Research & Development for Off-Road Fuel Cell Applications

Presented by Eric Simpkins
Matthew Steinbroner - Program Manager
IdaTech, LLC
4/12/05

This presentation does not contain any proprietary or confidential information
Overview

Timeline

- Project start date: 12/01/04
- Project end date: 12/31/07
- Percent complete: 7%

Barriers

- Barriers addressed
  - P. Durability

Budget

- Total project funding
  - DOE share: $418,912
  - Contractor share: $1,001,475
- Funding received in FY04
  - $50,000
- Funding for FY05
  - $418,619

Partners

- IdaTech, LLC
- The Toro Company
- Donaldson
- UC Davis
Objectives - 2005

- **Task 1: System Study**
  - Identify off road vehicle conditions, as pertains to fuel cell system power production and utilization
    - Including:
      - Load profiles
      - Drive train, PTO, actuators, etc.
      - Force & speed
      - Acceleration
Objectives - 2005

- Task 2: Impulse & Vibration Study
  - Utilize existing information to generate profiles for typical impulse and vibration forces on the off road vehicle
    - Equip Toro electric vehicle with accelerometers
Objectives - 2005

- **Task 3: Air Quality Study**
  - Develop a database of possible environmental contaminants that could affect the operation of the fuel cell system (cathode contamination)
  - Construct single cell fuel cell test systems to evaluate the effects of air contaminants on the cathode side of the fuel cell

- **Task 4: Fuel Cell Specification**
  - No work defined for this year
Objectives by contractor

- Report on Load Profiles & Lifetime  
  **Lead:** UC Davis, **Support:** Toro

- Air Filtration Project Report  
  **Lead:** Donaldson, **Support:** IdaTech

- Impulse & Vibration Project Report  
  **Lead:** Donaldson, **Support:** IdaTech

- PEM Fuel Cell System Specification  
  **Lead:** Toro, **Support:** UC Davis

- Final Report

- Actively communicate results in public forums and distributed media in support of DOE’s communications program.
Approach

- This program will utilize both existing and experimental data to generate information pertaining to the operation of a fuel cell system in an off-road environment. Specifically the program will address and identify:
  - Load profiles for an all electric Toro Workman
  - Load profiles for existing off road equipment (tractors, mowers, etc...)
  - Impulse and vibration information for existing off road equipment, as well as for a experimental data from a Toro Workman
  - Cathode contaminants that are “typical” in an off road environment
  - Fuel cell test apparatus that will identify the effects of the contaminants on the operation of a Fuel cell system
  - Design of mitigation for impulse, vibration, and air contaminants
  - Testing of the mitigation strategies
Technical Accomplishments: Task 1: System Study

- Identification of a variety of load profiles for off road vehicles (agricultural tractors) has been accomplished, including:
  - Engine power and torque, PTO (Power Take Off), and Drawbar power (the power required to pull an implement at a uniform speed).

Table 1: Power take-off torsional loads[7]

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>TRACTOR MODEL</th>
<th>APPROX. MAX TRACTOR HP</th>
<th>IMPLEMENT MAKE AND MODEL</th>
<th>COUPLING IN PTO DRIVE</th>
<th>MAX STARTING TORQUE WITH NORMAL CLUTCH ENGAGEMENT, LB-IN</th>
<th>MAX STARTING TORQUE WITH RAPID CLUTCH ENGAGEMENT, LB-IN</th>
<th>MAX OPERATIONAL TORQUE PEAKS WITH NORMAL CLUTCH ENGAGEMENT, LB-IN</th>
<th>AVE. TORQUE UNDER NORMAL OPERATING CONDITIONS, LB-IN</th>
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* SAFETY CLUTCH IN PTO LINE SLIPPED LIMITING TORSIONAL LOAD TO THIS VALUE
Technical Accomplishments: Task 1: System Study

Engine horsepower and speed for corn picking, subsoiling, field cultivating and soil packing.

