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

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FedEx Express

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

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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	Project Impact
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

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Program Overview

Timeline

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

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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

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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**

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Relevance: Mileage Management

Right Vehicle
Right Route
Mileage Bands – Miles Per Year

RANGE – SPEED – TIME

Right Technology | Right Duty Cycle

PAYLOAD – STOPS – VOLUME

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

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

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Milestones

Element Type (Task or Milestone)	Task Number (Milestone Number)	Task Title (Milestone Description)	Planned	Actual Completed	Current % Complete (0-100)
Task 3: First Fuel Cell Unit Build					
Task	3	Unit #1 Fuel Cell Fabrication	9/15/16	1/16/2017	100%
Task	3	Unit #1 Fuel Cell Factory Acceptance Testing	10/15/16	1/23/2017	100%
Task	3	DC/DC Converter Fabrication	10/15/16	1/5/2017	100%
Task	3	Hydrogen Tank packaging			100%
Task	3	System Factory Testing	11/15/2016	2/9/2017	100%
Milestone	3	Fuel Cell System Pass Factory Aceptance Test	12/01/2016	3/1/2017	100%
Task 4: First Unit Integration					
Task	4	Installation/Integration of Fuel Cell System and Electric Vehicle	2/15/2017	3/15/2017	100%
Task	4	Chassis Shipment to Plug Power	1/23/2017	1/27/2013	100%
Task	4	Bracketry Design	2/13/2016	2/21/2017	100%
Task		CAD Models finalized	2/10/2017	2/10/2017	100%
Task	4	Bracket installation	3/27/2017	4/17/2017	100%
Task	4	Ventillation Testing	3/13/2017	3/29/2017	100%
Task	4	WeatherProofing Test	3/29/2017	4/3/2017	100%
Task	4	Body Installation (Morgan Olson)	4/3/2017	5/8/2017	100%
Milestone	4	Integrated Truck Performs per Stated Specifications	2/28/2017	5/19/2017	100%
Task 5: First Unit Validation					
Task	**5**	Durability Test	6/1/2017		
Task	5	Shipping of Truck #1 to FedEx Station for testing (Menands, NY)	6/19/2017		0
Task	5	Driver/Personnel Training	6/20/2017		0
Task	5	Commissioning	6/21/2017		0
Task	5	Test and Validation of Unit #1 vehicle and powertrain requirements	6/21/2017		0
Task	5	Data Analysis	7/3/2017		0
Task	5	Data Transmission to DOE/NREL	6/30/2017		0
Milestone	5	Evaluation Document of First Unit Performance	7/31/2017		0
Budget Period 1 Go/No-Go Decision Point (September)					

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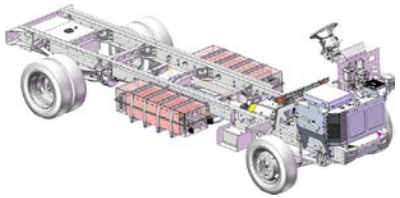
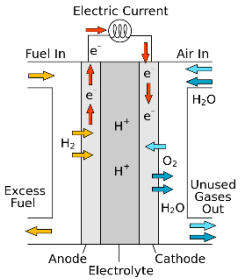
Approach

