VII.K.10 Diesel Fueled SOFC for Class 7/Class 8 On-Highway Truck Auxiliary Power

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Subcontractors:
International Truck & Engine Corp, Fort Wayne, IN
SOFCo-EFS Holdings LLC, Alliance, OH

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Projected End Date: August 31, 2007

Objectives

Overall:

- On-vehicle demonstration and evaluation of a solid oxide fuel cell (SOFC) auxiliary power unit (APU) with integrated on-board reforming of low sulfur diesel fuel

Sub-tasks:

- Define, analyze and design the balance of plant for a functioning SOFC APU
- Perform sub-system testing and development on SOFC stacks, diesel reformer system, power electronics and controls, isolation system etc.
- Perform laboratory evaluation of complete system
- Perform in vehicle evaluation of complete system

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Durability
- D. Thermal, Air and Water Management
- F. Fuel Cell Power System Integration
- G. Power Electronics

Technical Targets

Table 1. Progress Against Technical Targets

CPG Progress Toward Meeting DOE Auxiliary Power Unit Targets						
Characteristic	**Units**	**DOE 2006 Target**	**Diesel (1) APU Market Benchmark**	**Market (1) Entry Targets**	**CPG (1) Proposal 2006 Prototype**	**Current Status (estimate)**
Specific Power	W/Kg	70	25	16	17	17 (2)
Power Density	W/L	70	21	11	8	8 (3)
Efficiency @ rated power	%/LHV(4)	25	20	25	25	25
Cost	$/kWe	<800	400	600	1500	1500 (5)
Cycle capability (from cold start) over operating lifetime	No cycles	40	>1000	500	10	10
Durability	hours	2,000	10,000	5,000	1500	1500
Start up time	min	30 - 45	<10 sec	2 hours	1 hour	4 hours

[1]As included in CPG Proposal, DE-PS36-03GO9300
[2]Based on 2.5 KWe gross fuel cell and 136 Kg package
[3]Based on 2.5 KWe gross fuel cell and 337 liter package
[4]Lower heating value
[5]Based on 2.5 KWe gross fuel cell, excludes DC to AC Inverter

Approach

- Develop System Technical Profile to define SOFC APU output requirements and operating environment
- Analyze truck electrical and thermal load profile
- Utilize SOFC technology developed in parallel Solid State Energy Conversion Alliance (SECA) project
- Conduct bench testing to evaluate suitable diesel reformer catalysts
- Identify and evaluate potential solutions for internal water management concepts
- Obtain and analyze real world truck vibration data to support suitable analysis and design of SOFC APU isolation system
- Design and evaluate separate subsystems
- Integrate and evaluate overall system in laboratory and on truck

Accomplishments

- Technical Profile developed
- Analysis of truck electrical and thermal load profile requirements has shown that the thermal load can equal or exceed the electrical load
- Alternate approaches to providing thermal load have been examined
- A simulink-based system level model has been created to evaluate and optimize trade-offs between fuel cell (e.g. size, transient response) and the batteries (capacity, losses)
- Micro reactor testing is underway to support reformer catalyst evaluations
- Alternative internal water management concepts have been evaluated and an approach has been selected (this addresses the DOE technical barrier on water management)

- Preliminary design work has started on the SOFC hot box assembly
- Suitable truck vibration signatures have been identified to aid in SOFC isolation and design and test. (this work is to help address the DOE technical barrier for durability of a mobile system)

Future Directions

- Complete truck load profile analysis against time vs fuel cell output to optimize SOFC stack size vs battery capacity (efficiency/component sizing/cost tradeoffs) using the system model
- Complete reformer catalyst evaluation
- Design the controls and power electronics incorporating SECA project experience
- Continue with vibration analysis and design and the determination of vibration tolerance of fuel cell stacks
- Commence sub-system design

Introduction

The over the road Class 7/Class 8 truck is one of the mainstays of the U.S. economy. It is estimated that over 500,000 of these trucks travel more than 500 miles from their home base on their daily trips. These distances require the truck to overnight at truck stops. To provide heating and cooling and auxiliary power for lights and hotel loads for the sleeper cab, typically a part of these long distance trucks, the truck operator currently runs the main vehicle engine overnight. In doing so the truck typically consumes 1 gallon of diesel fuel per hour as well as contributing in a negative manner to the air quality in the neighborhood of the truck stop.