Distribution of hours of tractor use by operations (average of 340 hours for 25 tractors).
Technical Accomplishments: Task 1: System Study

- **20 kW (26 hp) example:**
  - In order to meet or exceed the performance of a traditional IC engine the hybrid fuel cell system would need to:
    - Have similar or greater torque reserve
    - Meet or exceed the rated power at operating speed
    - Be of equivalent or smaller size, weight, and weight distribution

- With the same tractor frame, a system with two electric motors, one for the drive and one for the PTO would be utilized. This would need to be a battery / fuel cell hybrid system, with the battery pack capable of meeting power spikes
Technical Accomplishments: Task 2: Impulse and Vibration Study

A fuel cell hybrid Workman e2050 was operated at Farmlinks Golf Course (Alabama), and generated data for operating speeds, motor current, and hybrid voltage stability. The Workman was also tied to a GPS system, to allow for synchronization of collected data, the vehicle activity, and location.

A Toro Workman 3000 tractor has been fitted with an electric power train, accelerometers, and is awaiting installation of the electric motor.
Technical Accomplishments: Task 3: Air Quality Study

- Air contaminant database under construction; this database will identify contaminants for investigation in the eight, single cell, test systems.

  - Sourced from:
    - Literature search internal and external to Donaldson
    - On-site air sampling of select off-road environments (i.e. mining, construction, airport, agriculture, grounds care)

- Fuel cell air quality test systems designed, and components ordered. The test systems are currently under construction.
Technical Accomplishments: Task 3: Air Quality Study

Test System Schematic

- Water Storage
- DI
- Flow Controller
- UHP Hydrogen
- UHP Air
- Temperature Controller
- Scrubber
- DC Load
- Impedance Analysis
- MEA
- End Plate
- Anode Plate
- Cathode Plate
- Heated Sample
- Dust Injection
- Contaminant Port
- Test System Schematic
- Flow Controller
- Water Storage
Future Work - 2005

During the rest of this year the following tasks will be accomplished:

- Identify fuel cell operating requirements 05/27/05
- Identify mechanical stresses to the fuel cell 06/24/05
- Provide power train recommendations 06/24/05
- Prepare source identification graph (vibration & impulse) 07/22/05
- Impulse & vibration testing 10/21/05
- Provide impact and vibration testing results 11/11/05
- Test fuel cell system, post vibration testing 12/09/05
Next Year the following tasks will be accomplished:

- Identify system vibration dampening strategies 03/01/06
- Delivery of air purifying and noise dampening solution 04/01/06
- A Toro Workman will be provided for testing 04/29/06
- List recommended air purification practices 06/01/06
- Build an implement dampening system 09/01/06
# Schedule

## Off Road Fuel Cell Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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<td>Task 1: System Study</td>
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<tr>
<td>Load Profiles</td>
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<td>Source Input &amp; Design Profile</td>
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<td>Post Test Performance Evaluation</td>
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<td>Mitigation Design</td>
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<td>Design Validation Testing</td>
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<td>Task 3: Air Quality Study</td>
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<td>Develop Database Baseline</td>
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<td>Construct Test Station</td>
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<td>Air Environment Field Testing</td>
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<td>Perform Air Contamination Study</td>
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<td>Design &amp; Test Filters</td>
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<td>Project Conclusion</td>
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Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

The operation of the single cell air quality test systems at the IdaTech facility. These systems are the only portion of this program which will actively utilize hydrogen.
Hydrogen Safety

Our approach to deal with this hazard is:

To utilize IdaTech’s experience in hydrogen production, and handling to provide a safe operating environment. IdaTech is an ISO 9001 company, which has acquired UL and CE certification on equipment in the field, and has hundreds of man years of experience in hydrogen production and utilization.

IdaTech’s test facility is equipped with hydrogen detectors which are connected to hydrogen sources to shut off in case of hydrogen detection.

IdaTech is familiar with UL and CE standards as pertaining to stationary and portable fuel cell and reformer applications, and will continue to put into practice these standards. These include standards from ANSI/CSA FC-1, ANSI/CSA FC-3, CSA 1.01 FC Supplemental, UL 2075, CGA G5.3, NFPA 70 article 692, NFPA 853, and other applicable standards.