Chassis



Fuel Cell



Integration

Body Installation

Durability Test

Commissioned

Utilized on Routes

Data transmitted to NREL

Results evaluated

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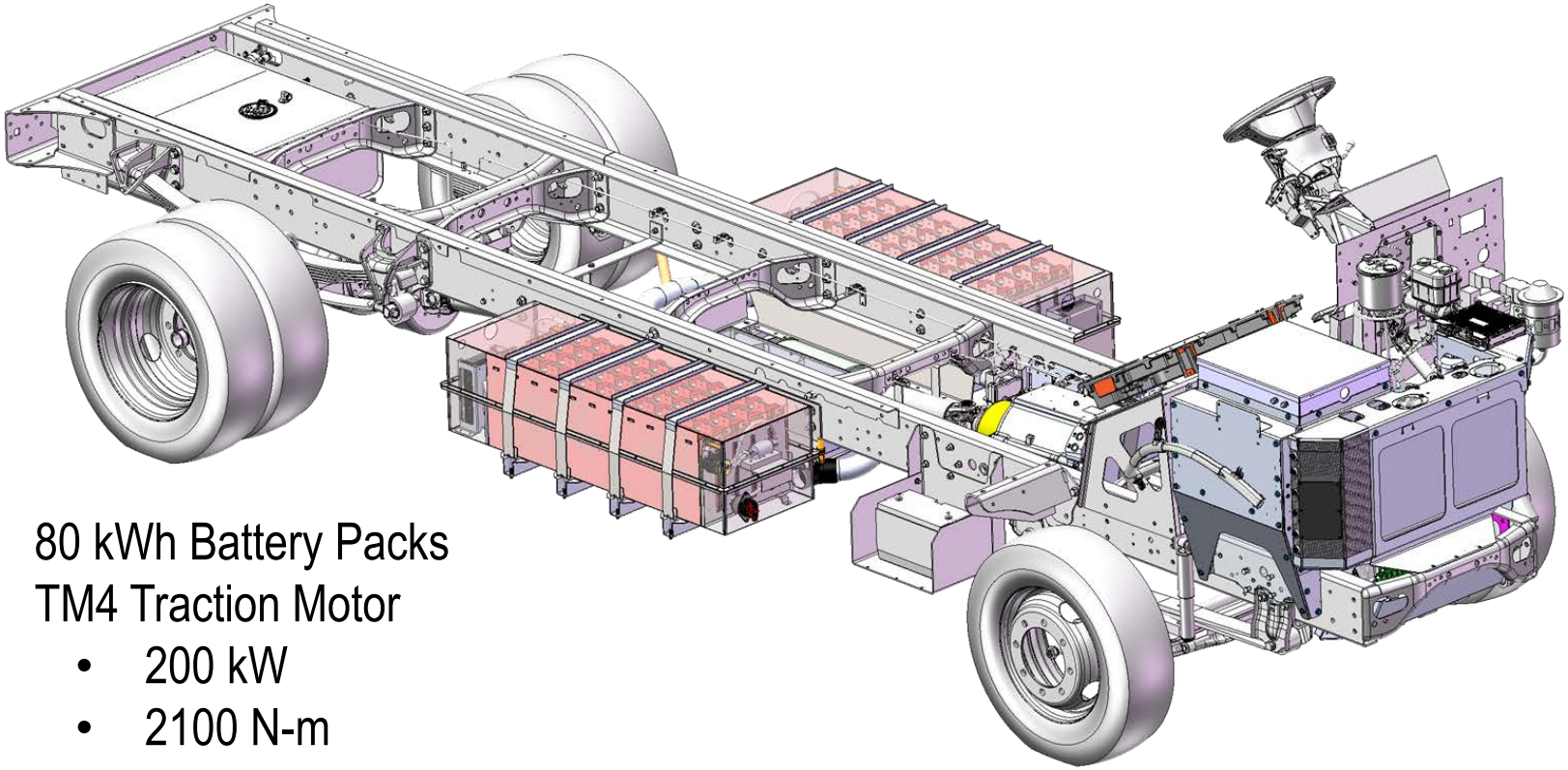
Workhorse Chassis



