CENTER FOR TRANSPORTATION
AND THE ENVIRONMENT

Fuel Cell Hybrid Electric Delivery Van Project

Project ID: MT016

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2015 DOE Annual Merit Review

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This presentation does not contain any proprietary or confidential information.

Overview

Timeline

Project Start: 7/15/2014

Project End: 10/15/2018

Budget

Total Project Budget: $10,119,904

Total Recipient Share: $7,137,833

Total Federal Share: $2,982,071

Total DOE Funds Spent*: $181,185

**As of 3/31/15*

Partners

US DOE
CEC
CTE
Hydrogenics
UT-CEM
USL
UPS
Valence

Barriers

Technology Validation

A. Lack of Fuel Cell Electric Vehicle and Fuel Cell Bus 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

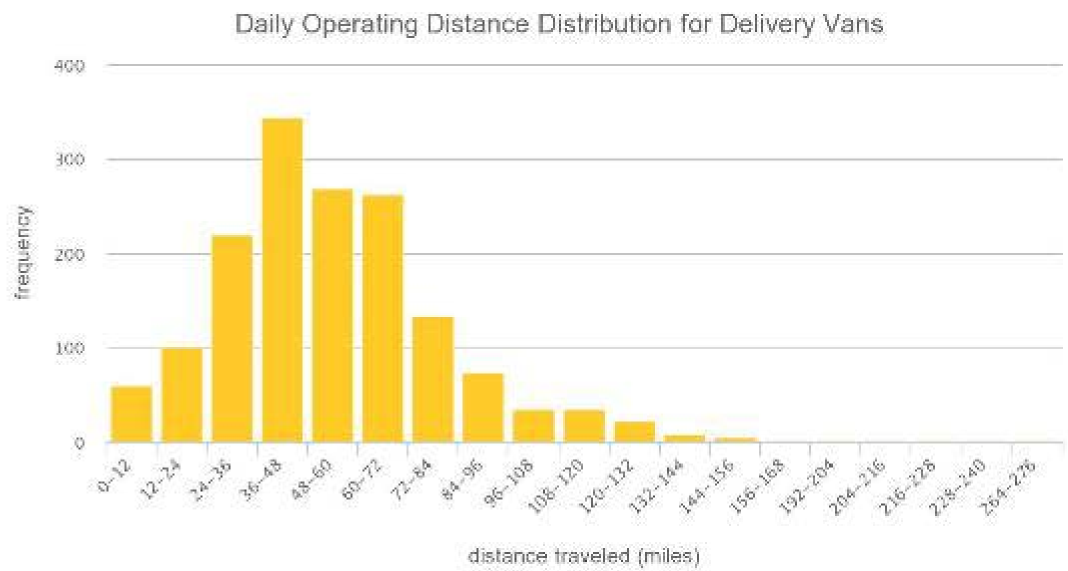
- Overall objective of the proposed effort is to substantially increase the zero emission driving range and increase the viability of electric drive medium duty trucks.
  - Phase 1 (Budget Period 1) the Project Team will carefully develop and fully validate (including in-service operation) a demonstration vehicle in order to prove its viability to project stakeholders, funders, and our commercial fleet partner, UPS.
  - Phase 2 (Budget Period 2), the Project Team will build and demonstrate a pre-commercial volume (up to 16) of the same vehicles for at least 5,000 hours of in-service operation.

Relevance of Work This Period

- Application-specific modeling and simulation
- Optimization and trade study of vehicle powertrain and energy storage components aimed at commercial viability
- Included involvement and feedback from commercial fleet operator
- Selection of appropriate commercial vehicle developer and manufacturer

Relevance – Project Goals

- 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**



[125 mile range meets over 97% of Class 3-6 Delivery Vans. Source: Walkowicz, K.; Kelly, K.; Duran, A.; Burton, E. (2014). Fleet DNA Project Data. National Renewable Energy Laboratory.]

