



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 locations in CA

Project Main Objectives

DOE Project Objectives	Project Impact
Demonstrate / deploy hydrogen and fuel cell technologies in real-world environments.	20 parcel delivery trucks will operate one shift 260 days annually for approximately 10 hours per day.
Ancillary Objectives	
Operate 5,000+ hours	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.)
Reduce petroleum consumption	Each diesel truck uses 2,600 gallons per year. The program will reduce diesel consumption by 100,000 gallons over ~1.92 years.
Reduce emissions	A net of 270 metric tons of CO2 will be prevented.

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 2020
- Project completion - < 5%
 - Phase 1 – 99.9% complete

Budget

- DOE – \$3.0M
- Partners – \$3.367M

Barriers

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

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
 - Diversify 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



HYBRID
 15,000 – 30,000



COMPOSITE BODY REACH
 10,000 – 40,000



EXISTING W700
 UP TO 20,000



SPRINTER TYPE
 10,000 – 50,000



PANEL VAN
 > 40,000



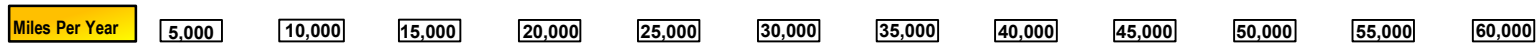
EV
 UP TO 16,000



eREV
 > 16,000



RANGE – SPEED – TIME
 Right Technology Right Duty Cycle
PAYLOAD – STOPS – VOLUME

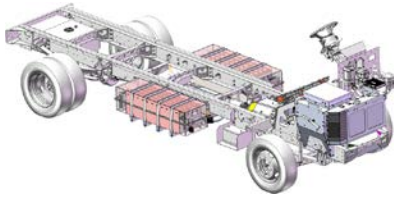


Milestones

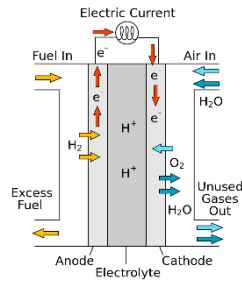
Milestone/Task Breakdown 5: First Unit Validation					
Element Type	Number	Description	Planned	Actual Completion	Completion %
Task	5	Durability Test	6/1/2017	12/1/2017	100%
Task	5	Shipping of Truck #1 to FedEx Station for testing (Menands, NY)	6/19/2017	1/25/2018	100%
Task	5	Driver/Personnel Training	6/20/2017	1/23/2018	100%
Task	5	Commissioning	6/21/2017	1/30/2018	100%
Task	5	Test and Validation of Unit #1 vehicle and powertrain requirements	6/21/2017	1/30/2018	100%
Task	5	Data Analysis	7/3/2017	6/30/2018	50%
Task	5	Data Transmission to DOE/NREL	6/30/2017	4/27/2018	100%
Task	5	Data Transmission to DOE/NREL	6/30/2017	6/8/2018	
Milestone	5	Evaluation Document of First Unit Performance	7/31/2017		
Budget Period 1 Go/No-Go Decision Point (6/30/2018)					