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

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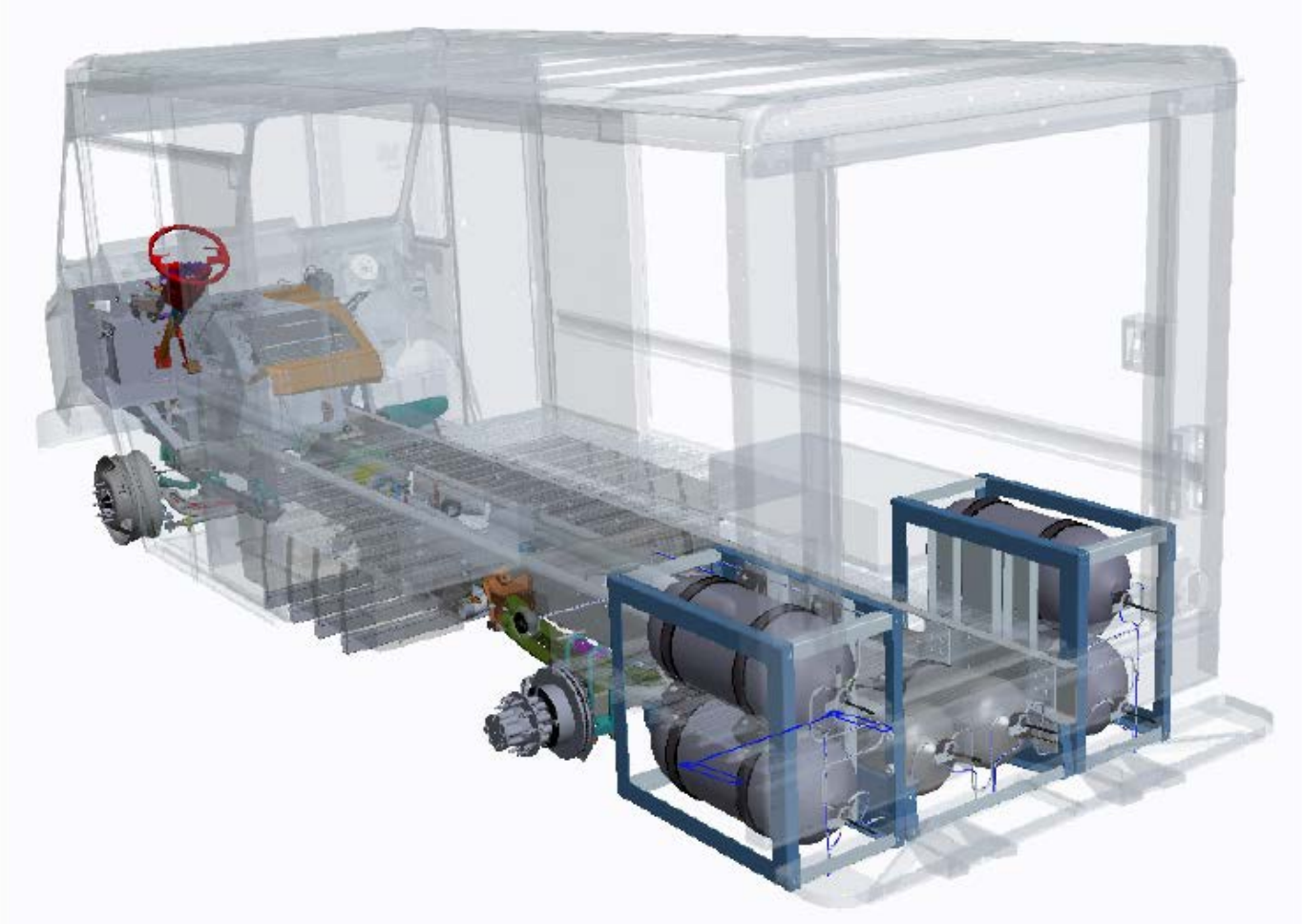
Technical Accomplishments and Progress
System Integration



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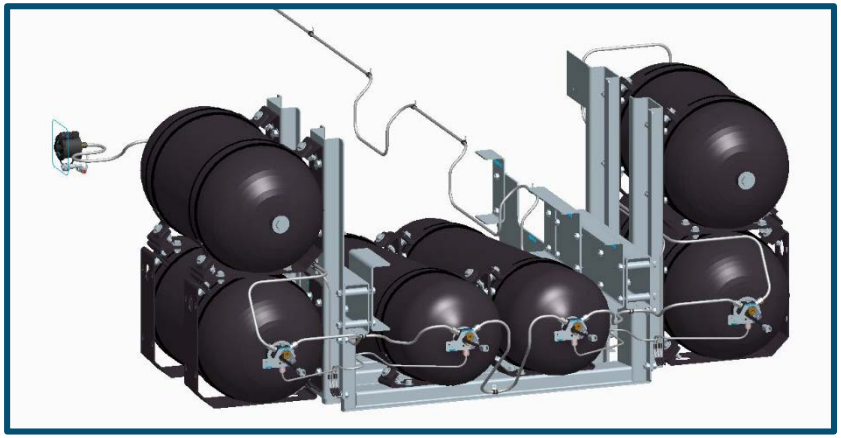
Technical Accomplishments and Progress
Hydrogen Storage | Dilution & Venting

