Assessment of Fuel Cell Auxiliary Power Systems for On-Road Transportation Applications

Masha Stratonova, Stephen Lasher (Primary Contact), Eric Carlson
TIAX LLC
15 Acorn Park
Cambridge, MA 02140
Phone: (617) 498-6108; Fax: (617) 498-7054; E-mail: lasher.stephen@tiax.biz

DOE Technology Development Manager: John Garbak
Phone: (202) 586-1723; Fax: (202) 586-9811; E-mail: John.Garbak@ee.doe.gov

Subcontractors: Dr. C.J. Brodrick and Dr. Harry A. Dwyer, Institute of Transportation Studies, University of California, Davis, CA; Mr. William Gouse, III, American Trucking Association, Alexandria, VA

Objectives

- Assess the viability of the use of proton exchange membrane fuel cells (PEMFCs) and solid oxide fuel cells (SOFCs) as auxiliary power units (APUs) for on-road vehicles.
- Identify major technical issues and key risk areas and determine research and development (R&D) needs and possible DOE roles.
- Project potential fuel cell APU benefits to the nation.
- Assess how fuel cell APUs may accelerate market introduction of fuel cells for propulsion and hybrid transportation applications.

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 R,D&D Plan:

- D. Fuel Cell Power System Benchmarking

Approach

- Determine PEMFC and SOFC performance parameters.
- Identify and select three promising near-term and future fuel cell APU applications.
- Develop design concepts and evaluate benefits and cost impacts for the three selected APUs.
- Perform an R&D gap analysis, determining gaps among fuel cell cost and technical performance/ market needs.

Accomplishments

- Identified direct hydrogen PEMFCs as the most attractive near-term fuel cell technology and diesel-fueled partial oxidation (POX) fuel processor with planar anode-supported SOFCs as the most attractive longer-term fuel cell technology for on-road transportation APU applications.
- Characterized fuel cell/APU applications including medium- and heavy-duty trucks and light-duty vehicles.

- Solicited data and feedback for promising APU applications and completed inventory of data gaps (e.g. capacity, fuel capability, duty cycle).
- Selected three APU applications for conceptual design and vehicle integration analysis including diesel-fueled POX/SOFC APUs for long-haul trucks and transit buses, and direct hydrogen PEMFC APUs for law enforcement vehicles.
- Estimated APU versus idling engine efficiency and emissions at rated power and part load for the three selected applications.
- Projected annual fuel and emissions savings using fuel cell APUs in three selected applications.

Future Directions

- Evaluate the benefits of a truck refrigeration unit (TRU) and perform a detailed analysis if appropriate.
- Finalize vehicle integration layouts and cost analysis for three fuel cell APU systems.
- Finalize comparisons of conceptual systems with competing technologies.
- Determine R&D gaps among fuel cell cost and technical performance/market needs.

Introduction

Over the last five years, interest in the use of fuel cells for auxiliary power units (APUs) in vehicles has risen, particularly for truck idling and truck refrigeration unit (TRU) applications, driven by increasingly stringent idling and TRU regulations. Fuel cell powered APUs have the potential to reduce emissions, noise, vibration, fuel consumption, and size relative to conventional, internal combustion engine (ICE) APUs. In this work, the DOE has commissioned TIAX to assess the viability of the use of proton exchange membrane fuel cells and solid oxide fuel cells as APUs for on-road vehicles.

Approach

After determining the fuel cell APU performance parameters, we selected three promising fuel cell APU applications, developed conceptual designs, and assessed the potential benefits of the systems. We concentrated on PEMFC and SOFC technologies and applications likely to be attractive at the present time and extending to 2010. We addressed applications that use the existing fuel infrastructure (namely gasoline and petroleum diesel), alternative fuels (e.g. propane), and future fuels (hydrogen). We considered passenger cars, class 1 and 2 light-duty trucks and sport utility vehicles (SUVs), class 3-8 trucks, recreational vehicles, transit buses, and specialized vehicle applications. Military applications are not part of the current scope of work.

The project involves five tasks: project kick-off, identification and selection of APU systems, development of design concepts and evaluation of potential benefits, analysis of R&D gaps, and analysis update after delivery of the draft final report.

