CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

Fuel Cell Hybrid Electric Delivery Van Project

Project ID: TV034

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2018 DOE Annual Merit Review

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This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

Project Start: 7/15/2014
Project End: 12/31/2021

Budget

Total Project Budget:	$ 11,264,505
Total Recipient Share:	$ 8,282,434
Total Federal Share:	$ 2,982,071
Total DOE Funds Spent*:	$ 779,869

*as of 2/28/18

Partners

US DOE, CEC, SCAQMD: Project Sponsors
UPS: Commercial Fleet Partner and Operator
CTE: Prime Contractor and Project Manager
Hydrogenics, UES, UT-CEM, Lithium-Werks: Subcontractors

Barriers

Technology Validation

A. Lack of Fuel Cell Electric Vehicle Performance and Durability Data

Market Transformation

D. Market uncertainty around the need for hydrogen infrastructure versus timeframe and volume of commercial fuel cell applications

F. Inadequate user experience for many hydrogen and fuel cell applications

Relevance – Project Objectives

Overall Objectives

- Substantially increase the zero emission driving range and commercial viability of electric drive medium-duty trucks.
  - **Phase 1:** develop a demonstration vehicle in order to prove its viability to project sponsors, commercial fleet partner (UPS), and other stakeholders. [Barriers A & F]
  - **Phase 2:** build and deploy a pre-commercial volume (up to 16) of the same vehicle for at least 5,000 hours of in-service operation. [Barriers A & F]
- Develop an Economic & Market Opportunity Assessment for medium-duty fuel cell hybrid electric trucks. [Barrier D]

Current Year Objectives (April 2017 – March 2018)

- Complete system integration
- Test and validate vehicle
- Complete training and education
- Begin demonstration of vehicle in UPS fleet service

Relevance – DOE Program Goals

Alignment with DOE Program Goals

- The project promotes commercialization of hydrogen fuel cell vehicles by:
  - designing energy storage and drive system for new-builds and conversion kit retrofits,
  - deploying multiple vehicles within the UPS delivery fleet,
  - utilizing hydrogen fueling infrastructure at multiple locations, and
  - publishing an Economic & Market Opportunity Assessment.
- The project will begin Phase 1 demonstration in 2018.
- The project will help determine how competitive hydrogen FC hybrid electric vehicles are to existing technologies by deploying the FC vans on routes that are also served by diesel, natural gas, and battery electric vans.
- The project increases end-user's experience and knowledge of H2 fuel cell vehicles and ensures the team creates a commercially acceptable product by involving UPS in design activity.
- The project pushes industry to address need for H2 infrastructure in medium-duty market.

Approach – Project Scope

16 Fuel Cell Hybrid Electric Walk-In Delivery Vans

- **Phase 1: Convert, demonstrate, and validate 1 vehicle**
  - Convert existing UPS diesel-powered van to a base electric-drive vehicle [out of DOE project scope]
  - Integrate FC, power electronics, hydrogen storage system, and controls
  - Train UPS fleet operators and support staff
  - Demonstrate and validate in UPS fleet for 6 months
- **Phase 2: Build and deploy 15 additional vehicles**
  - UES is responsible for full integration activities, with CEM assistance
  - CTE will coordinate training of UPS fleet operators and support staff
  - UPS will operate vehicles at multiple distribution centers in California
  - 2 years of data collection and project reporting
  - Develop an Economic & Market Opportunity Assessment

Any proposed future work is subject to change based on funding levels.

Approach – Project Milestones

Task	Description	% Complete	Estimated Completion Date
Phase 1 Demonstration			
1	Vehicle Build	90%	May 2018
2	Training and Education	25%	June 2018
3	Demonstration Vehicle Test and Evaluation	5%	Dec. 2018
4	Project Management Phase 1	82%	Dec. 2018

Go / No-Go Decision Point	**Dec. 2018**

Phase 2 Deployment			
5	Vehicle Build	0%	Dec. 2019
6	Training and Education	0%	Dec. 2019
7	Vehicle Test and Evaluation	0%	Dec. 2021
8	Project Management Phase 2	0%	Dec. 2021

Any proposed future work is subject to change based on funding levels.