- Close coordination with fueling infrastructure needs
- Focus on safety!
- Development of Economic/Market Opportunity Assessment

- Data generation
  - Maximize vehicle uptime during project

    Product reliability, risk identification and mitigation strategies, Operational support, and Training
  - Accurate performance data and cost reporting

Approach – Project Scope

17 Fuel Cell Hybrid Electric Walk-In Delivery Vans

Phase 1: Conversion, demonstration, and validation of one UPS diesel-powered walk-in van

- Conversion to base electric vehicle [out of DOE project scope]
- Integration of fuel cell, power electronics, hydrogen storage system, and controls
- Demonstrate and validate in UPS service in West Sacramento for six months

Phase 2: Build and deployment of an additional 16 vehicles

- Full integration at EV Manufacturer with CEM assistance
- UPS will operate at distribution centers in California
- 2 years of data collection and project reporting

Approach – Overall Milestones

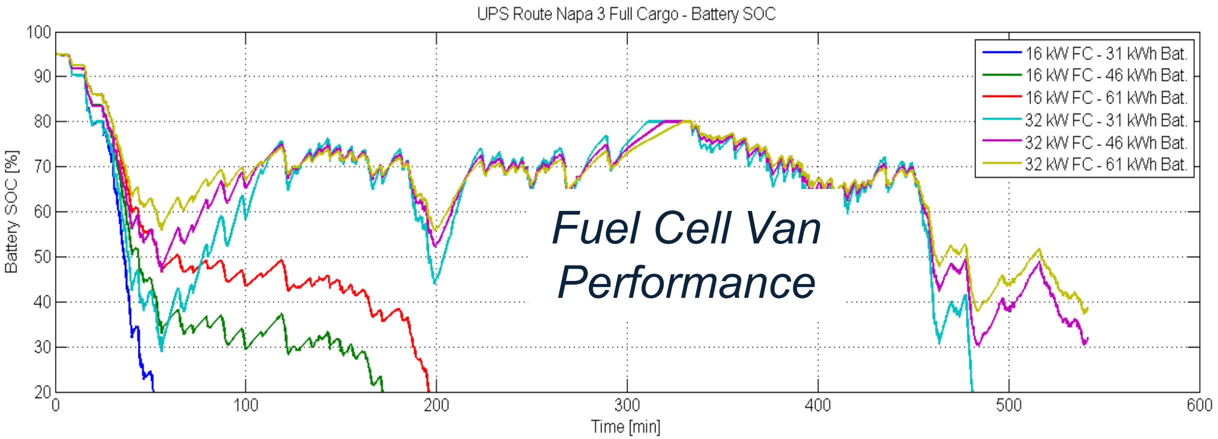
DOE Task	Task/Milestone Description	Period
Phase 1 Demonstration		
1	Vehicle Build	Jul ‘14 – Mar ‘15
2	Training and Education	Mar ‘15 – May ‘15
3	Demonstration Vehicle Test and Evaluation	May ‘15 – Sep ‘15
4	Project Management Phase 1	Jul ‘14 – Sep ‘15
--- GO/NO GO Decision Point ---		
Phase 2 Deployment		
5	Vehicle Build	Oct ‘15 – Sep ‘16
6	Training and Education	Jul ‘16 – Sep ‘16
7	Vehicle Test and Evaluation	Oct ‘16 – Sep ‘18
8	Project Management Phase 2	Oct ‘15 – Sep ‘18

