



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

**Phillip C Galbach**

June 15, 2018



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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

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

<b>Potential Expansion</b>	
<b>Similar Assets &amp; Duty Cycles (count)</b>	7000
<b>Annual Utilization Range (miles)</b>	20k - 50k
<b>Approx Annual Fuel Displaced (gal)</b>	14M
<b>Annual CO2 Avoided (Metric Tons)</b>	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



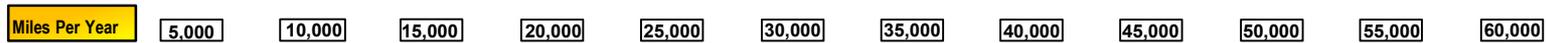
EV  
 UP TO 16,000



eREV  
 > 16,000



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

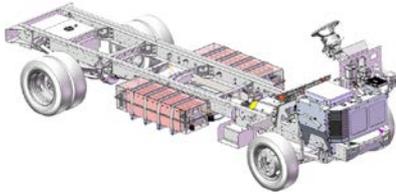


# Milestones

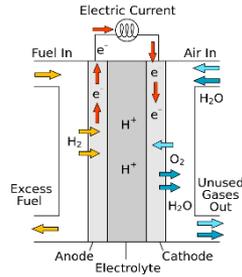
Milestone/Task Breakdown 5: First Unit Validation					
Element Type	Number	Description	Planned	Actual Completion	Completion %
<b>Task</b>	<b>5</b>	Durability Test	6/1/2017	<b>12/1/2017</b>	<b>100%</b>
Task	5	Shipping of Truck #1 to FedEx Station for testing (Menands, NY)	6/19/2017	1/25/2018	<b>100%</b>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