The SOFC APU is being designed and developed to provide the heating and electric power currently being provided by the main vehicle engine but at a lower fuel consumption and at a much lower emission level. By using an on-board diesel fuel reformer to provide hydrogen and carbon monoxide as the fuel for a SOFC, the SOFC APU will help support the hydrogen economy, significantly reducing/eliminating the current idling emission levels, and it will also support the DOE 21st Century Truck Initiative by reducing overall diesel fuel consumption. If all overnight trucks were equipped with SOFC APUs, it is estimated that over 600 million gallons of diesel fuel could be saved annually.

Approach

Cummins Power Generation is a SECA team member and is working on a project to develop a functioning SOFC suitable for mobile power. For the SOFC APU project the approach is to take the knowledge gained from the SECA project and build on this for the smaller stack required for the truck APU. To be successful, the SOFC APU has to provide a rapid payback, (18 to 24 months), for the truck owner/operator. Two of the key factors in this equation are initial cost and fuel consumption. As the size of the fuel cell stack is one of the key cost drivers, the fuel cell stack should not be any larger than that required to complete the mission. As the transient response of the fuel cell is not capable of responding to instantaneous load increases, the SOFC APU system will need to include a DC storage device to provide load “ride through” as the fuel cell output ramps up.

To obtain the correct size balance between the SOFC stack and the DC storage batteries, it will be necessary to accurately understand the expected truck loads and duty cycles. To aid in optimizing the correct fuel cell size and DC battery capacity, the APU system will be modeled and expected truck load duty cycles will be examined for their impact on fuel cell size and the minimum state of charge for the DC storage batteries.

Results

In developing the SOFC technical profile and working through the expected truck loads it was determined that the maximum thermal load during the heating months, i.e. the thermal output required to heat the main vehicle engine and provide heat for the sleeper cab is greater than the maximum electrical loads. This shows that for the SOFC APU to adequately satisfy the truck performance requirements the SOFC APU must be capable of providing both electrical and thermal output. As one characteristic of the SOFC is a high temperature exhaust stream, this exhaust stream will be used to heat the coolant loop which the truck manufacturer plans to use as the heat transfer medium for heating both the main engine and the sleeper cab. This approach will help maximize fuel efficiency during the heating months, an important factor in achieving the overall target efficiency level of 25% LHV.

Table 2. APU Thermal vs Electrical Loads

Peak electrical load during summer	4.4 Kwe
Average electrical load during summer	1.5 Kwe
Peak electrical load during winter	3.4 Kwe
Avg electrical load during winter	0.5Kwe
Peak thermal load requirement during winter	4.4Kwe
ie. During winter, the thermal load is *greater than* the electrical load	

Research [1] into the current emission levels of idling truck engines and diesel powered APUs has confirmed the significant fuel saving and emission benefits of the proposed SOFC APU (Figure 1).

To control reformer catalyst temperatures and to prevent soot formation, it is important that the reformer be supplied with appropriate quantities of water, the so called "water management" issue. Various methods were considered for this such as providing a separate water supply on the truck, but as this would entail the monitoring and supply of another fluid which was considered undesirable. Two internal water management approaches were considered and evaluated. The first was to recycle a portion of the anode gas, which contains moisture, and the second was to use a water separation membrane to extract the water from the anode gas.

Aspen modeling showed that the anode gas recycle approach has the potential to increase the fuel cell efficiency and reduce the reformer temperatures. The humidification membrane approach would permit smaller components than those required for the anode gas recycle approach. Testing of the recycle approach using a micro reactor showed no negative impact on reformer performance. However, testing of the humidification membrane resulted in less than target water recovery and also showed evidence of sensitivity to contaminants.

Based on these results the decision has been made to pursue anode gas recycling as the approach for providing internal water management (Figure 2).