Accomplishments and Progress

Base Electric Drive Van Assembly

- ✓ Received last long lead-time components for EV
- ✓ Mounted and plumbed radiator for power electronics and traction motor
- ✓ HV and LV wiring installed and reviewed by UPS
- ✓ Tested the SR traction motor and built a new motor cradle with greater vibration dampening
- ✓ Battery pack built and tested
- ✓ Developed vehicle control software and mounted new driver displays to dashboard

Photo: CTE

Vehicle lifted for integration and testing

Photo: UES

Battery modules installed in battery trays

Accomplishments and Progress

Began Fuel Cell Power System integration and testing

- ✓ Completed third-party review (CSA) of hydrogen P&ID
- ✓ Received and integrated vehicle Hydrogen Storage System (HSS) and Fuel Cell Power System (FCPS)
- ✓ Leak tested hydrogen plumbing
- ✓ Finalized fuel cell module control strategies, including key on/off control and max. power limits, to improve vehicle efficiency
- ✓ Conducted stationary tests of FCPS
- ✓ Finalized FC and balance of plant layout, plumbing, and mounting strategy on FC skid

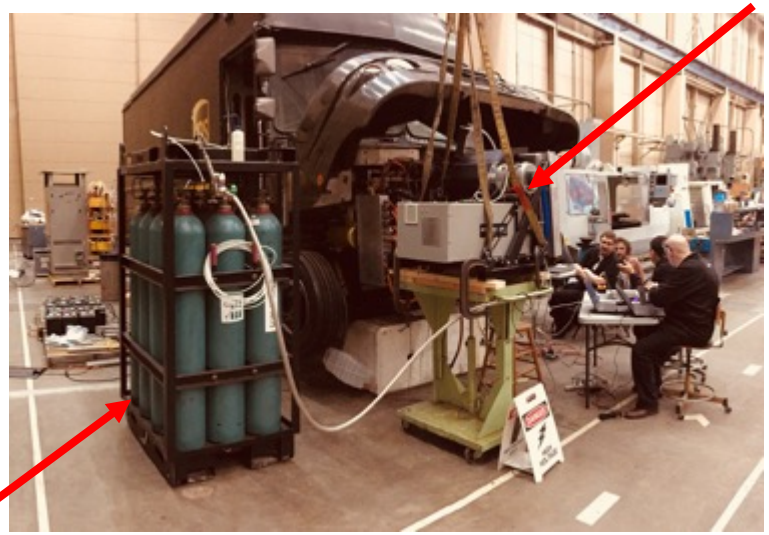


Photo: UES

UES, Hydrogenics, and UT-CEM meet for coordinated integration of fuel cell, power electronics and electric drive system

Accomplishments and Progress

Detailed vehicle demo preparation has begun

- ✓ Coordinating hydrogen test fills with Linde Gas in W. Sacramento
- ✓ Fueling test is scheduled to occur in June 2018
- ✓ Drafted fueling agreement between UPS and Linde Gas
- ✓ Developed a training matrix for station, maintenance, and operations staff as well as local First Responders

	Driver Training	H2 Fueling Staff Training	Maintenance Training	First Responder Training*
Scope	Ensure that UPS staff is prepared to drive the vehicle.	Ensure that UPS staff is prepared to fuel the vehicle at Linde's West Sacramento H2 station.	Ensure that UPS staff is familiar with vehicle technology and appropriate safety practices.	Ensure that local emergency services staff is prepared to handle an emergency related to the vehicle.
Date(s)	- TBD	- TBD	- TBD	- TBD
Trainer(s)	- Unique Electric Solutions	- Linde	- Unique Electric Solutions	- CTE
Attendee(s)	- UPS Lead Trainer(s) - UPS Driver(s)	- UPS Lead Trainer(s) - UPS Fueling Staff	- UPS Lead Trainer(s) - UPS Maintenance Staff	- CTE Trainer(s) - Local Emergency Services Staff
Location(s)	- UPS West Sacramento Distribution Center (1380 Shore St, West Sacramento, CA 95691)	- Linde West Sacramento fueling station (1515 S River Rd, West Sacramento, CA 95691)	- UPS West Sacramento Distribution Center (1380 Shore St, West Sacramento, CA 95691)	- TBD
Timing	~2 Hours in "Classroom" ~2 Hours On-Board Vehicle	~1 Hour in "Classroom" ~1 Hour at Fueling Station	~2 Hours in "Classroom" ~2 Hours On-Board Vehicle	~2 Hours in "Classroom" ~2 Hours On-Board Vehicle
Materials & Deliverables	- Driver Training PowerPoint - Driver Quick Reference Card - Operator's Manual	- H2 Fueling Training PowerPoint - Fueling Quick Reference Card - Operator's Manual	- Maintenance Staff Training PowerPoint - Facility Quick Reference Card - Operator's Manual	- Emergency Services Staff Training PowerPoint - Facility Quick Reference Card - Operator's Manual
Notes	- make sure training includes any manual data logging requirements (fueling reports, incident reports, maintenance reports…)	- make sure training includes any manual data logging requirements (fueling reports, incident reports, maintenance reports…)	- make sure a communication procedure is in place in the event a vehicle issue is identified. - make sure training includes any manual data logging requirements (fueling reports, incident reports, maintenance reports…)	- make sure hazards are properly marked on the vehicle (e.g. high voltage/hazard decals, e-stop location)