Results

The key factors that influence fuel cell APU technology selection are cost, weight (i.e. power density), efficiency, and system volume. Other important factors are technology maturity, fuel capability/flexibility (and associated complexity of a fuel reformer), startup time, and fuel cell stack life. A high-level ranking showed that direct hydrogen PEMFC was the most attractive near-term technology and diesel-fueled partial oxidation (POX) fuel processor with planar anode-supported SOFC was the most attractive longer-term technology for fuel cell APUs.

Two types of screens were used to identify three applications for detailed analysis. The initial screening criteria focused on application characteristics:

- Duty cycle - vehicle accessory duty cycle (i.e. load profile) should be suited to APU use (e.g. hotel loads during idle times)

- Market size - market potential must be adequate to support investment in APU technology
- Vehicle cost - initial vehicle cost must be high enough that an APU would likely represent a relatively small portion (<15 %) of the total cost

The second screening criteria focused on both the short- and long-term benefits related to:

- Energy savings
- Emissions savings
- Cost savings
- Acceleration of fuel cell technology commercialization

Vehicle applications meeting both screening criteria were long-haul truck cabs, transit buses, and law enforcement vehicles. Both long-haul trucks and the transit bus applications are attractive longer-term SOFC APU applications because they have potential to reduce fuel use and emissions significantly at relatively modest additional capital cost. As designed, both the truck and bus APU applications process the on-board diesel fuel in a POX reformer to generate fuel for the SOFC. Law enforcement vehicles are an attractive near-term PEMFC APU application because they are often centrally refueled and maintained by a fleet operator, mitigating alternative fuel infrastructure problems. They have the potential to accelerate fuel cell introduction by employing direct hydrogen fueling and storage, as well as to reduce fuel use and emissions. Law enforcement vehicles are also attractive because of their relatively low cargo needs, leaving space available for compressed hydrogen fuel tanks. For the purposes of this analysis, we assume the law enforcement vehicle has a hydrogen ICE powertrain and a direct hydrogen PEMFC APU.

Accessory duty cycle and fuel cell system efficiency are used in a modified drive cycle model to estimate fuel consumption, emissions, and fuel cell sizing for the APU. Figure 1 illustrates the conceptual framework of the modified ADVISOR drive cycle model. Representative vehicle duty cycle(s), fuel cell performance data, and engine-specific emissions and fuel consumption maps are input, and fuel and emissions estimates are output.

Long-Haul Truck Cab. The accessory duty cycle for a long-haul truck sleeper cab was estimated using industry-supplied data. The fuel cell system energy conversion efficiency was determined at various loads and design capacities using detailed thermodynamic and fuel cell performance models. The SOFC stack part load efficiency was optimized by choosing the appropriate combination of cell voltage and fuel utilization at each point (TIAX, 2002). The analysis shows that there is not a large difference in efficiency with rated capacity in the range of 5 to 9 kW, especially near full load (see Figure 2). Using the accessory duty cycle and fuel cell system efficiencies in the modified drive cycle model, a 4-kW APU system was found to minimize fuel consumption. Estimated annual fuel savings and

