MT017: FedEx Express Hydrogen Fuel Cell Extended-Range Battery Electric Vehicles

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Program Overview

Hydrogen Fuel Cell Extended-Range Battery Electric Vehicles Demonstration

- $3.0 million from Department of Energy
- Integration of fuel cells into 20 battery electric pickup and delivery vehicles, PUDs
  - **BP1 – 1 truck**
    - Design
    - Integrate & test fuel cell systems
      - Safety
      - Communication
      - Performance
      - Reliability
    - Validate in revenue service
  - **BP2 – 19 trucks**
    - Integrate hydrogen fuel cell systems
    - Operate in revenue service in Memphis, TN and several locations in CA
## Project Main Objectives

<table>
<thead>
<tr>
<th>DOE Project Objectives</th>
<th>Project Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrate / deploy hydrogen and fuel cell technologies in real-world environments.</td>
<td>20 parcel delivery trucks will operate one shift 260 days annually for approximately 10 hours per day.</td>
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<tr>
<td><strong>Ancillary Objectives</strong></td>
<td><strong>Project Impact</strong></td>
</tr>
<tr>
<td>Operate 5,000+ hours</td>
<td>Over approx. 1.92 years, this amounts to approximately 5,000 hours per truck. Total fleet activity is 100,000 hours annually. (Numbers represent minimum.)</td>
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<tr>
<td>Reduce petroleum consumption</td>
<td>Each diesel truck uses 2,600 gallons per year. The program will reduce diesel consumption by 100,000 gallons over ~1.92 years.</td>
</tr>
<tr>
<td>Reduce emissions</td>
<td>A net of 270 metric tons of CO2 will be prevented.</td>
</tr>
</tbody>
</table>

### Potential Expansion

| Similar Assets & Duty Cycles (count)         | 7000                                      |
| Annual Utilization Range (miles)             | 20k - 50k                                 |
| Approx Annual Fuel Displaced (gal)            | 14M                                       |
| Annual CO2 Avoided (Metric Tons)              | 69,500                                    |
Program Overview

Timeline
• Grant awarded – October 2015
• Kickoff meeting – May 2016
• Project end – October 2019
• Project completion - < 5%
  – Phase 1 – 85% - 90% complete

Barriers
• Unknown ability to meet safety, performance & reliability needs
• Variable energy requirements
  – Route differences
  – Parasitic losses (HVAC, ancillary systems, effects of temperature)
• Fuel availability

Budget
• DOE – $3.0M
• Partners – $3.367M

Partners
• U.S. Department of Energy
• FedEx Express – Prime recipient
• Plug Power – Fuel cell manufacturer
• Workhorse Group – Truck manufacturer
Relevance: DOE Strategy

DOE Goals

- Office of Energy Efficiency and Renewable Energy
  - Fuel Cell Technology Office
    - Provide clean, safe, secure, affordable and reliable energy
    - Diverse domestic resources, provides energy security, reduces petroleum use, lower GHG emissions and criteria pollutants
Relevance: FedEx Express Strategy

Connect the world responsibly and resourcefully

- **Business case**
  - Energy independence
  - Sustainability
  - Reduce fuel use
  - Lower Total Cost of Ownership

- **Desire for long-range zero emission PUD**

- **Zero emissions alternative to traditional battery EV**
  - Weight reduction
  - Cost reduction
  - Refueling time reduction

- **Evaluation of Hydrogen Fuel Cells as an On-Board Traction Battery Charger**
Relevance: Mileage Management

Right Vehicle
Right Route
Mileage Bands – Miles Per Year

RANGE – SPEED – TIME

PAYLOAD – STOPS – VOLUME

Right Technology
Right Duty Cycle

HYBRID
15,000 – 30,000

COMPOSITE BODY REACH
10,000 – 40,000

EXISTING W700
UP TO 20,000

SPRINTER TYPE
10,000 – 50,000

EV
UP TO 16,000

eREV
> 16,000

PANEL VAN
> 40,000

Miles Per Year
5,000  10,000  15,000  20,000  25,000  30,000  35,000  40,000  45,000  50,000  55,000  60,000
# Milestones

<table>
<thead>
<tr>
<th>Element Type (Task or Milestone)</th>
<th>Task Number (Milestone Number)</th>
<th>Task Title</th>
<th>(Milestone Description)</th>
<th>Planned</th>
<th>Actual Completed</th>
<th>Current % Complete (0-100)</th>
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<tbody>
<tr>
<td>Task 3: First Fuel Cell Unit Build</td>
<td>3</td>
<td>Task</td>
<td>Unit #1 Fuel Cell Fabrication</td>
<td>9/15/16</td>
<td>1/16/2017</td>
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<td>Unit #1 Fuel Cell Factory Acceptance Testing</td>
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<td>1/23/2017</td>
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<td>Hydrogen Tank packaging</td>
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<td>Task</td>
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<td>System Factory Testing</td>
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<td>Fuel Cell System Pass Factory Acceptance Test</td>
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<td>Task 4: First Unit Integration</td>
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<td>Bracket Installation</td>
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<td>Integrated Truck Performs per Stated Specifications</td>
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<td>5/19/2017</td>
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<td>Task</td>
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<td>Milestone</td>
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</table>