Table: CTE

Vehicle Deployment Training Matrix

Responses to Last Year AMR Comments

"The project demonstrates improved progress in this past fiscal year, although it still has a long time horizon and seems to be struggling to keep pace with that. There is a concern that while this project is working to get off the ground, other technology developments will be occurring that will make the results of this analysis less relevant."

- FY17 was delayed by significant vehicle build work and custom DC/DC converter
  - Limited resources were devoted to a similar EV development project that was foundational to this project. Lessons learned were incorporated.
  - Some long lead time components arrived late and were defective, further delaying testing and integration
  - Unforeseen delays in creating and testing a custom DC/DC converter
- Significant technical activity since last AMR
  - began vehicle build
  - began vehicle integration
  - on-track for 2018 vehicle demonstration
  - began vehicle demonstration preparation

Responses to Last Year AMR Comments

“It is not clear whether the arrangement (fueling contract and payment card) is in place to fuel vehicles at a hydrogen station (West Sacramento or elsewhere).”

“It would be good to hear that a fueling contract is in place and that fueling tests are scheduled."

- We are coordinating closely with Linde Gas in West Sacramento since the outset of the project. Linde has reviewed dual port HSS layout design. Even though this is public station, we are negotiating a fueling agreement for card access, payment, and data tracking. We are coordinating training and station availability with respect to capacity.
- Accomplished CSA review and approval of dual port HSS design.
- Fueling tests and related training activities are planned upon vehicle delivery – July 2018.