Approach

Chassis



Fuel Cell



Integration



Commissioned



Durability Test



Body Installation



Utilized on Routes



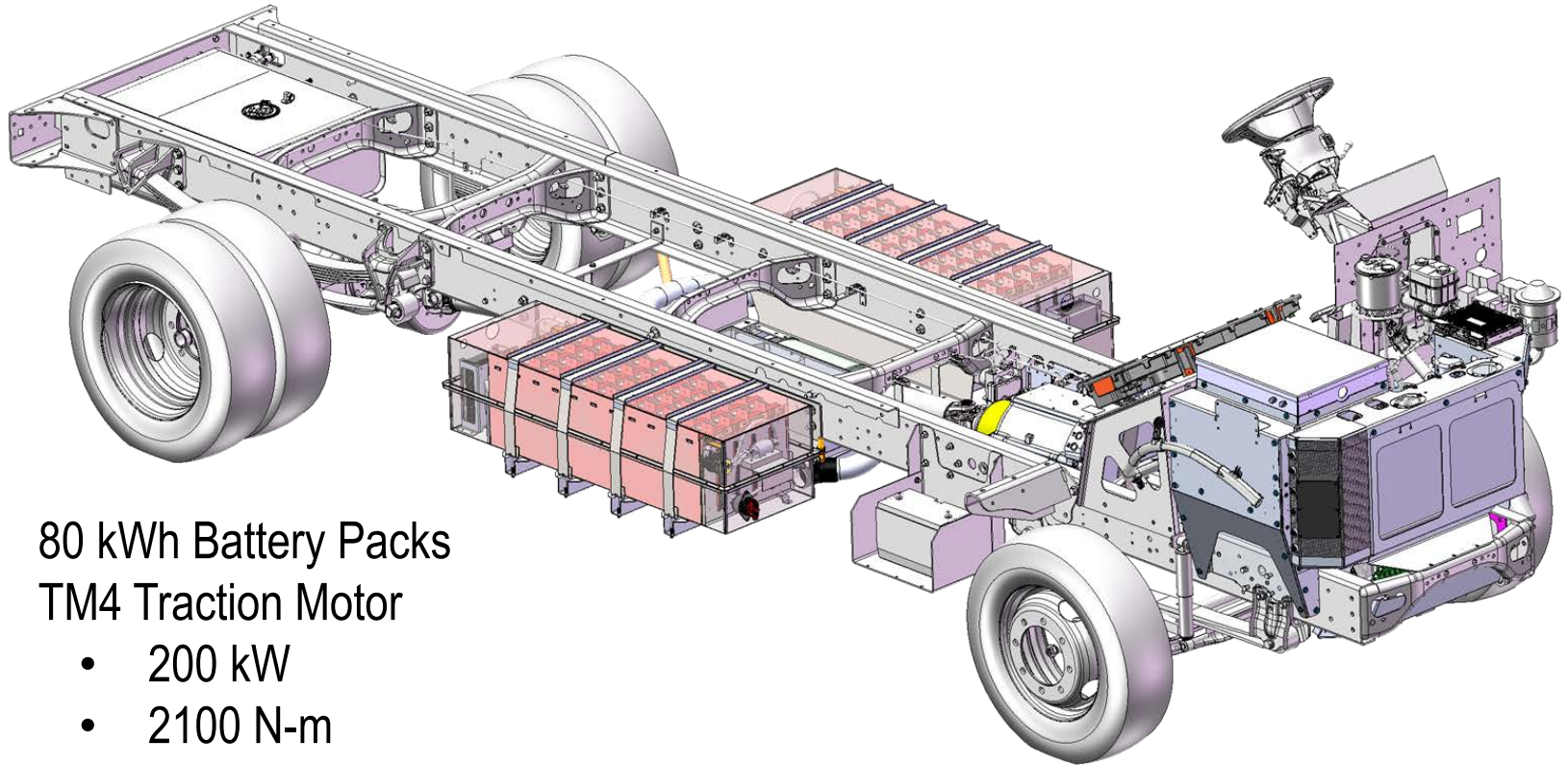
Data transmitted to NREL



Results evaluated

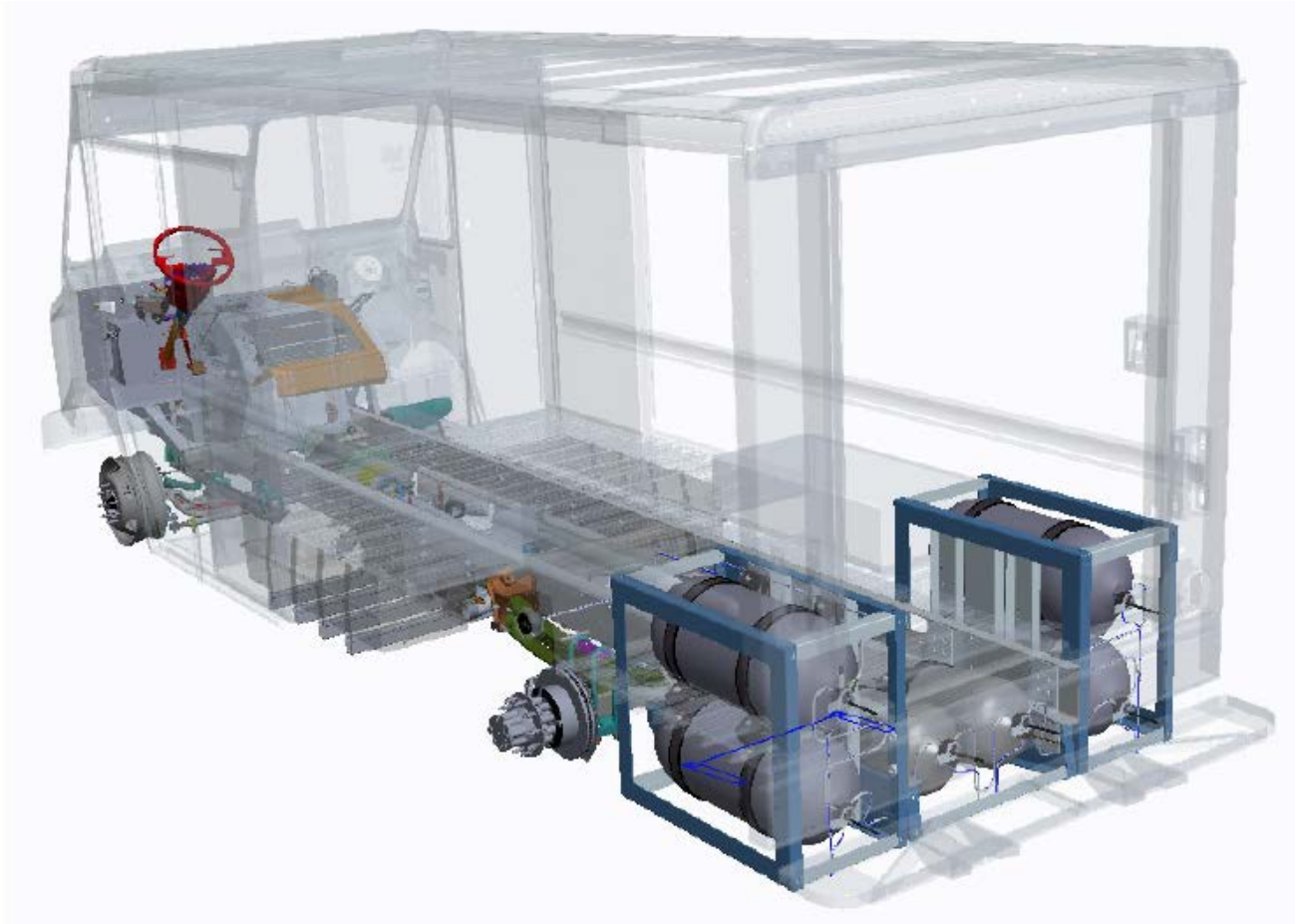


Workhorse Chassis