Budget Period 1 Go/No-Go Decision Point (September)
Approach

Chassis Fuel Cell Integration

Body Installation Durability Test Commissioned

Utilized on Routes Data transmitted to NREL Results evaluated

Commissioned Durability Test Body Installation

Utilized on Routes Data transmitted to NREL Results evaluated

FedEx Express

FedEx Express
Workhorse Chassis

- 80 kWh Battery Packs
- TM4 Traction Motor
  - 200 kW
  - 2100 N-m
Technical Accomplishments and Progress
System Integration
### Technical Accomplishments and Progress

#### Hydrogen Storage | Dilution & Venting

<table>
<thead>
<tr>
<th>Fuel System</th>
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</thead>
<tbody>
<tr>
<td>- Fuel storage: 11.6 kg @ 350 bar (11 kg usable)</td>
</tr>
<tr>
<td>- Located in the least valuable real estate</td>
</tr>
<tr>
<td>- Wheel wells extended to cover tanks inside</td>
</tr>
<tr>
<td>- Incremental energy to batteries: 165 kWh</td>
</tr>
<tr>
<td>- Fueling receptacle in same location as diesel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety - Dilution &amp; Venting</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Leak detection via hydrogen sensors</td>
</tr>
<tr>
<td>- Shutdown at 25% of LEL of H2</td>
</tr>
<tr>
<td>- Regulation down to 30 bar at tanks</td>
</tr>
<tr>
<td>- Emergency venting through vertical chimney in rear corners per DOT recommendation</td>
</tr>
</tbody>
</table>
Technical Accomplishments and Progress
Power Generation / Vehicle Connection

10 kW Fuel Cell System x 2
- Power: 20 kW total
- Voltage Output: 48VDC

DC/DC Converter x 2
- Buck / boost dual functionality
- Voltage Output: 310-430VDC

Vehicle HV Junction Box
- Common bus for batteries and fuel cell / converter output
Technical Accomplishments and Progress Thermal Management

Electronics: Separate Radiator
- Vehicle: Traction motor, inverter, 12V converter for cab loads
- eREV: DC/DC converters

Power: Dedicated Radiator x 2
- Radiator for each fuel cell
- Independent control of singular loops by individual fuel cells

Benefits
- Ram air provides additional cooling to largest heat loads
- Fuel cells can run independently, providing 10 kW if one FC is down
- Serviceability of fuel cells increases dramatically (completely independent)
Technical Accomplishments and Progress Communications

Fuel cell (FC)                        Battery Management System (BMS)

- FC Transmit to BMS
- Fuel Level
- FC Power Output
- FC Running Status
- Refueling Indicator
- Low Fuel Level
- Service Indicator
- H2 Leak Detection
- Overtemp Detection
- Available FC Power
- Available Energy

- FC Receive from BMS
  - FC Enable (12V tied to ignition)
  - FC On for Battery Charging
  - Power Request
  - Max Power Allowed

Part of WH Software

- Coolant pump/fan on whenever FC is turned to cool converters
  (same as truck-mounted charger)

Additionally, there will be system parameters sent over CAN to Workhorse’s Metron telemetry.

CAN messaging to the Instrument Cluster
(Using what is already available on eGEN)

- 20 – Fuel level
- 21 – FC service alert
- 21 – FC service diagnostic (fault alarm)
- 22 – Low fuel
- 23 – FC enabled
- 24 – FC disabled
Technical Accomplishments and Progress

Control Strategy

Truck Power Requirements

Simple On-Off Operation

<table>
<thead>
<tr>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain batteries between 20% and 90% SOC</td>
</tr>
<tr>
<td>90% maximum allows for regenerative braking</td>
</tr>
<tr>
<td>20% ensures long battery life</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Starting Point (On/Off Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 kW operation on/off operation</td>
</tr>
<tr>
<td>Fuel cell is only required 57.7% of time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optimization (Variable Output)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run FC at most efficient points to improve economics</td>
</tr>
<tr>
<td>Could run fuel cell as low as 11.5 kW constant if we were smart enough about the route</td>
</tr>
<tr>
<td>Ideally, the fuel cell will be on as much as possible</td>
</tr>
<tr>
<td>Fuel Cell Output Power = f(battery SOC, vehicle speed)</td>
</tr>
</tbody>
</table>
Current status

- Chassis integration completed
- Body build completed
## Future Tasks

<table>
<thead>
<tr>
<th>Task 5: First Unit Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task</strong></td>
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<td><strong>Task</strong></td>
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<tr>
<td><strong>Task</strong></td>
</tr>
<tr>
<td><strong>Milestone</strong></td>
</tr>
</tbody>
</table>

**Budget Period 1 Go/No-Go Decision Point (September)**
Project Phase BP2

Budget Period 2
- Fuel system design
- Safety planning

Optimization modeling
- Battery capacity (kW-hr)
- Fuel Cell Power (kW)
- Hydrogen Tank capacity (kg H₂)

Safety Planning
- Communications and Control Strategies
- Leak detection and fuel isolation or purging

Integration of fuel cell into first truck
- Performance testing
- Shock and vibration testing

Commissioning
- Place into revenue service
- Validation
- Prepare for BP2
Thank You

- earthsmart
  - FedEx Low Emission
  - Hybrid Electric

- earthsmart
  - FedEx Zero Emission
  - All Electric

- earthsmart
  - FedEx solutions for a more sustainable world

- earthsmart
  - FedEx Extended Range Electric

- earthsmart
  - FedEx Fuel Sense