# Approach

Chassis



Fuel Cell



Integration



Commissioned



Durability Test



Body Installation



Utilized on Routes



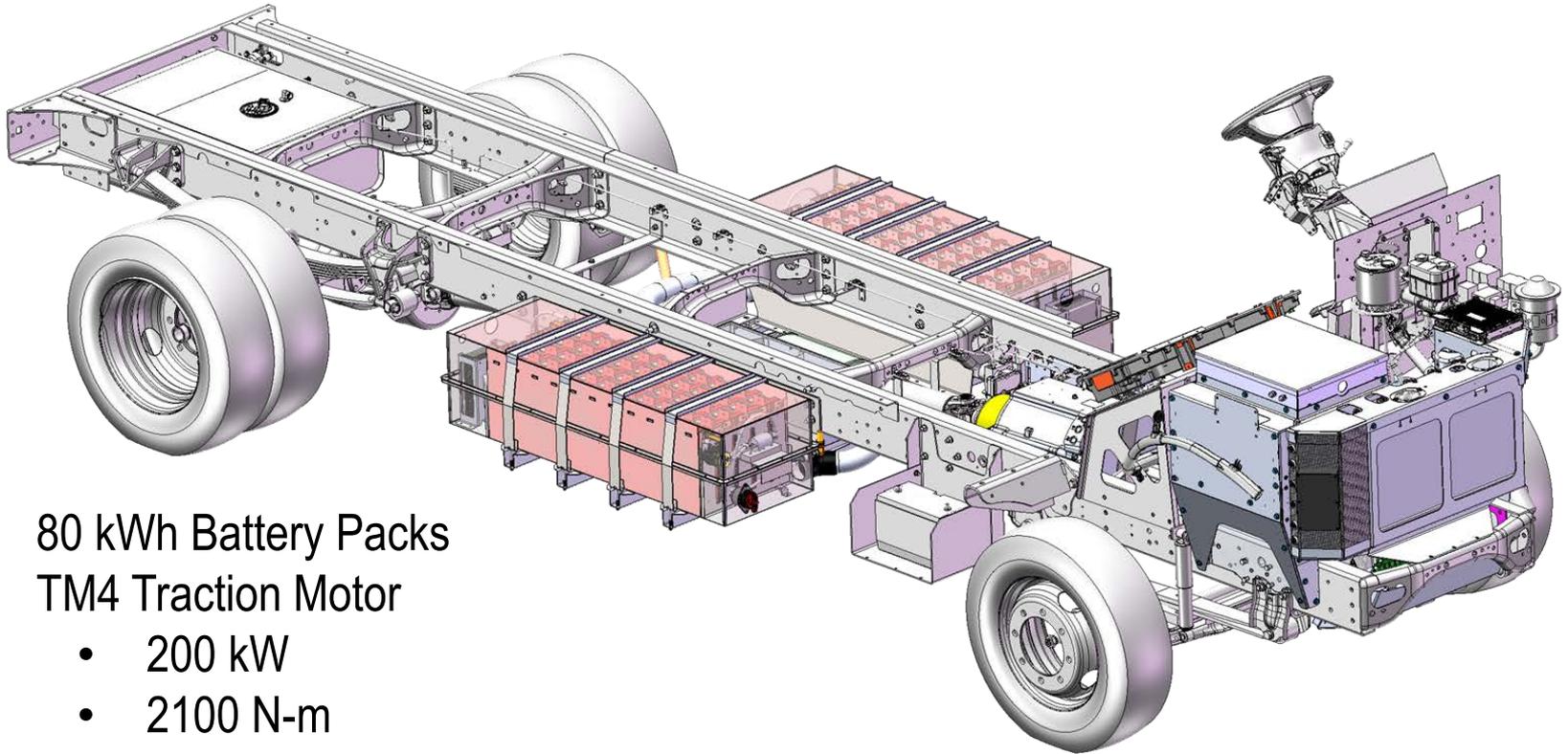
Data transmitted to NREL



Results evaluated

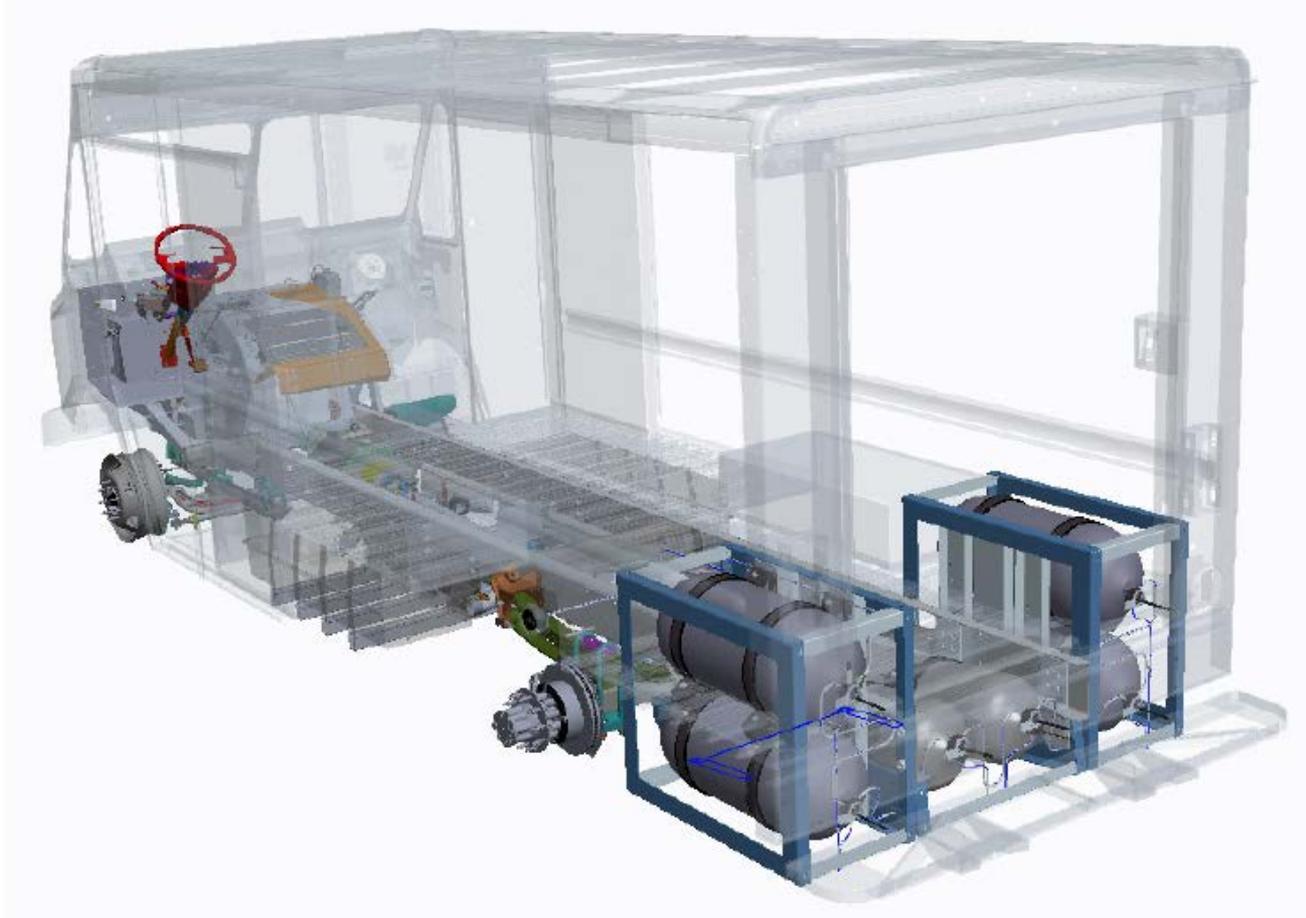