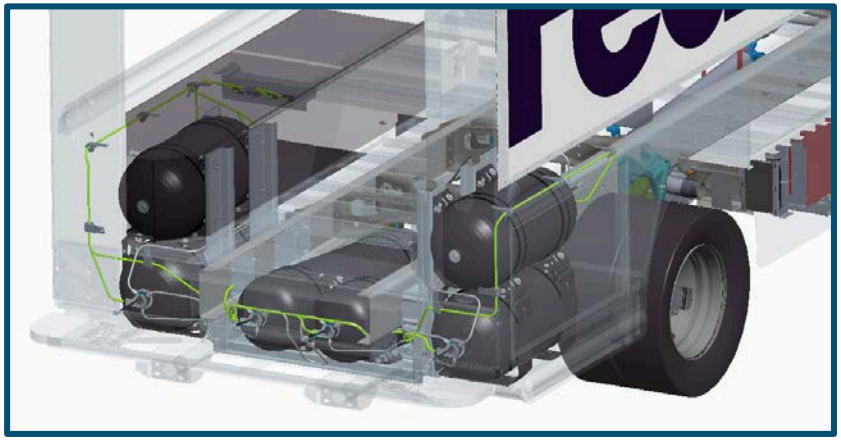
Fuel System

- 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





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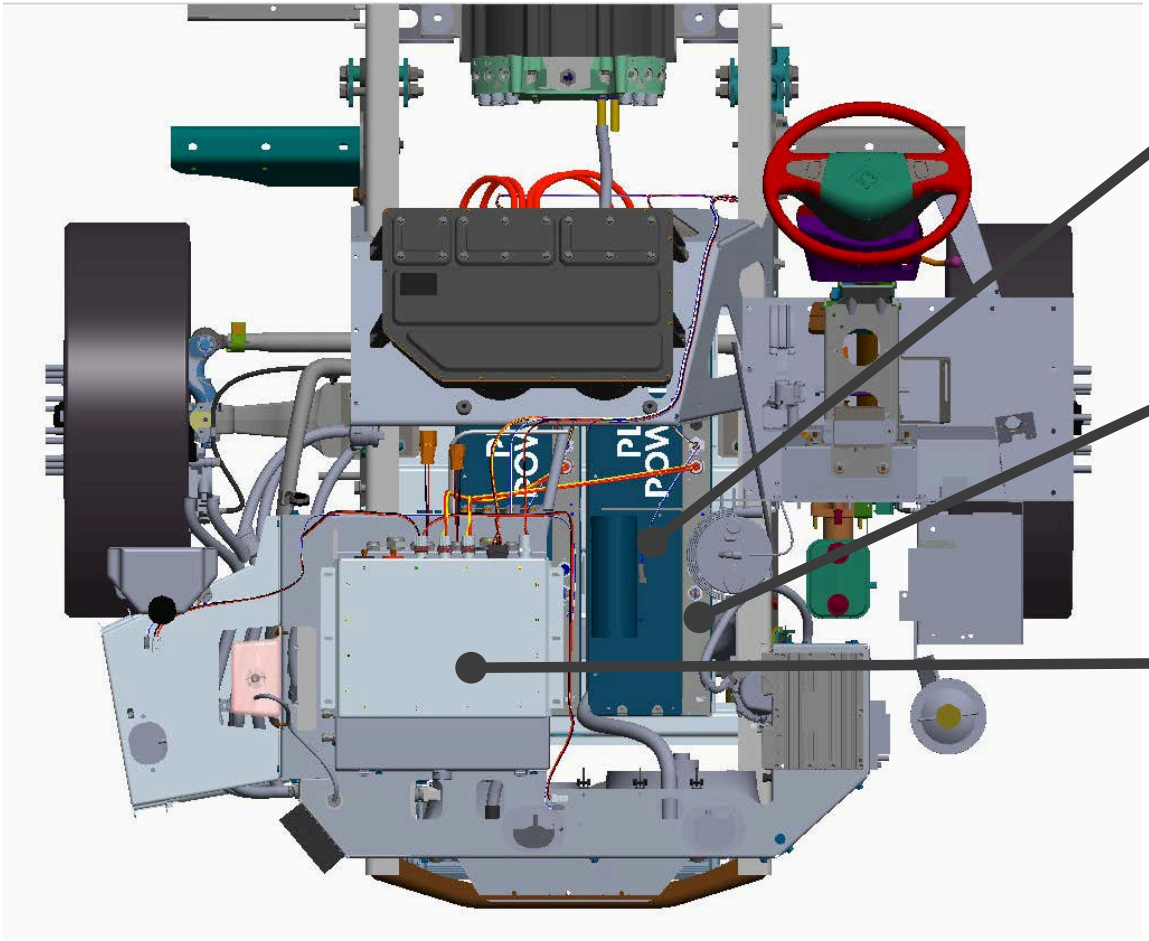
Technical Accomplishments and Progress
Power Generation / Vehicle Connection