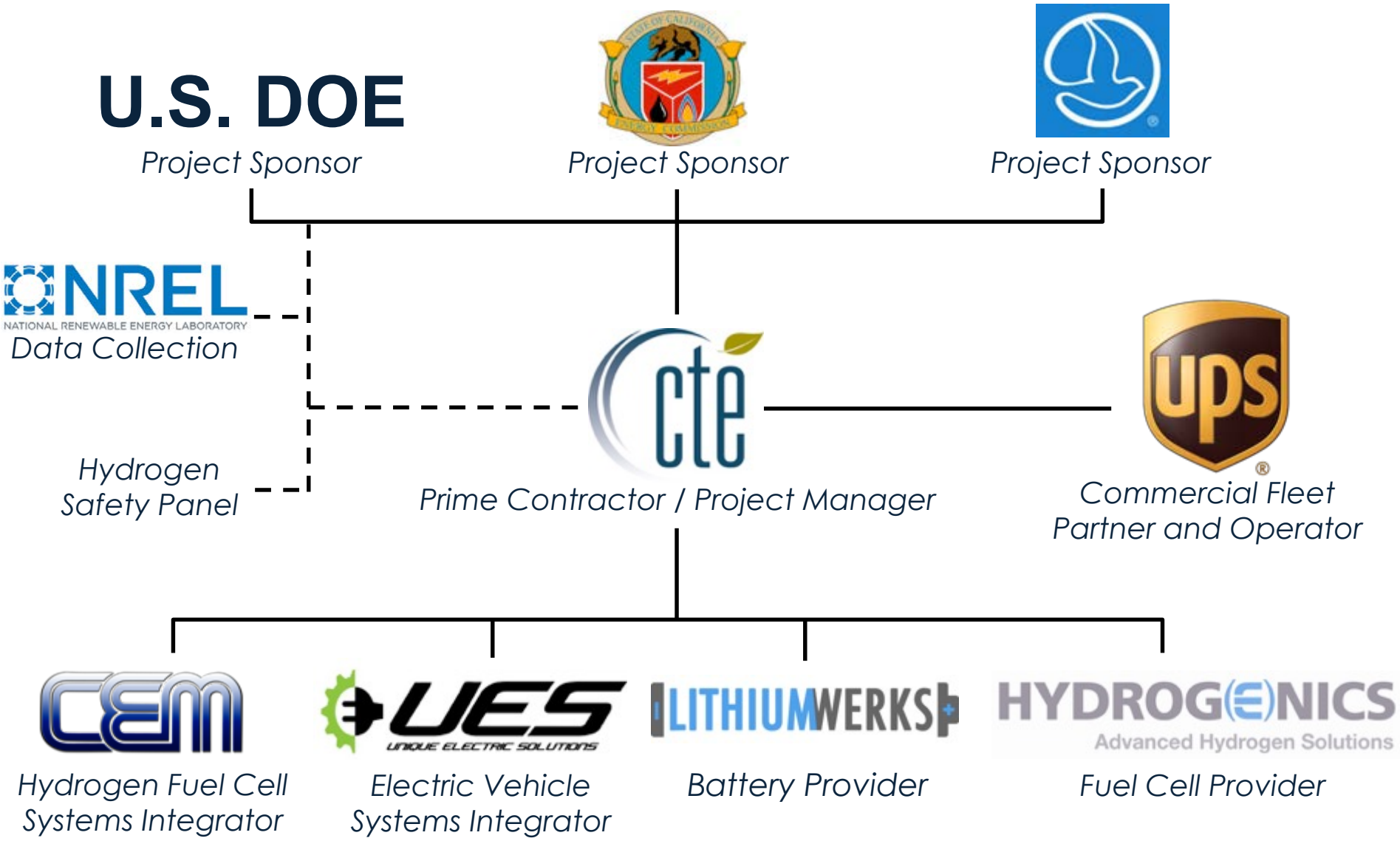
Responses to Last Year AMR Comments

"The project design appears sound, although the criteria for the decision to move to Phase 2 are not clear."

- Criteria:
  - Results from the six-month demonstration will be compared to the previously established project goals, vehicle specifications, and performance metrics (range, efficiency, emissions, and reliability/availability)
  - The project will move to Budget Period 2 if the vehicle successfully demonstrates a zero-emissions driving range of at least 125 miles on a single hydrogen fill and meets the operator's performance expectations as a comparably functional vehicle to its existing fleet.

- Potential restructure plans for Phase 2 vehicle development but continue investment into commercialization of vehicles:
  - Clear production requirements
  - Cheaper batteries
  - 700 bar hydrogen storage tanks

Collaborations and Project Partners



Remaining Barriers and Challenges

Issue – Phase 2 Cost Share Incomplete

- CTE received $1.1M of the original $3M state match due to program funding caps that were established after agency support commitment and DOE Award.
- Additional cost share required to cover cost increases from design changes and additional administration

Resolution – Manage Existing and Seek Additional Funds

- ✓ CTE has ensured Phase 1 (through go/no go decision) is fully funded with existing funds.
- ✓ CTE has secured funding to allow 6 vehicles to be built and demonstrated during Phase 2.
- CTE continues to pursue additional funding from State opportunities from Clean Transportation initiatives to build/demo more Phase 2 vehicles.
- Organizations that may provide additional project funding, like SCAQMD, have expressed to the team that getting the Phase 1 vehicle operational and demonstrating success is critical to acquiring more financial support.

Remaining Barriers and Challenges

Issue – Delays Increase Cost and Affects Project Impact

- The project has been significantly delayed by subcontractor replacement, administrative issue resolution, and slow vehicle build
- Budget did not account for labor cost escalation and administrative activity during delays
- Project must be demonstrated before its relevance to hydrogen range-extension technology development diminishes

Resolution

- Propose alternative smart criteria to measure project success during Phase 1 deployment and allow sponsor to expedite go/no-go decision
  - Current scope includes a 6-month demonstration period in Phase 1
  - Team should investigate the possibility of shortening the demonstration period if specific vehicle performance goals are met prior to the end of the 6-month period
- Implement specific Phase 2 schedule controls and constraints as a condition of moving forward to Phase 2, to prevent further issues

