DOE MERIT REVIEW
2013

"Solid Oxide Fuel Cell Diesel Auxiliary Power Unit Demonstration"

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DELPHI
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Partners: PACCAR, TDA Research, Inc

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Project ID: H2RA002

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

Overview

Timeline

- August 2009
- April 2013
- 90% 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

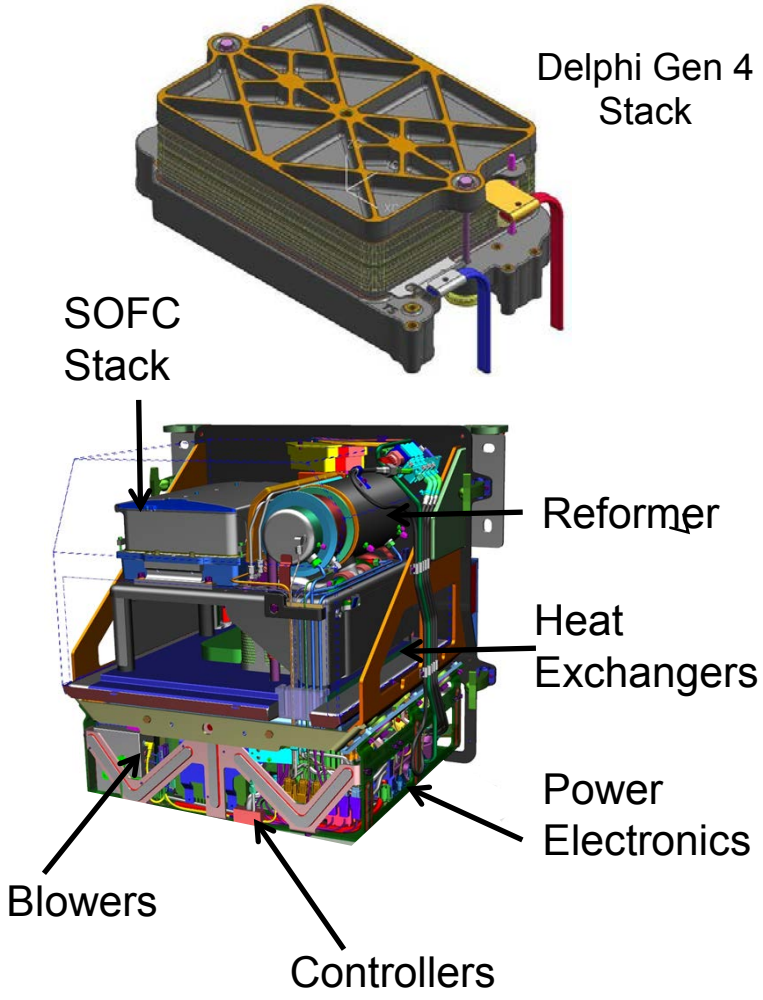
- 2014-2018 NHTSA/EPA Fuel Economy Standards do not mandate an APU, but requires the main engine to shut off.
- An APU provides the solution to the driver's need for electricity

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:

- Covering the costs in addition to the ARRA funding
- Behind schedule for long term fleet test due to balance of plant components
- Designing components and subsystems capable of meeting production requirements



Approach: Objectives

Complete a 30-month contract with the DOE EERE:

- Define System Specifications and Commercial Requirements
  - Define subsystem requirements
  - Develop subsystem requirements document
- Design, Build and Test the Diesel APU System
  - Verification testing of APU subsystems
  - Form and packaging re-design
  - 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 2013**)	**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 Delphi redesigned and recalibrated the APU system to operate without a desulfurizer.
- The demonstration phase will now be shortened due to timing.
- The data gathered during the demonstration will be analyzed and reported.

