V.G.4 Research and Development for Off-Road Fuel Cell Applications

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Subcontractors:
- The Toro Company, Bloomington, MN
- University of California, Davis, CA (UC Davis)

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Objectives

- Develop a proton exchange membrane (PEM) fuel cell system to operate in off-road applications.
- Established comprehensive set of PEM fuel cell system requirements for turf and grounds maintenance vehicles.
- Evaluate air-filtration technologies for off-road applications.
- Shock and vibration testing in the lab and field.
- Fully integrate prototype PEM fuel cell system in a Toro® Workman® e2065 – series utility vehicle for field trials.
- Fully integrate second generation PEM fuel cell system in a Toro® Mid-Duty Electric (MDE) light-duty maintenance truck.
- Conduct field trials utilizing two vehicles at various venues.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability

Accomplishments

- Measured the shock and vibration spectrum for golf course maintenance vehicles.
- Gathered information on the air contaminants that may have an effect on fuel cell operation and developed an air filter for fuel cell systems.
- Developed the Workman® Model e2065 lawn tractor equipped to operate on direct current (DC) voltages, had accelerometers installed and evaluated shock and vibration.
- Measured the power load profiles on two golf courses.
- Designed and installed an IdaTech Liquid Fueled Fuel Cell System in a Toro® Workman® Model e2065 light-duty maintenance truck.
- Installed a 2nd generation IdaTech Liquid Fueled Fuel Cell System in a Toro® Workman® model MDE light-duty maintenance truck.
- Completed field trials with two vehicles.

Introduction

Nearly no practical work has been performed by the fuel cell industry, its suppliers and trade associations on the subject of off-road fuel cell operation. The environments encountered in off-road applications could adversely affect fuel cell performance and life, requiring re-designing for the harsher environment.

One of the recognized challenges in fuel cell systems air purification is in providing a highly efficient particulate and chemical filter with minimal pressure drop. PEM integrators do not want additional parasitic loads added to the system as compensation for a highly efficient yet highly restrictive filter. Additionally, there is challenge in integrating multiple functions into a single air intake module tasked with efficiently and effectively filtering high dust loads, diesel soot, pesticides, ammonia, high frequency noise, and other anticipated off-road contaminants.

It is one key project objective to develop a strategy, and through it a solution, for achieving clean cathode inlet air. Other off-road concerns are related to fuel cell power requirements and the effect of shock and vibration.

Approach

- Measure the air quality for off-road application and develop an air filter.
- Measure the shock and vibration spectrum for off-road vehicles, and then subject an IdaTech fuel cell system to the spectrum.
- Design, assemble, and test a Toro® Workman® Model e2065 light-duty maintenance truck with an IdaTech Liquid Fueled (methanol/water) Fuel Cell System.

Results

An IdaTech Liquid Fueled Fuel Cell System was assembled, tested at IdaTech, delivered to UC Davis and demonstrated at UC Davis. Initial shock and vibration testing was completed at UC Davis followed by field trials at River's Edge golf course and The High Desert Museum, Wildlife and Living History. Accelerometers were mounted in the rear compartment next to the fuel cell system for all shock and vibration testing. The field trial results indicate the rear of the vehicle sustains higher shock g-forces than the front with the maximum recorded shock of 117 g-forces. The vibration results show that the terrain provides input vibrations in the range of 1 to 20 Hz at 2 to 3 g-forces and that the vehicle does not sustain any vibration amplitudes greater than 1 g-force.

Toro® determined that the IdaTech FCS 3000 fuel cell system matched the operational requirements of the Workman® Model e2065. As a result, a Toro® Workman® Model e2065 light-duty maintenance truck was received and retrofitted to house an IdaTech FCS 3000 fuel cell system. The model e2065 unit was designated test vehicle-one (TV-1).

Three fuel cell systems were assembled and all three passed operational testing. One fuel cell system, while sitting next to the vehicle, was used to charge the batteries. After successfully demonstrating that the fuel cell system could charge the batteries, the fuel cell system was reconfigured and installed into the vehicle. The vehicle has accumulated 63.5 hours of off-road operation at the River's Edge Golf Course. A photo of TV-1 on the golf course is shown in Figure 1. During the summer of 2008, TV-1 accumulated 62 hours of maintenance duties. During the winter an upgrade was performed on the fuel cell system. Wiring connections were reduced, a smaller, lighter DC-to-DC converter on studier sheet metal support and onboard data acquisition were incorporated. Every ten seconds data is stored on a replaceable memory card. The installed upgraded fuel cell system is shown in Figure 2. TV-1 has accumulated the following statistics:

System run time = 318 hrs
Total fuel feed = 474 liters

FIGURE 1. TV-1 on Golf Course

FIGURE 2. Upgraded IdaTech Liquid Fueled Fuel Cell System Installed in TV-1

Total energy = 357 kW-hrs
Total thermal cycles = 172

A second vehicle, designated TV-2, was procured from Toro® which Toro® has designated an MDE model (Mid-Duty Electric). The new vehicle design incorporates front wheel shocks and an accessible area under the front hood. An upgraded fuel cell system was installed in the vehicle. The batteries were placed two in front and two in the rear compartment. This eliminated the "saddle bag" batteries external to the rear compartment in the first vehicle. The vehicle rear compartment was modified to provide ease of removal of the whole system for maintenance. Onboard data acquisition was added with data collection every 10 seconds on a memory card. The fuel cell system installed in TV-2 is shown in Figure 3. The second vehicle was deployed at The High Desert Museum (HDM) Wildlife and Living History south of Bend, Oregon. This field trial differed in that the terrain was flatter, the operators more educated and the vehicle accumulated more operating hours. The vehicle is

FIGURE 3. IdaTech Liquid Fueled Fuel Cell System Installed in TV-2

FIGURE 4. TV-2 at the High Desert Museum

shown in front of the HDM in Figure 4. TV-2 has accumulated the following statistics:

System run time = 368 hrs
Total fuel feed = 315 liters
Total energy = 149 kW-hrs
Total thermal cycles = 63

The present systems have four generic printed circuit boards installed. Many of the functions on the boards are not used with the present system. Many wires could be eliminated by consolidating the four boards onto one board. We have contacted the Etrix Group Inc., a local electronic design company, to consolidate the needed functions onto one board.

Conclusions and Future Directions

Overall the prototype vehicle project was a great success making significant progress toward manufacturing of a green vehicle for golf course and parks and recreation maintenance vehicles with potential for liquid fuelled fuel cell powered vehicles in industrial settings. Operation at two test venues was successful, however, improved reliability is required. Some example of faults and corrections:

- System over heated on very hot day – added cooling fan.
- Thermocouple shorted – added restraint.
- Wires fell off coolant switch – restrained wires.
- Fuel pump slowed down, dirt was cause – sealed pump gearbox opening.
- Fuel line dry – removed tank dip tube and place exit at tank bottom.
- Inverter not ramping up – installed improved inverter and improved firm ware.
- Troubleshooting faults takes too much time – added onboard data acquisition.
- Multiple printed circuit boards with unused capability and extra connectors increase wiring breakage – consolidation of board recommended.

The two test units have completed filed trials and are in the process of being disposed.

Work on air filtration (Task 3) has been restarted due to Donaldson's decision to cease fuel cell filter production and support. The objective is to evaluate commercially available air filters for off-road applications. The work has just commenced with UC Davis.