- 80 kWh Battery Packs
- TM4 Traction Motor
 - 200 kW
 - 2100 N-m

Technical Accomplishments and Progress System Integration



Technical Accomplishments and Progress

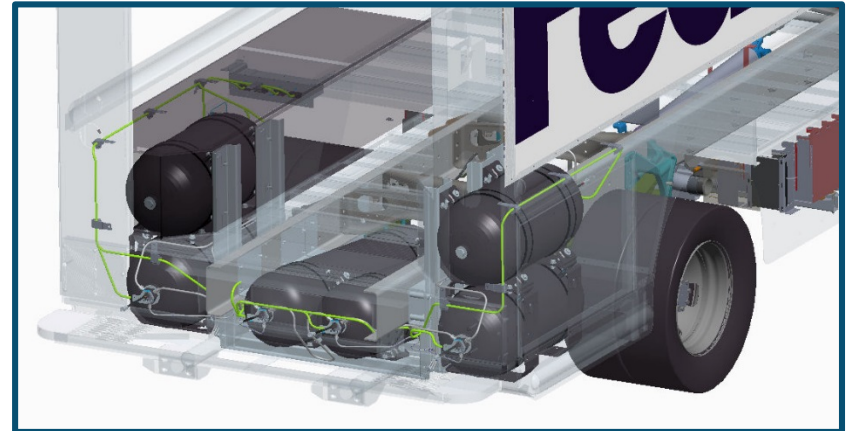
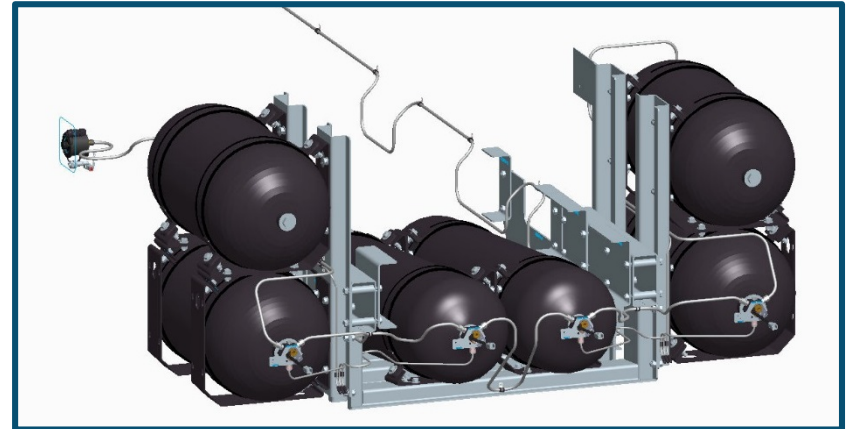
Hydrogen Storage | Dilution & Venting