Remaining Barriers and Challenges

Issue – Custom DC/DC Converter is Unproven

- Initial project proposal included a modified Rinehart DC/DC converter
- Subcontractor decided to develop a custom DC/DC with in-house expertise
- Unexpected design, build, and test issues have slowed vehicle build progress
- This custom DC/DC is unproven in the field and is a risk to the demonstration success

Resolution

- Test plan that includes component, system, and vehicle level testing before demonstration begins
- Team member collaboration: UES, Hydrogenics, and UT-CEM on-site for integration and test activities
- Subcontractor has purchased and maintains backup spare components and hardware

Proposed Future Work (Next Year)

Task 1 – Vehicle Build

- Complete system integration [2Q 2018]
- Test and validate vehicle [2Q 2018]

Task 2 – Training and Education

- Complete training and education [3Q 2018]

Task 3 – Demonstration

- Demonstrate and evaluate vehicle in UPS fleet service [3Q – 4Q 2018]
- Data collection and reporting [3Q – 4Q 2018]

Task 4 – Project Management

- Coordinate Phase 1 H2 fueling availability [2Q 2017 – 4Q 2018]
- Monitor budget, schedule, risk, and mitigation [2Q 2017 – 4Q 2018]

Go / No-Go Decision Point [4Q 2018]

Kickoff Phase 2 [1Q 2019]

All quarters are calendar quarters – "1Q" is January 1 to March 31.
Any proposed future work is subject to change based on funding levels.

Technology Transfer

DOE project has encouraged partnerships between team members on other zero-emission medium-duty vehicle projects

- ✓ Showed chassis at ACT Expo 2017
- ✓ UPS Announced in November 2017 that "UPS and the New York State Energy Research and Development Authority (NYSERDA) today announced that new technology will be developed to convert UPS package delivery vehicles from diesel to electric. UPS and Unique Electric Solutions LLC (UES LLC) will design, build, test and make the conversions"

Photo: CTE

Project Team at ACT Expo 2017

Photo: UPS

All electric vans for UPS and NYSERDA

1. Petrella, Kristen. "UPS And NYSERDA To Convert UPS Diesel Delivery Trucks In NYC To Electric." UPS Pressroom, 9 Nov. 2017, www.pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1510239934903-452.

Summary

Objective: To substantially increase the zero emission driving range and commercial viability of electric drive medium-duty trucks.

Relevance: Fuel cell hybrid electric delivery van design, build, validation, deployment, and data collection project in the UPS fleet environment. Multi-location demonstration that utilizes multiple hydrogen fueling stations. Deployment data will be comparable to existing diesel, CNG, and BEB vehicles that are used in the same application. Performance objectives includes 125 mile range and over 95% of UPS routes

Approach: Two phase project, with go/no go decision. Phase 1 includes the design, build, validation, and demonstration of one vehicle. Phase 2 includes the build, deployment, and data collection of up to 15 additional vehicles. Each phase includes training and end-user education tasks.

Accomplishments: Completed vehicle design, conducted hazard analysis, ordered and received long-lead time components, completed majority of integration and vehicle build, began vehicle deployment preparation.

Collaborations: Full project team dedicated to commercialization of viable technology, including a world-class and internationally recognized commercial fleet operator in UPS. Strong set of project sponsors leveraging federal, state, and private funding.