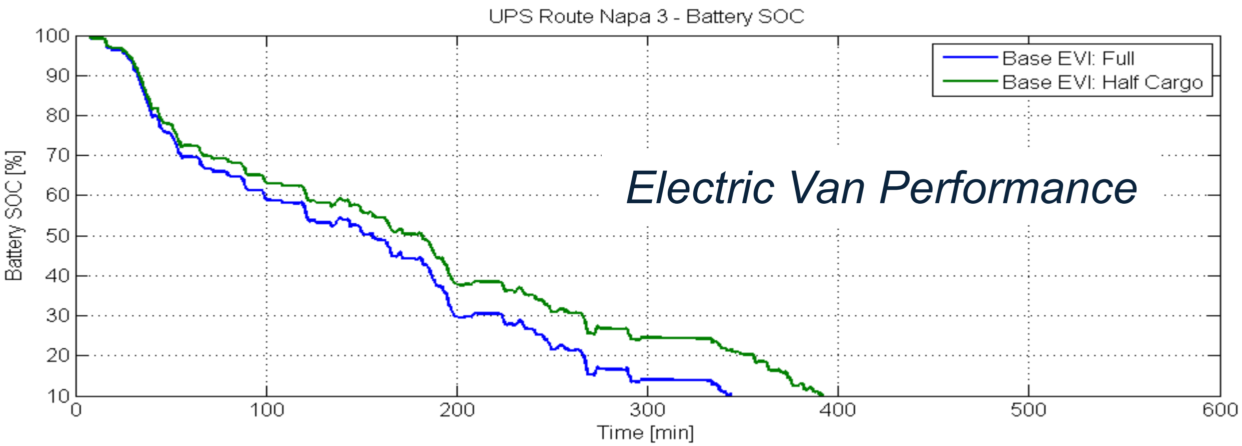
Note: Original planned periods shown. Schedule delays have occurred and no-cost time extension will be requested by CTE.

Accomplishments – MS 1 Vehicle Build

- ✓ Project Started: 7/15/14
- ✓ Completed Final Vehicle Specification
- ✓ Investigated available options for hydrogen storage system (HSS) and DC-DC converter and solicited quotes
- ✓ Developed vehicle solid models and completed preliminary physical layout of major battery, fuel cell, and HSS
- ✓ Completed analysis of representative duty cycles
- ✓ Simulated all potential vehicle configurations on modeled routes
- ✓ Completed trade study and downselected major propulsion system components
    - Fuel Cell, Hydrogen Storage, Battery

Accomplishments – Vehicle Development





- Trade study performed on numerous application-specific duty cycles
- Outperform battery-electric
- 16 – 32 kW fuel cell output power
- 30-60 kWh battery energy storage
- 10-15 kg hydrogen storage

Optimized fuel cell hybrid propulsion system components specifically to meet unique delivery van duty cycle requirements and commercial requirements.

Accomplishments - Packaging / Integration

- Component requirements to surpass battery-electric vans on 125 mile routes
  - 32 kW Fuel Cell power module
  - 45 kWh battery energy storage
  - 10-15 kg hydrogen storage
- Hydrogenics HD30
  - Fits within engine compartment
  - Along with dc/dc converter and thermal management systems
- Able to package 45 kWh Valence power cell pack within frame rails
- Storage vessel availability limited to Luxfer W205 cylinders, outside frame rails
  - 10 kg at 350 bar