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

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Technical Accomplishments and Progress
Thermal Management

Electronics: Separate Radiator

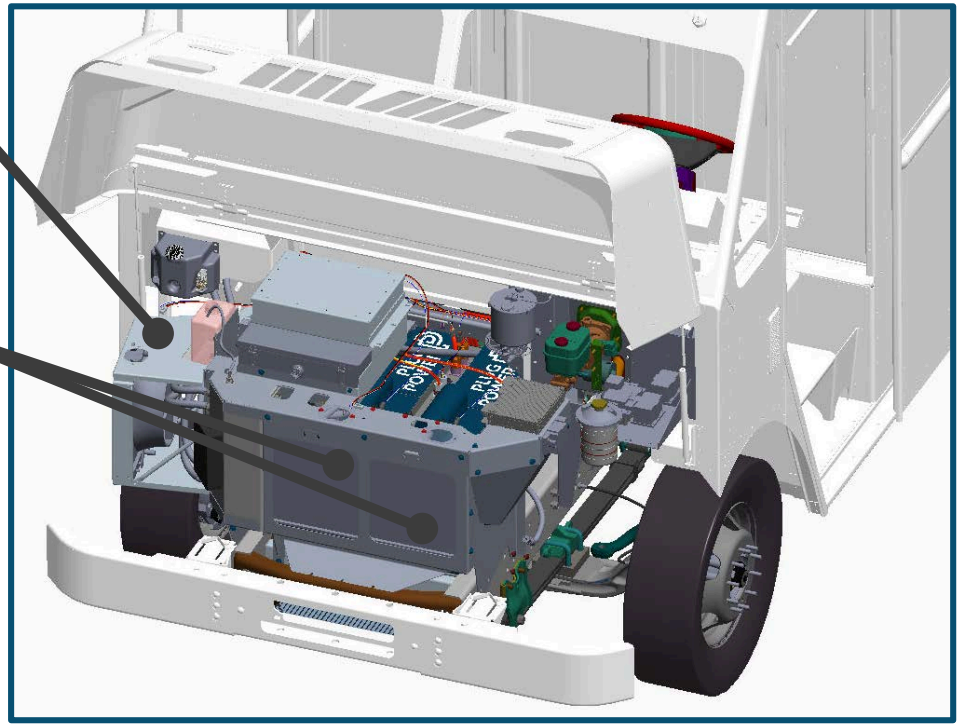
- Vehicle: Traction motor, inverter, 12V converter for cab loads
- eREV: DC/DC converters

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)



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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

