safety
4. Data Collection

Technical Accomplishments and Progress

Delphi SOFC APU User Manual

- Driver Interface
- Safety Systems
  - Extinguisher System
  - Idling in a garage area
- Data acquisition systems
- APU to truck connections
  - Fuel connection, power connections, fire suppression system, controls
- General system information
  - Fuel
  - Start up shut down
  - Other
- Other Information
  - Key contacts
  - Service Maintenance plans
  - Operating limits

Technical Accomplishments and Progress

Delphi Fuel Cell APU User Manual: Operation / Driver Interface

- The Fuel Cell APU controls are mounted in the sleeper control panel as shown below. These are the main control interface between the driver and the Fuel Cell APU. These controls allow the driver to start up and shut down the system and provides the driver information about the operating status of the system.

Technical Accomplishments and Progress

Delphi SOFC APU User Manual: Safety System

- As the SOFC APU is a development system, Delphi has included a fire suppression system in the installation. The SOFC APU has a sensing and dispensing fire suppression built into the APU so the system is fully automated. An external bottle is mounted to the back of the cab and connected to the APU.
- Controls for the fire suppression system are also included in the sleeper control panel.
- The system can be manually actuated through the large red button at the bottom of the sleeper control panel.
- In case of a fire, activate the fire suppression system first and then the APU E-Stop button.
- Note: This fire suppression system is only for Development.

Technical Accomplishments and Progress

Delphi SOFC APU User Manual: Extinguisher System Control Panel Indicator Lights

System Control Indicators
Operational, ok
Green light– ON

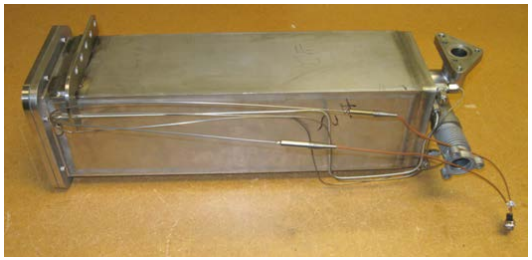
System activated
Red light – ON

Recharge tank required
Red LED – ON

Technical Accomplishments and Progress

♦ **Sorbent Bed for H2S Removal from the Reformate**

- Requirements
  - 3.8 liter Sorbent Bed
  - Removes H_2S to below 10 ppbv
  - Functional life of 6 months at normal APU operating conditions
  - Sorbent Cartridge is readily exchanged for fresh sorbent
- Issues
  - Initial selection for Sorbent Material has safety issues
  - Second selection for Sorbent Material:
    - Has been difficult to produce repeatably
    - Has lower capacity
    - Has an interaction with the reformer during startup operation
      - Reaction of sorbent with air and reformate cause a Non Combustible Mixture in the recycle loop.
      - The Recycle Loop Mixture is used to fuel the combustor during start up elevate the reformer/system temperature.
- Truck Delivery has been delayed to solve the problem during startup