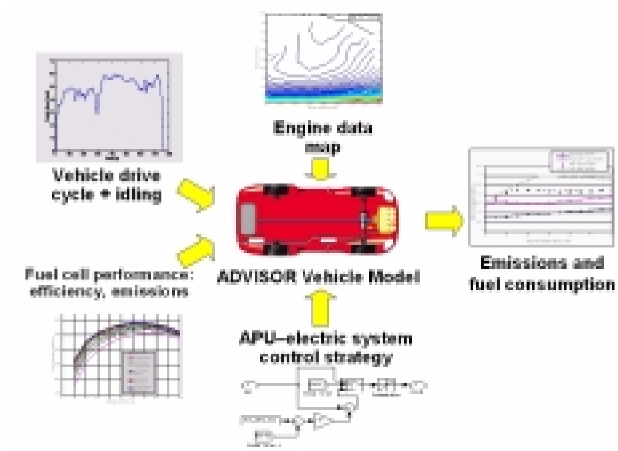

Figure 1. Conceptual Framework of ADVISOR-based Vehicle System Model

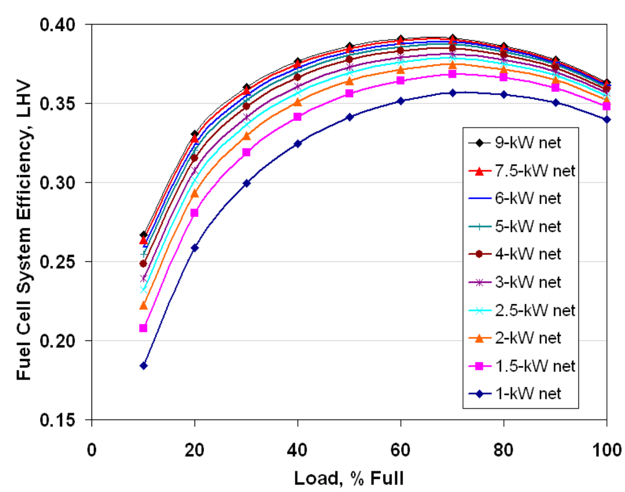

Figure 2. SOFC System Efficiency as a Function of Load

emissions benefits per truck are shown on Figure 3 for a 4-kW SOFC APU. Savings will depend on engine idling speed, or rotations per minute (rpms), which in turn depends on the engine design. Savings will also depend on the duty cycle, which varies over a wide range. Approximately 15-20% of the market idles <2 hours/day, 60-70% idles 2-10 hours/day, and 15-20% idles >10 hours/day.

Transit Bus. The accessory duty for transit buses was estimated to be 11 kW to run the air conditioner (A/C) in warm weather operation and a 3-kW baseload to run other accessories all the time. We evaluated two cases, one where the APU supplies power for the baseload only (3 kW), and one where it supplies both the baseload and A/C load (14 kW). The fuel cell system energy conversion efficiency was similar to the truck cab application. Estimated fuel savings and emissions benefits per bus are shown on Figure 4 for a 14-kW SOFC APU. Fuel savings are negative (i.e. more fuel is consumed) for the transit bus APU application because it is never practical to turn off the main engine during normal stop and go operation. Since engine idling is required in the typical drive cycle, it is more efficient to use the engine to supply all accessory power. While the SOFC is more efficient than the ICE, idling the ICE with no load plus operating the APU is less efficient than idling the engine to supply 3-14 kW of accessory power with no APU. Annual emissions are reduced only slightly.

Law Enforcement Vehicle. The accessory duty cycle for law enforcement vehicles was developed from a survey of police fleet operators. An APU for this application would require up to 5 kW for lights, radio, etc. during idling situations (e.g. traffic surveillance). The fuel cell system energy conversion efficiency was determined at various loads using detailed thermodynamic and fuel cell performance models (see Figure 5). The PEMFC system pressure and stack cell voltage are assumed to

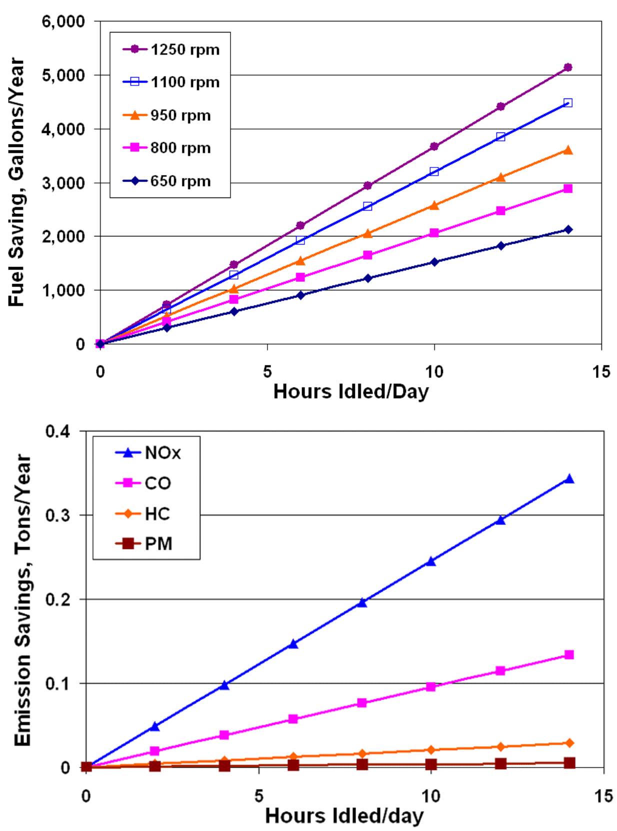

Figure 3. SOFC APU Annual Diesel Fuel and Emissions Savings - Long-Haul Truck Cab