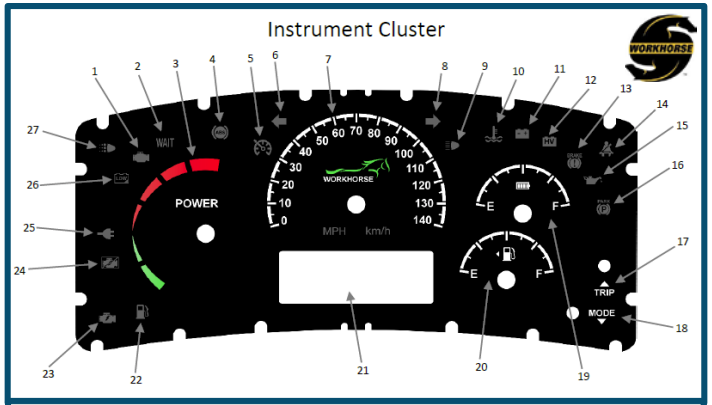
- FC Enable (12V tied to ignition)
- FC On for Battery Charging
- Power Request
- Max Power Allowed

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)

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

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Technical Accomplishments and Progress
Control Strategy

Constraints

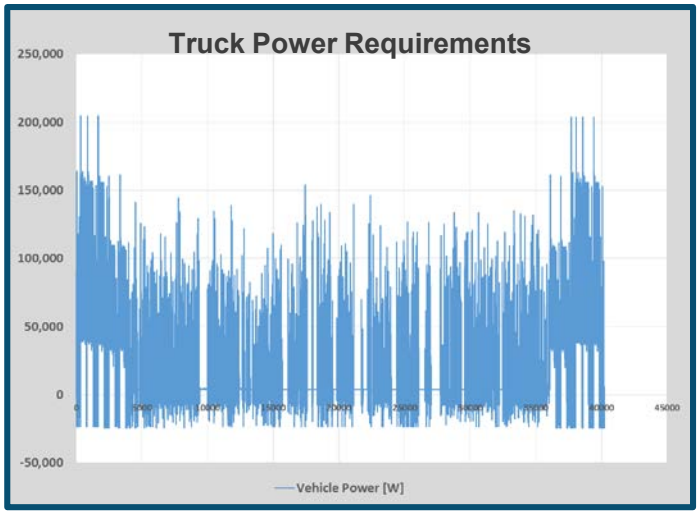
- Maintain batteries between 20% and 90% SOC
- 90% maximum allows for regenerative braking
- 20% ensures long battery life

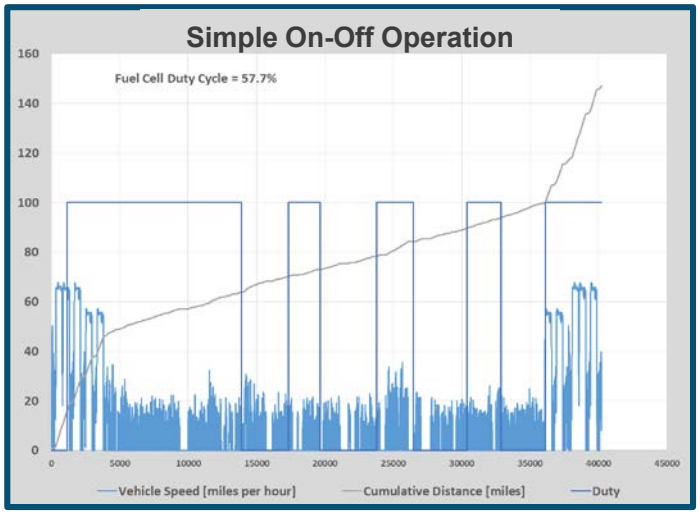
Starting Point (On/Off Operation)

- 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(battery SOC, vehicle speed)





