Application of a SECA stack design into a Heavy Duty Truck APU.

12th Annual SECA Workshop

July 28th, 2011
SECA stack design concept utilization in an APU

Delphi is utilizing the development activity completed on the SECA stack design to be adapted into an APU application.

The benefits of doing so are:
- Transfer of technical and stack development activities into a new application.
- APU application environment and requirements are driven back into the SECA stack design making it a more robust design.
- As part of the APU the stacks are being subjected to the harsh environment required to operate in a heavy duty truck application.
- Utilize common test equipment and tooling.
- Potentially earlier implementation date into a commercial application.
Delphi Solid Oxide Fuel Cells
Market Opportunities

- Delphi Solid Oxide Fuel Cells Provide:
  - Ultra-clean, near zero emissions
  - High-quality, reliable power
  - High fuel efficiency
  - Fuel flexibility
  - Low noise

Heavy Duty Trucks
Auxiliary Power Units

Residential Power
Stationary CHP Power Units

Commercial Power
Stationary Power Units

Clean Coal & Natural Gas
Power Systems

Military
Auxiliary & Mobile Power Units

Clean Coal Power Plant
Advanced Power Systems

Application of a SECA stack design into a Heavy Duty Truck APU.

July 28, 2011
Delphi Has Chosen Three Main Markets for SOFC

◆ Heavy Duty Truck Auxiliary Power Units (APU) (3-5kW)
  - Greater than 50% of the states have regulations that limit HD truck idling.
  - DOE / EERE sponsored programs used for vehicle development and validation in 2010 to 2012.
  - Development with heavy duty truck OEM’s.
  - Delphi maintains a market leading position.

◆ SECA Stationary Power
  - Partnered with United Technologies in DOE SECA Coal Based Power System.

◆ Military Applications and Mobile Generators (5-50kW)
  - Testing underway Naval Undersea Warfare Center (NUWC).
  - Potential opportunities with office of Naval Research (ONR)
Delphi Solid Oxide Fuel Cell

SOFC APU's Enable Fuel Savings while Meeting Stringent Emission and Anti-idling Regulations

◆ Market Drivers/Regulations
  – Greater than 50% of states currently have anti-idling regulations
  – Delphi SOFC APU meets 2012 EPA emissions regulations

◆ Compared to diesel engine APU's, SOFC APU's are:
  – 40% more efficient than the diesel APU's
  – Able to provide longer maintenance intervals and better durability
  – Very quiet (<60dBA)
  – Significantly lower emissions

◆ SOFC APU takes advantage of Delphi’s engineering/manufacturing capabilities for:
  » Controllers  » Sensors
  » Power Electronics  » Ceramics
  » Heat Exchangers  » Fuel Systems
System Development Activities
Delphi Solid Oxide Fuel Cell
Development and Validation Planning Process

- System requirements are developed based on heavy duty truck usage, environmental and vibration profiles with assistance from Truck OE’s. These are then translated into system requirements.
  - Usage Profile determines:
    » Number of Thermal Cycles
    » Number of Load Cycles
    » Peak Electrical Load
    » Amount of time operating at all Electrical Loads
  - Environmental Profile determines:
    » Ambient Temperature Requirements
    » Altitude Requirements
    » Fuels
  - Vibration Profile determines:
    » Accelerated Vibration test
    » Shock and impact that the Unit must withstand
Delphi Solid Oxide Fuel Cell System Acceleration Factors

System test acceleration factors for SOFC
- Time
- Load Cycling
- Thermal Cycle Acceleration
- Vibration Energy

Results from accelerated tests are then compared to baseline durability.

As data set/population increases>>> accelerated tests are further refined.
Delphi Solid Oxide Fuel Cell
DPS3000D A-Level Layout

SOFC Stacks

Endothermic Diesel Reformer with integrated combustor

Desulfurizer Bed

Highly integrated manifold and heat exchanger assembly

12 V Power Electronics
Delphi Electronic Controller

Air Supply Systems
Delphi Solid Oxide Fuel Cell
A-Level System Testing

Accomplishments

- 1.5 kW net peak load
- 25% system efficiency
- 440 hrs, 2200 miles operation on truck

Next Steps

- Continue to use as a test bed as B level APU design testing is initiated.
Delphi Solid Oxide Fuel Cell
A-Level Testing On Vehicle-SOFC System Power

- System capable of responding to load transients
- Operating on road diesel (ULSD)
System capable of maintaining desired stack temperatures during load transients
Delphi Solid Oxide Fuel Cell
Performance Comparison: Efficiency vs Power

- Delphi’s SOFC APU has higher efficiency compared to a diesel engine gen set.
Delphi Solid Oxide Fuel Cell System Emissions

◆ Delphi’s SOFC APU meets current EPA emissions standards

![Graph showing emissions comparison]

<table>
<thead>
<tr>
<th></th>
<th>HC (g/bhp-hr)</th>
<th>NOx (g/bhp-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline Engine</td>
<td>5.01</td>
<td></td>
</tr>
<tr>
<td>Gasoline GenSet</td>
<td>1.64</td>
<td></td>
</tr>
<tr>
<td>Diesel Engine</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Diesel GenSet</td>
<td>0.00</td>
<td>0.16</td>
</tr>
<tr>
<td>Delphi SOFC APU</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>EPA Diesel Truck</td>
<td>0.14</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Application of a SECA stack design into a Heavy Duty Truck APU.
Delphi Solid Oxide Fuel Cell Noise Evaluation

- Delphi’s SOFC APU is quieter than current diesel gensets

Relative Noise Levels

- Snowmobile (100dBA)
- Telephone Dial Tone (80dBA)
- Current Diesel Gen Set APU (75-80dBA)
- Normal Conversation (60-70dBA)
- Delphi SOFC APU (60dBA)
- Whisper Quiet Library (30dBA)
Delphi Solid Oxide Fuel Cell
A –Level to B-Level System Features

- Increased net power output
- Smaller package size
- Reduced mass
- Anode Oxidation Protection System included
- Reduced sensor requirements
- High volume manufacturable sub-systems
Delphi Solid Oxide Fuel Cell Current System Layout

Stack
Fuel Reformer
Desulfurizer
Integrated Heat Exchanger
Power Electronics
Dedicated Reformer
Air/Fuel Module
Delphi Solid Oxide Fuel Cell Summary

Delphi’s SOFC Stack developed for SECA meets many market needs:
- Auxiliary Power Units
- Military applications
- Residential & Commercial stationary power
- Coal-based, stationary power generation

Delphi SOFC APUs have demonstrated:
- 25% efficiency
- Ability to meet 2012 EPA emission regulations
- Low noise (<60dBA)

Compared to diesel engine APUs, SOFC APUs are:
- 40% more efficient
- Have significantly lower emissions
- Very Quiet
- Able to provide longer maintenance intervals and better durability

Delphi is focused on the commercial viability of its SOFC
- Manufacturability and cost reduction
- System level durability and validation