Questions and Comments

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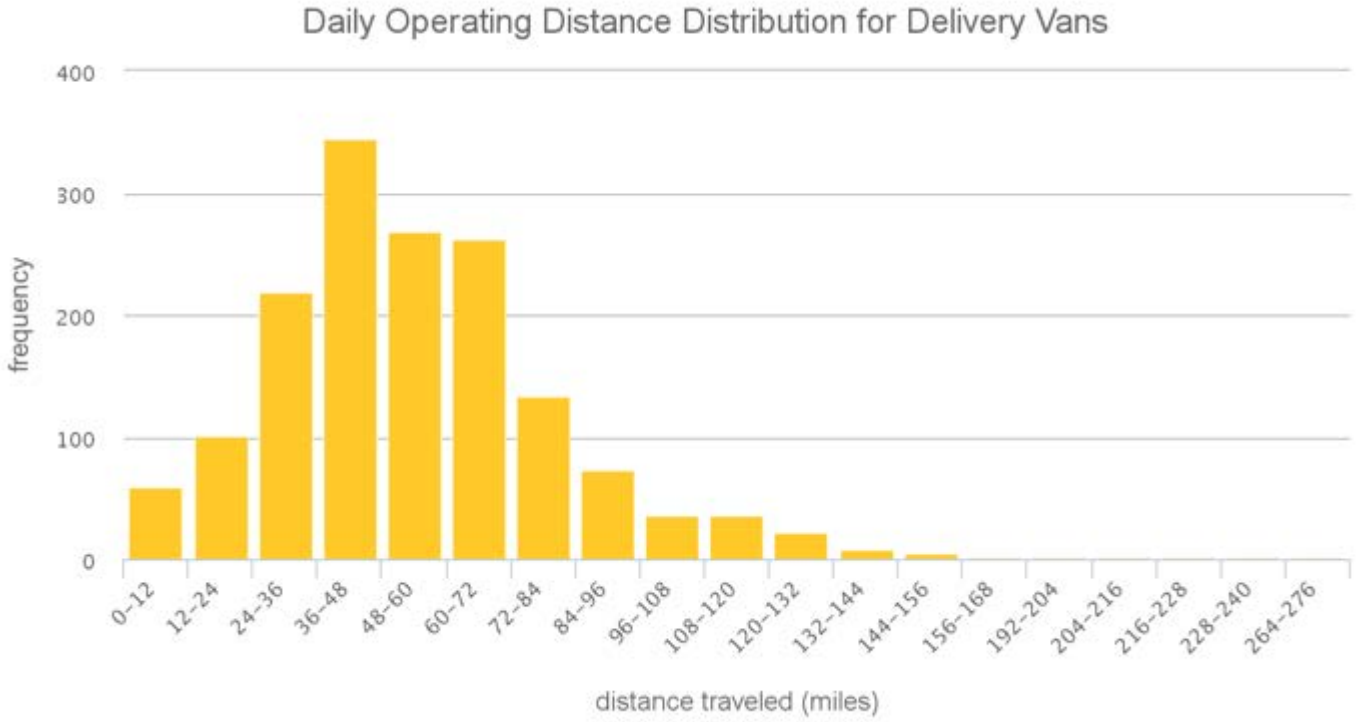
Technical Backup Slides

Delivery Van Range

Goal: Meet vehicle performance specifications (contractual and fleet operator)

- Meet performance of existing delivery vans (diesel, CNG, electric)
- Increase existing route length capability of zero-emission delivery van from 70 miles to 125 miles. **97% of Class 3-6 Delivery Van deployments require < 125 mile range.**
- Model the project vehicle to ensure components are sized appropriately for 125 mile range



Source: Walkowicz, K.; Kelly, K.; Duran, A.; Burton, E. (2014). Fleet DNA Project Data. National Renewable Energy Laboratory.]

Vehicle Component Trade Study

Goal: Minimize component sizes to reduce cost while meeting UPS route demands and outperforming battery electric vans.

- Fuel Cell Size
  - Trade 16 kW fuel cell vs. 32 kW fuel cell vs. 64 kW fuel cell
  - Cost and size implications
- Battery Energy Storage Size
  - Trade 30 kWh pack vs. 45 kWh and 60 kWh
  - Cost and size implications, as well as thermal performance
- Hydrogen Fuel Storage Size
  - Determine minimum hydrogen required to satisfy duty cycle
  - Trade available tanks with available real estate on van

Vehicle Modeling and Assumptions

- Validated base electric van model against empirical performance data

- Vehicle Mass
  - Base Vehicle Curb Weight without batteries – 5300 kg (11,700 lbs)
  - Added additional battery and fuel cell mass per trade study iterations
  - Applied packaging mass penalty for each component
  - Assumed dc/dc mass of 1.5 kg/kW
  - Used common hydrogen storage mass of 436 kg
  - Cargo load 6000 lbs

Modeled Mass with full Cargo Load

Battery Size	HyPM HD 16 kW	HyPM HD 30 kW
30 kWh	9,484	9,634
45 kWh	9,915	10,065
60 kWh	10,347	10,497