Technical Accomplishments and Progress

Major Design Efforts in APU Development

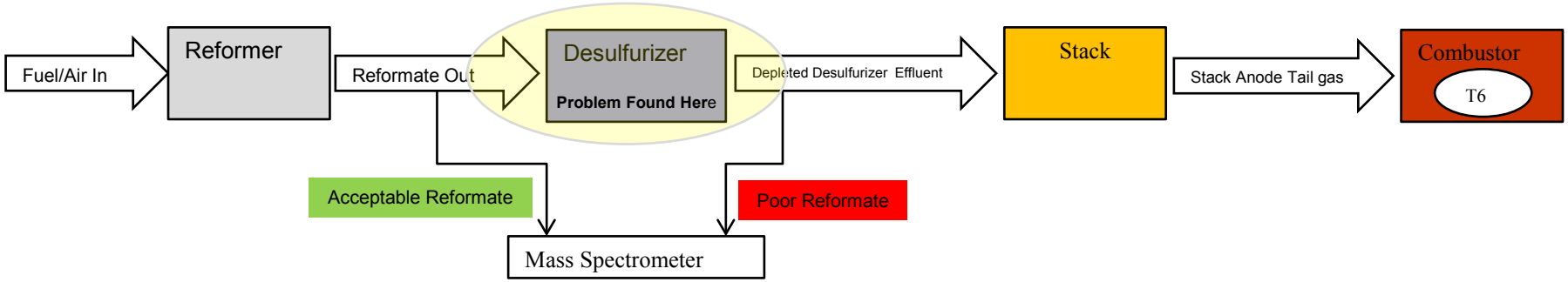
Rev 2 APU Vehicle Testing

- Wal-Mart provided the truck that was to be used in the test.
- Desulfurizer removed due to difficulty with sorbent
- System redesigned and recalibrated, to operate without sorbent
- APU operation confirmed in the lab
- APU operation confirmed on the truck, including installation of the required accessory equipment.
- Delivered truck with APU to Wal-Mart on Nov 15.
- Fuel reformer failure on first full day of operation in Wal-Mart fleet

- Additional discussion with Wal-Mart and PACCAR led Delphi to decide to complete an abbreviated testing period on a development truck within the Rochester, NY area. Proposal confirmed with DOE.

System Design Required Hot Reformate Desulfurizer

The desulfurizer is an integral part of the system, impacting reformate quality, temperature and flow.



Very Limited Options for Hot Reformate Desulfurizing

In additional to TDA development efforts, Delphi has made efforts on the search of hot reformate DeS sorbents capable to operate at ~750°C.

- Evaluated multiple potential materials with no success
  - Zeolite: confirmed that did not work at 750°C
  - Zinc titanate: confirmed that it is NOT stable at 750°C in H_2
  - NiCu-SBA16: it can only be used at a temperature < 500°C
  - Cu doped zinc oxide/silica; per patent, operating temperature: 300°C/400°C
  - Mn-based sorbent working at 600-700°C ; did not remove enough H_2S
  - ZnO: Confirmed it is NOT stable at 750°C in H_2
  - Ce and Zr oxides- Not expected to achieve 30-ppb based on literature data
  - La oxide: fine particles caused plugging issue
- After the evaluation, no sorbent performed well enough to be incorporated within the APU.
  - The decision was made to remove the Desulfurizer.
  - The performance of the Delphi stack allows for the system to be redesigned to achieve 3 kW, even with the degradation caused by Sulfur.