Future Work

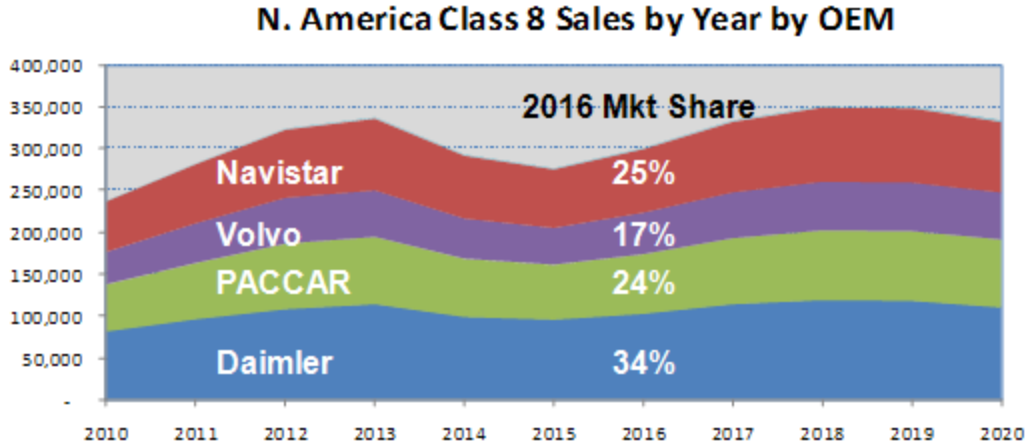
2012

- Address Desulfurizer issues / concerns
  - Low capacity issue
    - Will replace sorbent cartridge more frequently
    - Working with TDA to develop a higher capacity material
  - Startup issue
    - Developing start up strategy that will avoid the introduction of the reformate to the sorbent material during a critical temperature range.
- Complete one year Demonstration

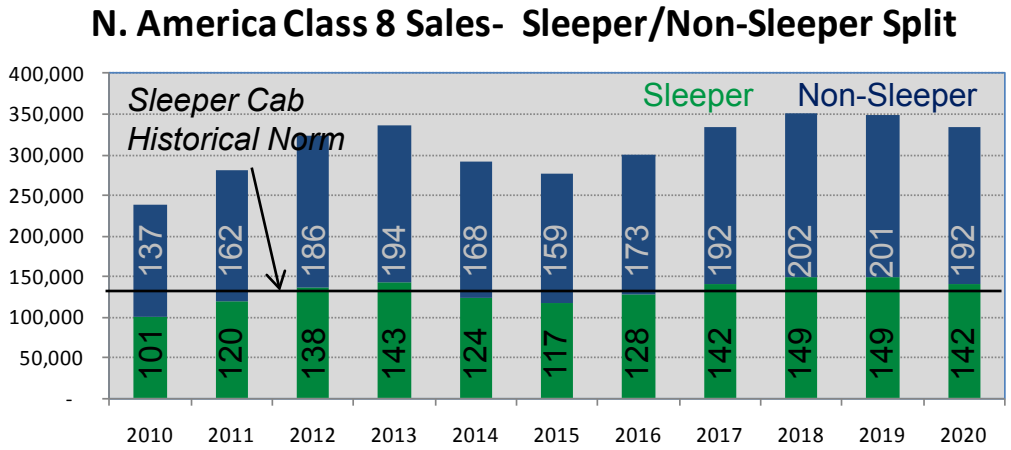
Questions/Comments from 2011 Review

- Commercialization
  - Market Analysis (See next page)
  - Capability of Technology to be Commercialized
    - Results of this demonstration and additional validation vehicles are key
  - System Costs
    - Delphi is monitoring the costs of competitive solutions and will make the decisions for cost and commercialization with our customers/partners.

US Class 8 Truck Regulations are Driving Volume Requirement



- Class 8 Sleeper Trucks represent the initial SOFC Application
  - APU's to meet emission and anti-idling regulations
  - Sleeper Trucks average 43% of all Class 8 Trucks



Volume Source: Apr '11 IHI
Sleeper/Non-Sleeper Split: ACT Research & Delphi Mktg

Collaborations

Delphi has teamed with OEM' PACCAR Incorporated to define system level requirements for a Fuel Cell (SOFC) based Auxiliary Power Unit (APU) for the commercial trucking industry and TDA Research, Inc. for desulfurization guidance and material/production development.

PACCAR
KENWORTH
Peterbilt
DAF
Foden Trucks

PACCAR, Mt. Vernon, WA

TDA Research

Wheat Ridge, CO

Summary

- **Delphi, PACCAR and TDA have:**
  - Built the APU for the demonstration
  - Demonstrated Low Fuel Consumption at Idle and High Efficiency at Normal Operating Conditions
  - Identified a Knowledgeable, Sophisticated Fleet Partner for the Demonstration
  - Installed the APU on the Wal-Mart Truck
  - Developed users manual and training for the driver
  - Fallen behind on timing due to ability to Desulfurize Diesel Fuel

- Delphi is Working to Introduce SOFC Diesel Technology in Full Scale Production for Heavy Duty Truck Applications