Route Data

- HTUF Parcel Delivery Routes
  - HTUF PD Class 4 (primarily represents residential delivery)
  - HTUF PD Class 6 (primarily represents commercial delivery)
  - Cycles are accepted by NREL as Industry Drive Cycles
  - Cycles are included in the Autonomie standard medium and heavy duty parcel delivery vehicle drive cycles

- Coordinated with UPS to place GPS data logger on multiple vehicles to collect actual route data
  - West Sacramento (site of first demo vehicle)
    - Route lengths were short (~50 miles) and relatively flat
  - Oakland / Berkley Hills
    - Increased grades but route lengths still short (<65 miles)
  - San Bernardino
    - Extreme grades, unreasonable for fuel cell vehicle
  - Napa
    - Over 100 miles with demanding elevation
  - Houston
    - Routes up to 100+ miles with low grades

Modeling and Simulation Results

Route	Van Configuration	Distance	Missed Route	Min SOC	H2 Use	Ave Battery Current	Battery Temp (°C)	Ave Motor Power
HTUF PD Class 4 125 miles	16 kW - 33 kWh	124.45 mi	0.33%	66%	9.88 kg	92.59 A	n/a	37.56 kW
	16 kW - 49 kWh	124.44 mi	0.33%	68%	9.87 kg	94.92 A	n/a	39.26 kW
	32 kW - 33 kWh	124.45 mi	0.34%	76%	10 kg	87.77 A	n/a	38.15 kW
	32 kW - 49 kWh	124.44 mi	0.34%	78%	9.91 kg	87.94 A	n/a	38.6 kW
	99 kWh Electric Van	101.37 mi	18.67%	10%	n/a	42.47 A	n/a	36.01 kW
HTUF PD Class 6 125 miles	16 kW - 33 kWh	124.54 mi	0.22%	68%	9.96 kg	88.5 A	n/a	36.51 kW
	16 kW - 49 kWh	124.53 mi	0.22%	71%	9.96 kg	90.93 A	n/a	38.24 kW
	32 kW - 33 kWh	124.54 mi	0.23%	76%	10.02 kg	70.27 A	n/a	37.07 kW
	32 kW - 49 kWh	124.53 mi	0.23%	79%	9.92 kg	70.84 A	n/a	37.52 kW
	99 kWh Electric Van	100.11 mi	19.66%	10%	n/a	34.39 A	n/a	34.75
Oakland / Berkley 64 miles	16 kW - 33 kWh	11.80 mi	82.66%	20%	0.24 kg	187.65 A	n/a	101.66 kW
	16 kW - 49 kWh	63.81 mi	0.23%	44%	6.52 kg	114.17 A	n/a	55.16 kW
	32 kW - 33 kWh	63.86 mi	0.20%	31%	8.09 kg	41.79 A	55C	54.1 kW
	32 kW - 49 kWh	63.84 mi	0.21%	52%	7.68 kg	43.21 A	35C	54.67 kW
	99 kWh Electric Van	63.98 mi	0.11%	11%	n/a	35.57 A	n/a	52.21 kW
Napa 125 miles	16 kW - 33 kWh	18.75 mi	85.21%	20%	0.48 kg	136.64 A	n/a	84.45 kW
	16 kW - 49 kWh	38.49 mi	69.85%	20%	2.41 kg	172.74 A	n/a	78.23 kW
	32 kW - 33 kWh	97.79 mi	22.10%	20%	13.99 kg	175.46 A	95C	78.76 kW
	32 kW - 49 kWh	123.68 mi	1.04%	33%	15.65 kg	179.96 A	55C	77.05 kW
	99 kWh Electric Van	62.37 mi	49.60%	10%	n/a	74.72 A	n/a	73.45 kW
Houston 102.5 miles	16 kW - 33 kWh	14.75 mi	85.80%	20%	0.2 kg	194.96 A	n/a	105.52 kW
	16 kW - 49 kWh	102.3 mi	0.19%	24%	8.03 kg	126.65 A	n/a	53.41 kW
	32 kW - 33 kWh	17.62 mi	83.58%	20%	0.62 kg	184.89 A	n/a	105.81 kW
	32 kW - 49 kWh	102.03 mi	0.19%	40%	9.78 kg	47.98 A	n/a	52.83 kW
	99 kWh Electric Van	74.41 mi	27.11%	10%	n/a	38.39 A	n/a	45.64 kW