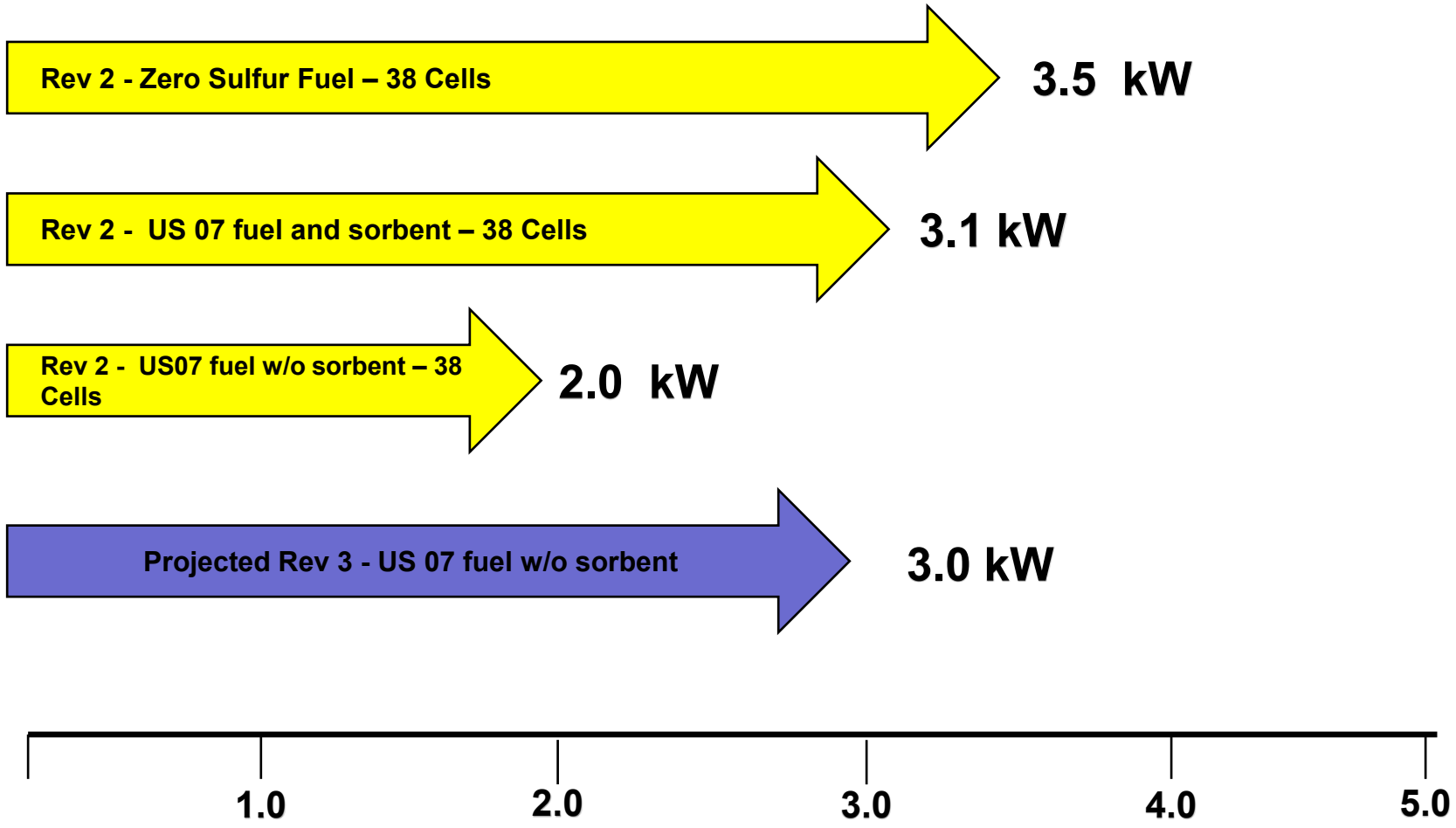
Very Limited Options for Hot Reformate Desulfurizing

The removal of Desulfurizer allowed/required redesign of the system

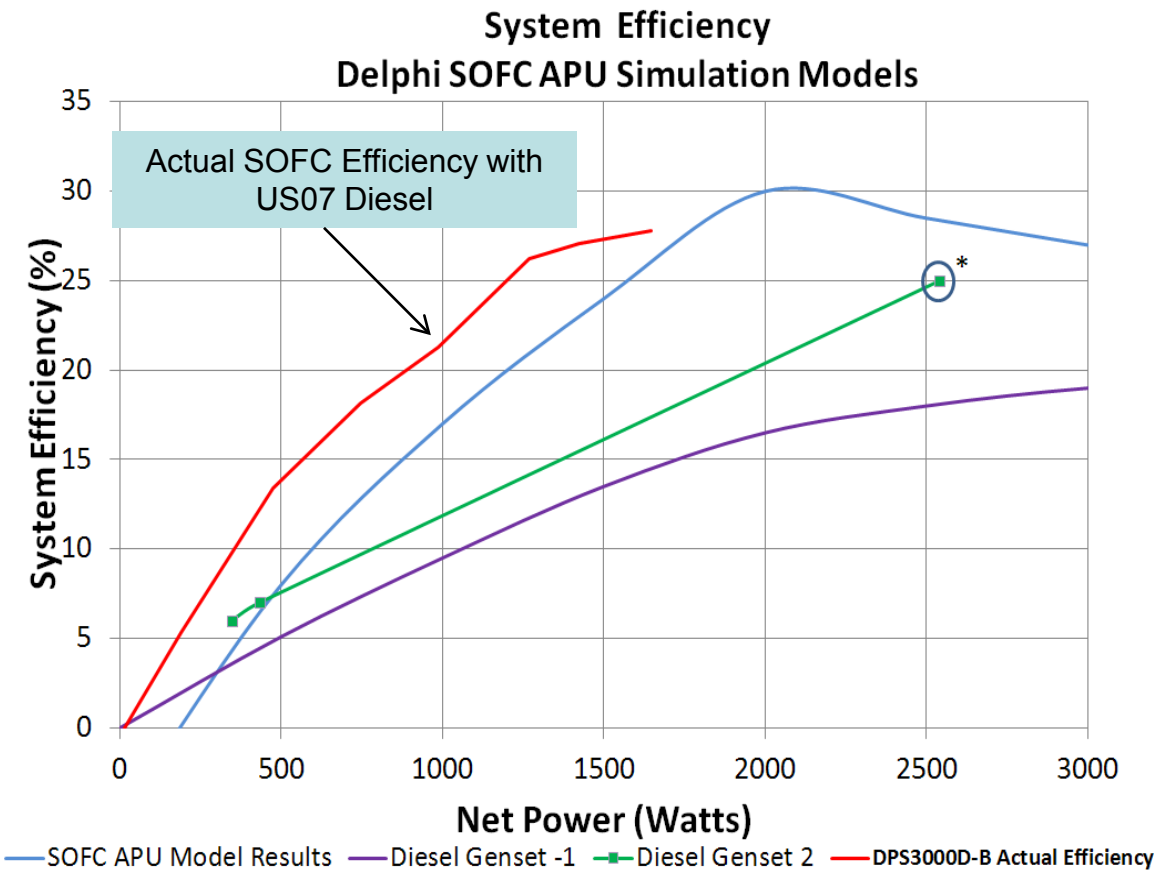
- Take advantage of additional space in the tightly packaged APU to:
  - Increase stack size
    - Potential for up to 45 cells
  - Improve airflow for cooling and reduced parasitic losses
    - Internal stack temperature is one of the key limiting performance factors
    - Parasitic loads from cooling fans and blowers reduce the system output and increase fuel consumption.
- Take advantage of reduced thermal mass during start up