Fuel System

- Fuel storage: 11.6 kg @ 350 bar (11 kg usable)
- Located in the least valuable real estate
- Wheel wells extended to cover tanks inside
- Incremental energy to batteries: 165 kWh
- Fueling receptacle in same location as diesel

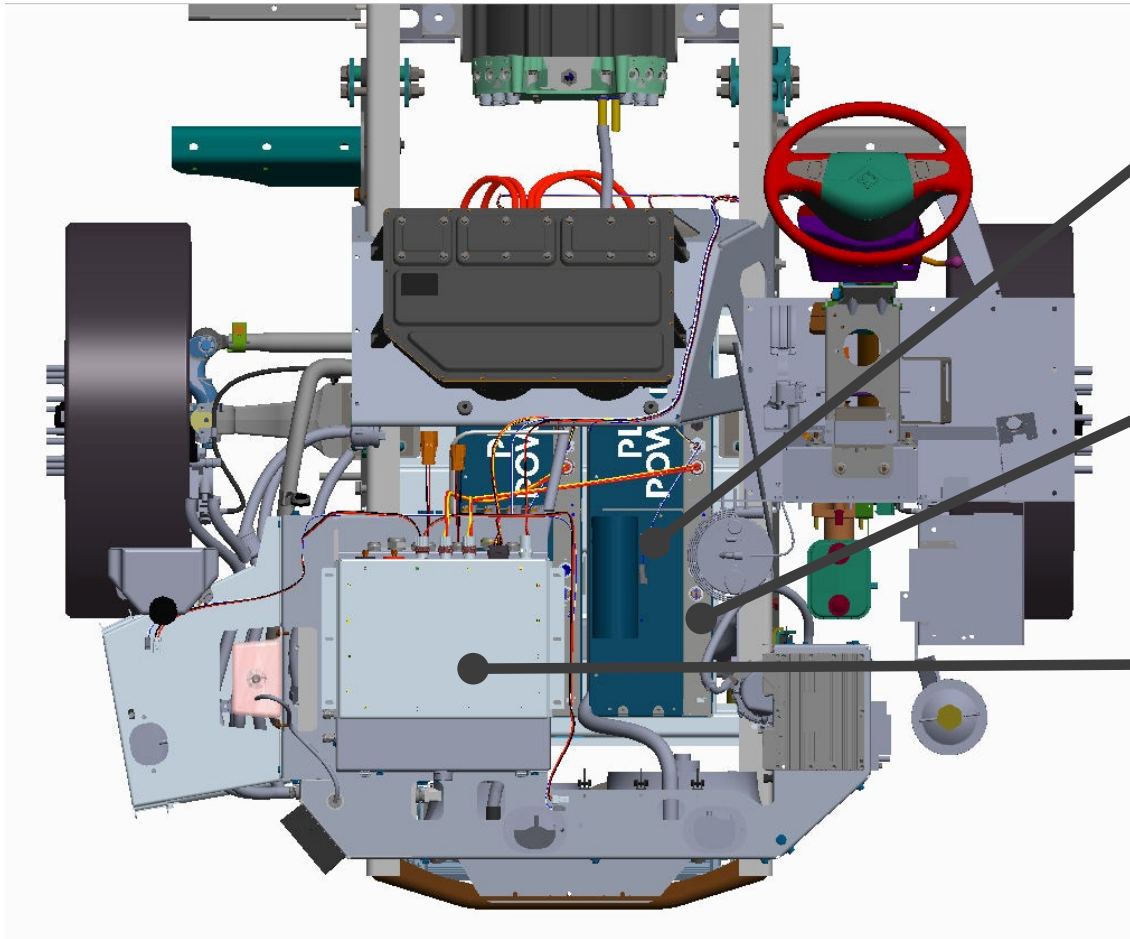
Safety - Dilution & Venting

- Leak detection via hydrogen sensors
- Shutdown at 25% of LEL of H₂
- Regulation down to 30 bar at tanks
- Emergency venting through vertical chimney in rear corners per DOT recommendation