Hydrogenics HD30

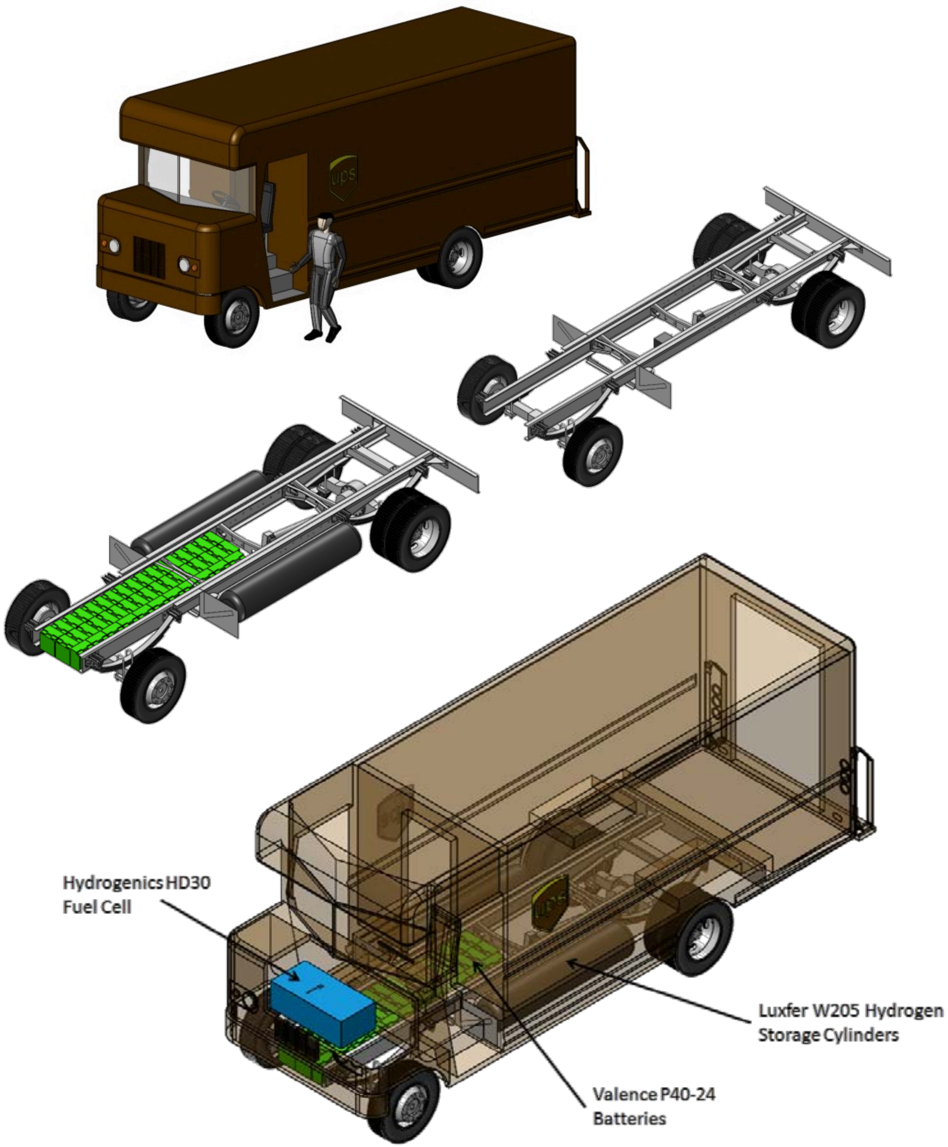
Valence P40-24

15S3P

Luxfer W205 HSS

Accomplishments – Vehicle Specification

Key Specifications	Fuel Cell Hybrid Van
Vehicle Chassis	Navistar International 1652SC 4X2
Maximum Speed	65 mph
Maximum Range	125 miles
Acceleration (0-60 mph)	26 seconds at 19,500 lbs
GVW	Class 6 (23,000 lbs)
Wheel Base	176"
Capacity	970 ft^3
Battery System	Valence Technology P40-24
Chemistry	$LiFeMgPO_4$
Energy	45 kWh
Charger	110 VAC
Battery Life	1,500 Cycles / 5 Years
Fuel Cell	Hydrogenics HD30
Rated Power	32 kW continuous
Peak Efficiency	55%
Hydrogen Storage	Luxfer W205 (x2)
Capacity	9.78 kg
Pressure	350 bar