	Engine Only	SOFC	Engine w/SOFC	Engine+SOFC	Reduction
Fuel Use	**gal/hr**	**gal/hr**	**gal/hr**	**gal/hr**	**%**
Base load	3.5	0.2	3.4	3.6	**-2.1**
A/C full time	4.2	0.9	3.4	4.3	**-1.2**
NO_x Emissions	**g/mile**	**g/mile**	**g/mile**	**g/mile**	**%**
Base load	24.6	0	23.2	23.2	5.8
A/C full time	31.5	0	23.2	23.2	27
PM Emissions	**g/mile**	**g/mile**	**g/mile**	**g/mile**	**%**
Base load	0.3	0	0.3	0.3	1.1
A/C full time	0.3	0	0.3	0.3	1.9

Figure 4. SOFC APU Diesel Fuel and Emissions Savings - Transit Bus

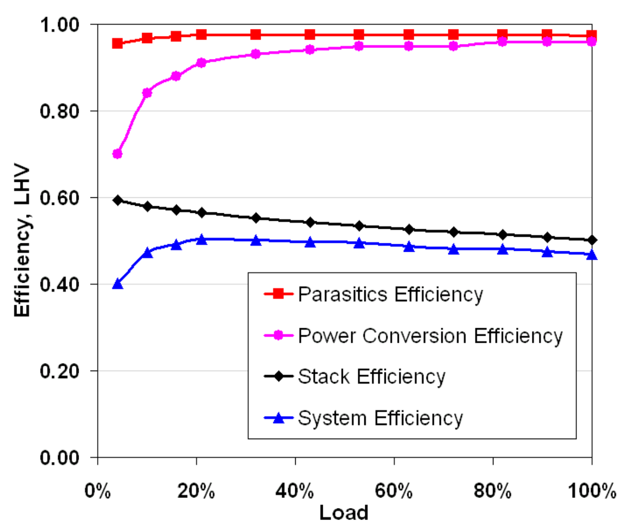

Figure 5. Direct Hydrogen PEMFC Efficiency as a Function of Load

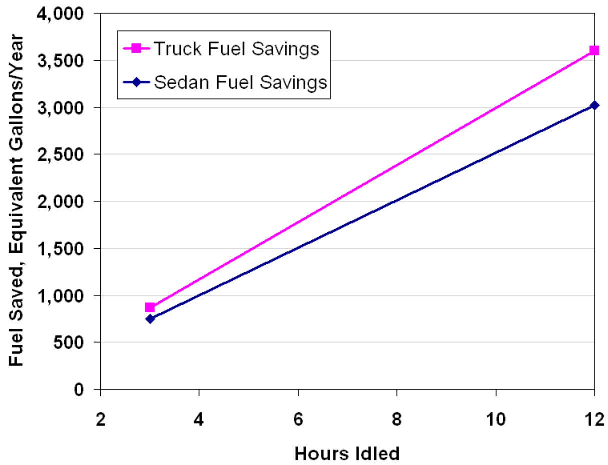

Figure 6. Direct Hydrogen PEMFC APU Annual Fuel Savings - Law Enforcement Vehicle

vary with load (pressure decreases and cell voltage increases at lower load). Estimated annual fuel savings per vehicle are shown in Figure 6 for a 5-kW PEMFC APU. Savings will depend on idling time, which varies significantly. Emissions savings were not evaluated because it is assumed that the engine utilizes clean-burning hydrogen (i.e. hydrogen ICE powertrain).

Conclusions

Introduction of APUs for long-haul truck and law enforcement vehicle applications can provide significant fuel and emissions savings proportional to the amount of abated idling time. Transit bus applications, however, are unlikely to result in significant benefits due to the necessity for engine idling even with an APU. In place of a detailed vehicle integration and cost analysis of the transit bus application, we will instead evaluate the benefits of a TRU and perform a detailed analysis if appropriate.

References

1. TIAX, "Grid-Independent, Residential Fuel-Cell Concept Design and Cost Estimate", *Final Report to DOE NETL in Subcontract to Parsons,* Subcontract Number 73622-30005, October 18, 2002

FY 2003 Publications/Presentations

1. Presentation to 21st Century Truck Industrial Working Group in conjunction with SAE Government & Industry meeting, Washington, DC, May 15, 2002