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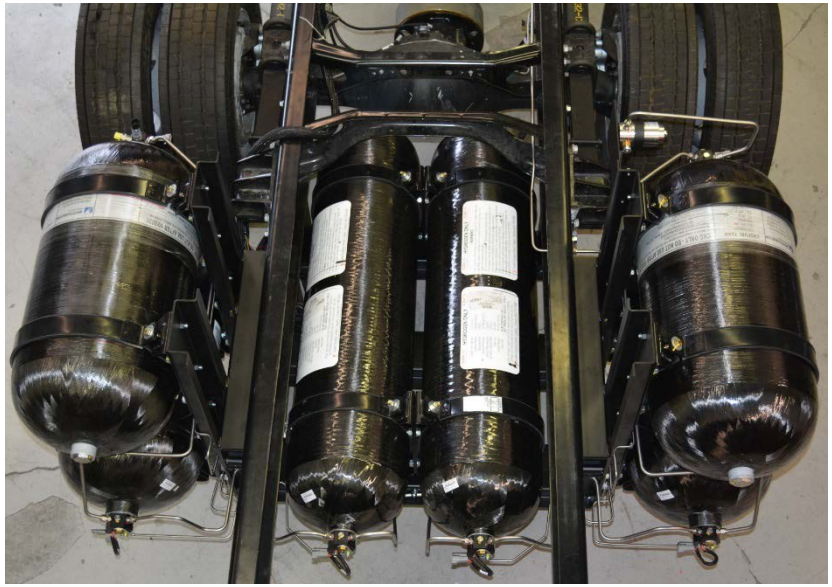
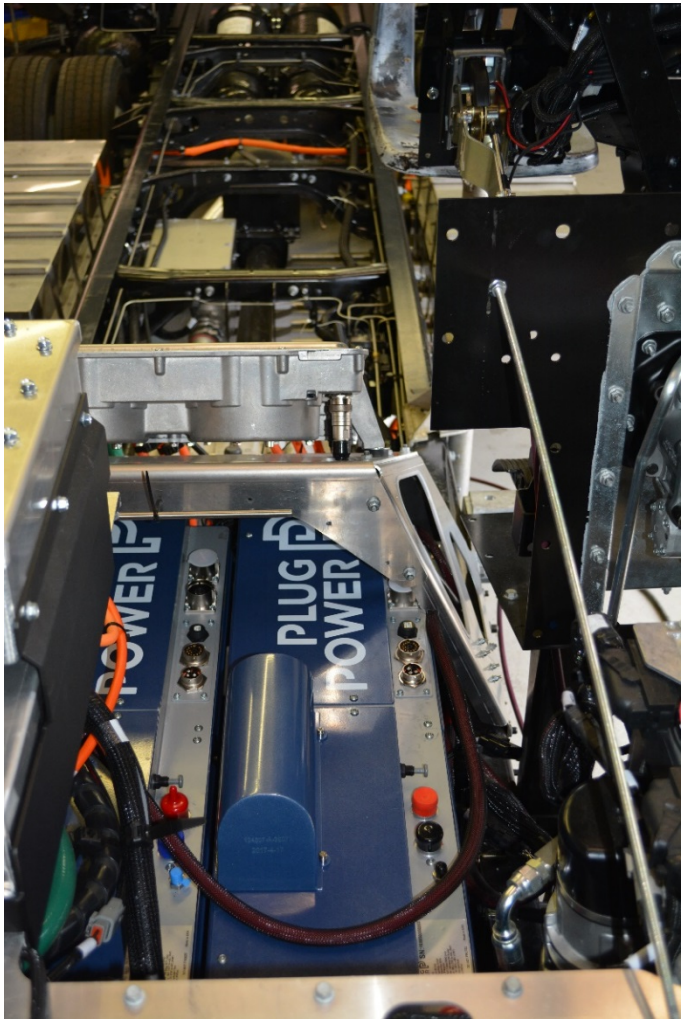
Current status

- Chassis integration completed
- Body build completed





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Future Tasks

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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 H_2)

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

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Collaborations

Project Sponsor

Prime Recipient

Vehicle and Fuel Cell Data Collection

Vehicle Safety Regulations

Hydrogen Safety Advisors

Fuel Cell Manufacturer

EV chassis and Powertrain Manufacturer

Subrecipients

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Thank You

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All Electric

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