To achieve the durability goals expected by the trucking industry, any fuel cell APU will need to be extremely rugged. Unlike APUs powered by reciprocating engines, where the isolation goal is to isolate the truck from APU induced vibrations, the challenge for fuel cells is to isolate the APU from the truck shocks and vibration induced by road hazards. To aid in the isolation system design, vibration data collected from appropriate over-the-road truck testing has been analyzed and a model has been created to replicate the truck frame response. This vibration response can be used as the input to a

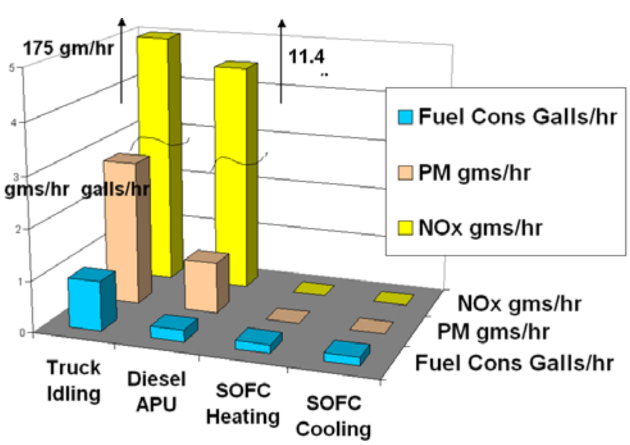

Figure 1. SOFC APU Fuel Consumption and Emission Benefits

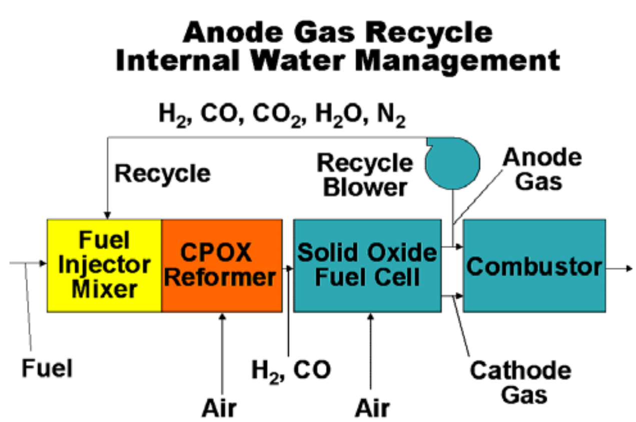

Figure 2. Diesel Fueled SOFC APU with Anode Exhaust Gas Recycle

model of the SOFC APU and its isolation system to predict the expected response of the SOFC APU. Based on preliminary modeling work, the results indicate that the fuel cell stack will be subjected to peak acceleration levels in excess of 4g (Figure 3). As the ability of the fuel cell stack to withstand vibration is not well understood, testing is planed to better understand the vibration limits of the fuel cells components themselves.

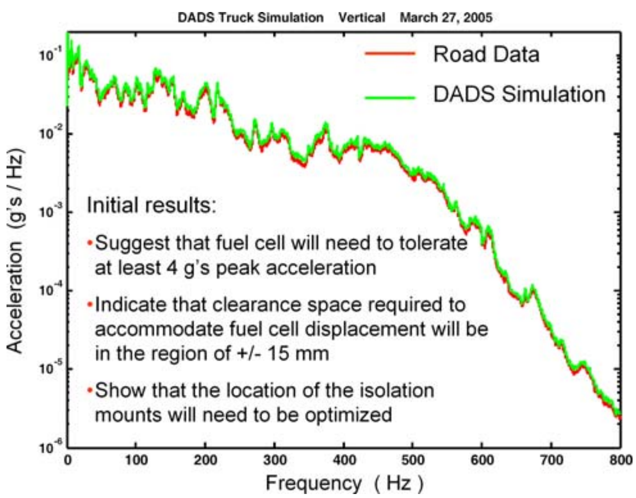

Figure 3. Vibration Isolation of SOFC APU

Conclusions

The thermal load requirement for cab and engine temperature control for over-the-road sleeper trucks can equal or exceed the electrical load requirement

SOFC exhaust energy can be used as an efficient way to provide this thermal load

Internal water management can be achieved by means of recycling a percentage of the anode exhaust gas, eliminating the need for a separate water supply

An effective SOFC APU isolation system is going to be required to ensure adequate SOFC APU durability

FY 2005 Publications/Presentations

1. Presentation given at the 21st Century Truck Merit Review, March 16, 2005, Washington DC.
2. Poster presentation given at the DOE 2005 Hydrogen Program Review, May 24, 2005, Washington DC.

References

1. SAE Paper 2003-01-0289, "Particulate Matter and Aldehyde Emissions from Idling Heavy-Duty Diesel Trucks", Storey et al.