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

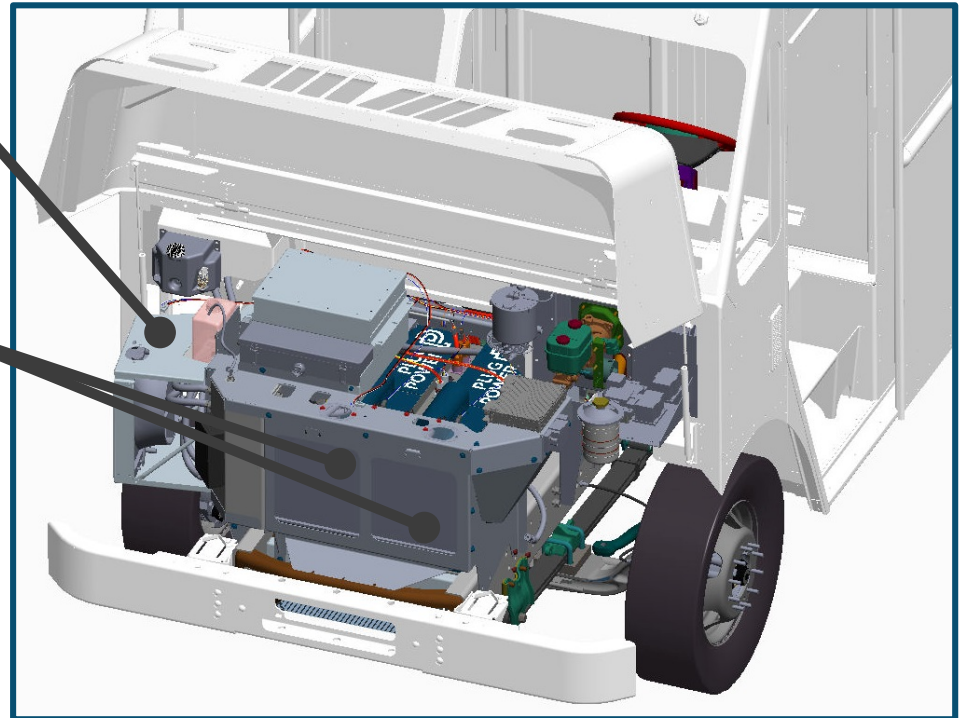
- Vehicle: Traction motor, inverter, 12V converter for cab loads
- eREV: DC/DC converters

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



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

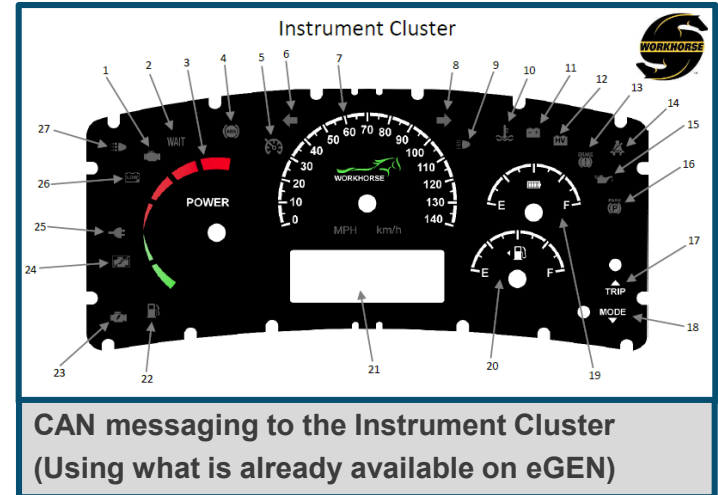
FC Receive from BMS

- 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 are 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

Constraints

- Maintain batteries between 20% and 90% SOC
- 90% maximum allows for regenerative braking
- 20% ensures long battery life

Starting Point (On/Off Operation)

- 20 kW operation on/off operation
- Fuel cell is only required 57.7% of time

Optimization (Variable Output)

- Run FC at most efficient points to improve economics
- Could run fuel cell as low as 11.5 kW constant if we were smart enough about the route
- Ideally, the fuel cell will be on as much as possible
- Fuel Cell Output Power = $f(\text{battery SOC, vehicle speed})$

Remaining Challenges and Barriers

- **Reliability**
 - Support to keep the vehicle on the road.
 - Location of the Vehicle vs the location of the partners.
- **Budget Period 2**

Current status

- First Unit Validation
 - Evaluation and Documentation of the first unit.



Future Tasks

Budget Period 1 Milestones

- Evaluate and Document first unit
 - Complete demo and data collection
 - Make a Go/No Go decision.

Budget Period 2 Milestones

- Remaining fleet builds
- Remaining Fleet integration
- Continued Deployment and Operation

Summary

Budget Period 1

- 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

Collaborations

*Project Sponsor
Department of
Energy*

*Vehicle and Fuel Cell
Data Collection:
NREL*

*Vehicle Safety Regulations:
US Department of
Transportation*

*Hydrogen Safety Advisors:
Pacific Northwest National
Laboratory*

Hydrogen Safety Panel



Prime Recipient

Fuel Cell Manufacturer: Plug Power Inc. *EV chassis and Powertrain
Manufacturer: Work Horse Group Inc*

Subrecipients



Thank You.

Questions?