# Workhorse Chassis



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

# Technical Accomplishments and Progress System Integration



# Technical Accomplishments and Progress

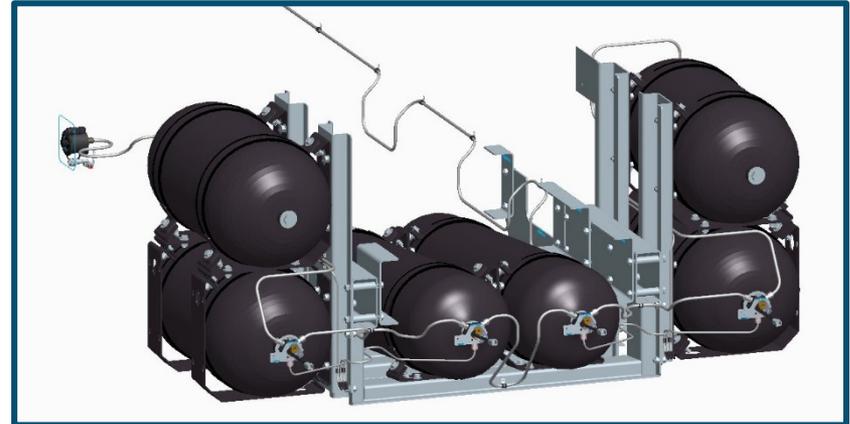
## Hydrogen Storage | Dilution & Venting