The system redesign will not be ready for the shortened demonstration

System Net Power Walk Shows Impact of Sulfur and Redesign

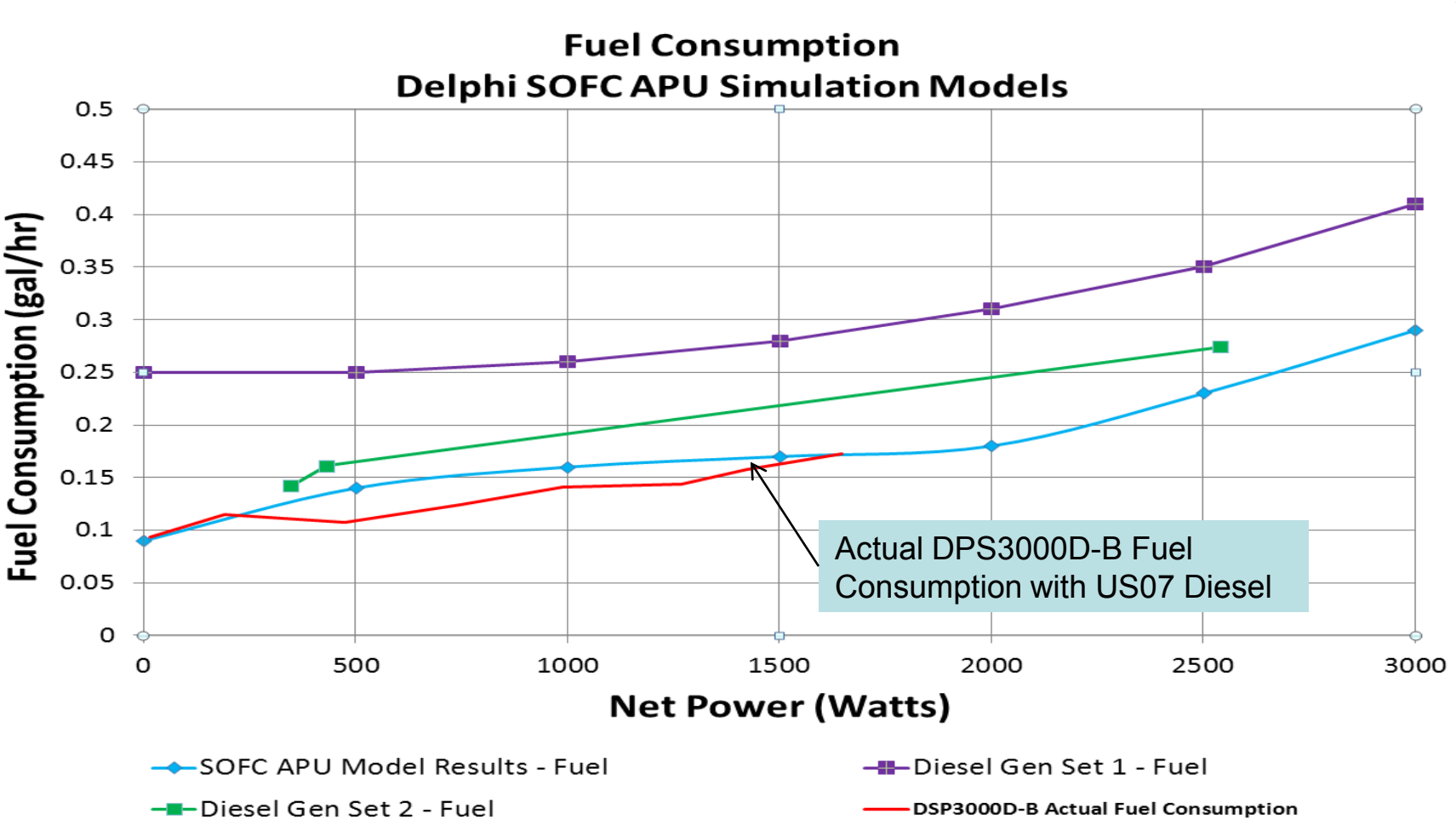


System Efficiency vs. Power Shows Benefit compared to Diesel APUs



* Calculated : Electric Power + Assumed 13,000 BTU/hr Cooling Capacity from mfr

Fuel Consumption vs. Power Shows Benefit compared to Diesel APUs



Preparation for Road Test

Delphi received good Partner cooperation with the development of the operation schedule.

- Operator Instructions and Training
  - Manual was prepared
  - Driver will be trained before initial use
- Service Plan
  - Frequency of assessment by Delphi engineers
  - On site training of technicians
- Safety
- Data Collection

Preparation for Road Test

Developed SOFC APU User Manual

- Driver's interface
- Safety systems
- Data acquisition systems
- APU to truck connections
- General system information

Control Panel Mounted in Sleeper Cab

Installed Control Panel In Truck

- Main control interface between the driver and the Fuel Cell APU.
- Allows the driver to start up and shut down the system
- Provides the driver information about the operating status of the system

Results of Road Test

During the first drive by the Wal-Mart operator there was a failure within the fuel reformer.

- The ceramic monolith cracked due to insufficient mounting and clearance with internal reformer tube.
- Required APU shut down and removal from truck

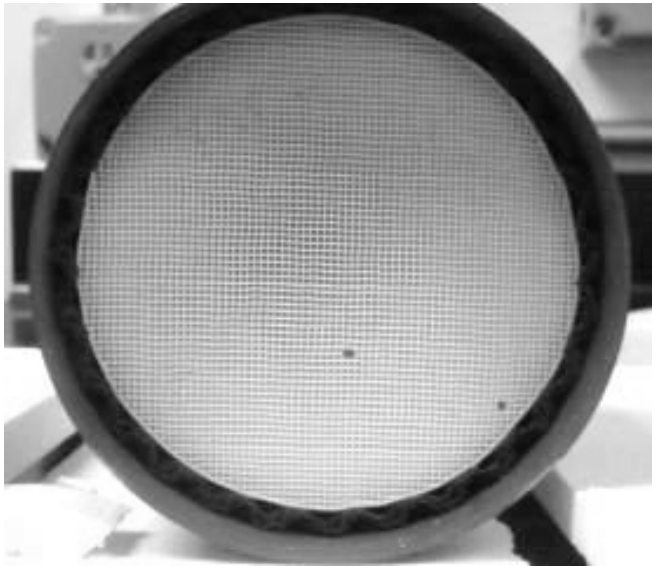


Figure 1: Normal Ceramic

Figure 2: Cracked Ceramic

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

Future Work

2013

- Install the APU on Peterbilt 386 Truck on loan from PACCAR
- Complete one month demonstration
- Report the results

Summary

Relevance

– Delphi's SOFC APU provides an efficient, durable, low emissions, and low noise solution for the 2014 – 2018 NHTSA/EPA Fuel Economy standards.

Approach

– Develop Commercial and System Requirements

– Design, Manufacture, and Evaluate the Diesel APU

Technical Accomplishments

– Wal-Mart provided a vehicle for integration and testing.

– The SOFC APU operated and successfully passed all confirmation testing prior to truck integration.

– The Wal-Mart truck was delivered with integrated SOFC APU.

Future Work

– Integration of SOFC APU with Peterbilt 386 truck from PACCAR.

– Demonstrate the unit for one month and report results.