### 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

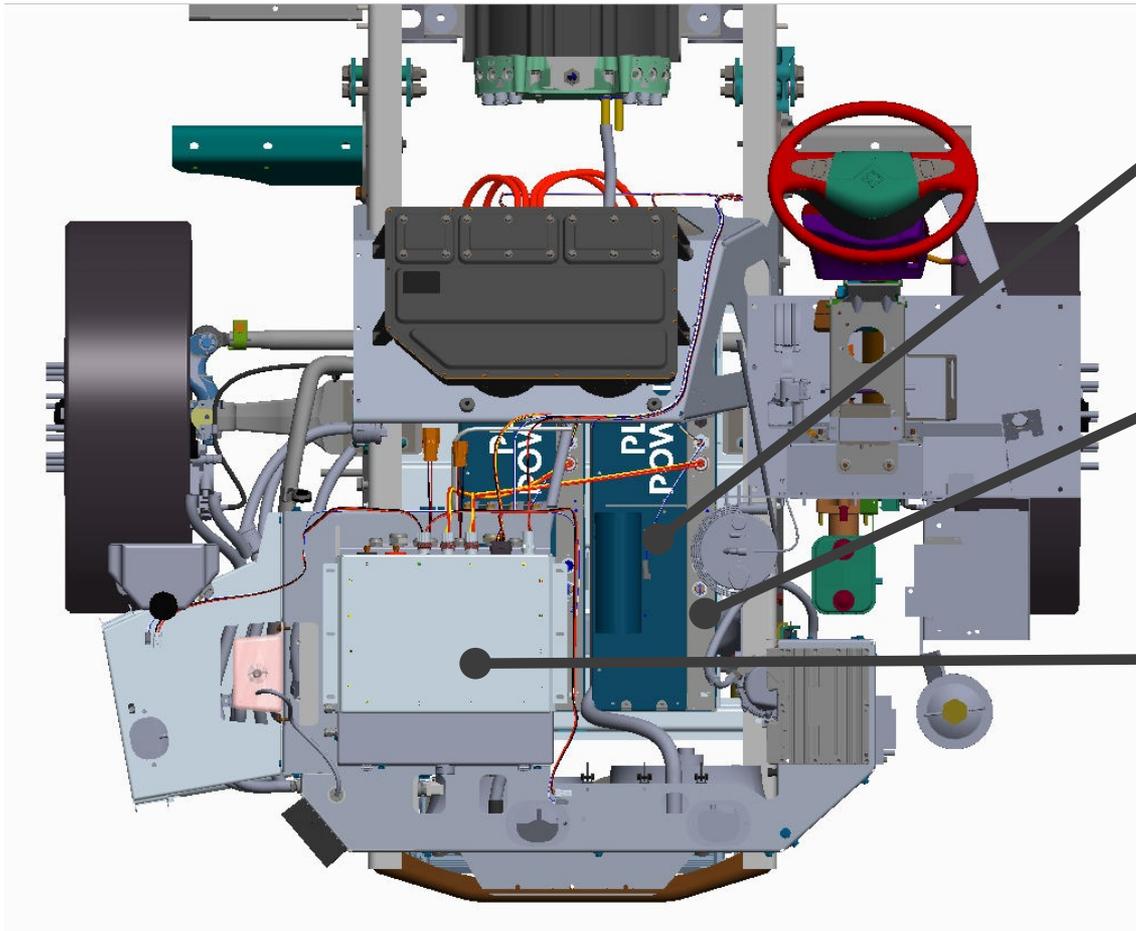
### Safety - Dilution & Venting

- Leak detection via hydrogen sensors
- Shutdown at 25% of LEL of H<sub>2</sub>
- 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

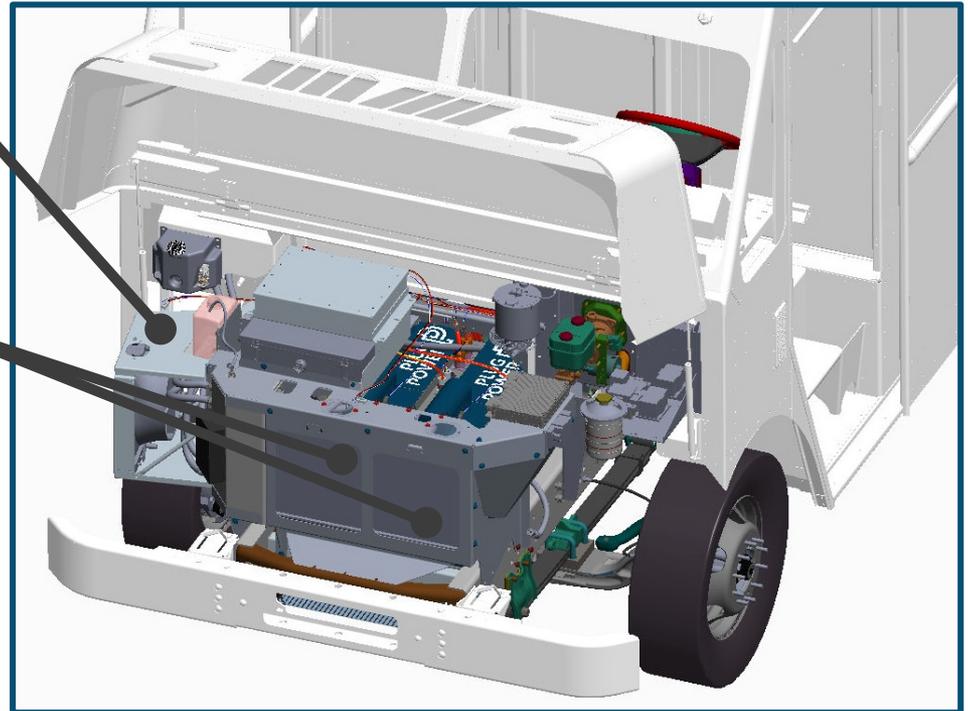
- Vehicle: Traction motor, inverter, 12V converter for cab loads
- eREV: DC/DC converters

### 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

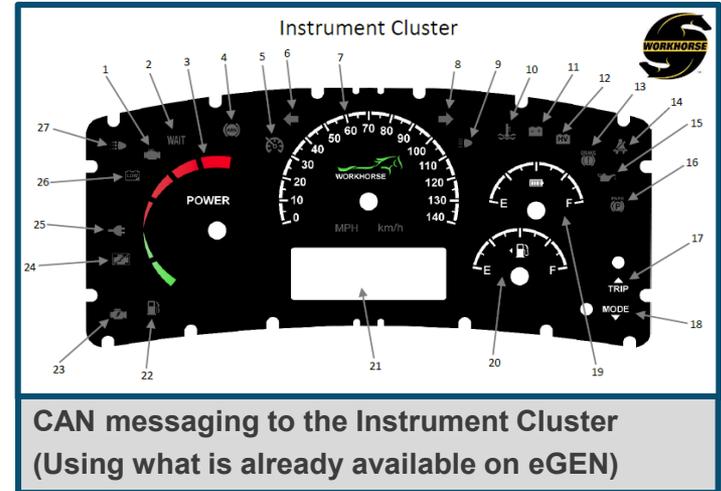
## FC Receive from BMS

- 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 H<sub>2</sub>)

## **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?