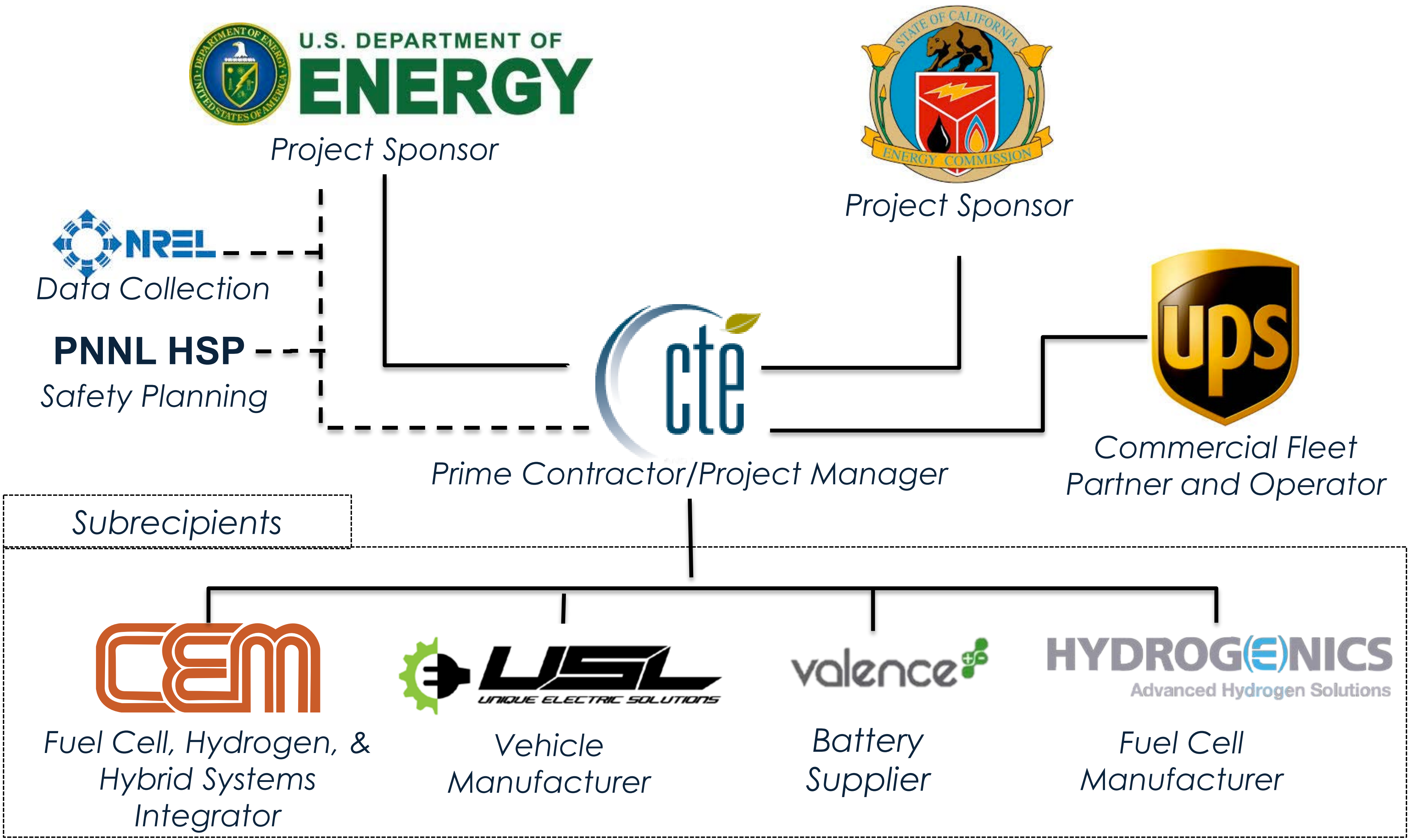
Accomplishments – MS 4 Project Mgmt

- ✓ Held kickoff meeting
- ✓ Secured additional cost share through California state funding
- ✓ Developed subcontracts
- ✓ Addressed fuel cell build location and NEPA review
- ✓ Completed reporting
- ✓ Addressed issues with original EV Manufacturer
- ✓ Held design review / project review meeting with stakeholders
- ✓ Seeking remaining cost share through opportunities with SCAQMD and CEC, among others

Responses to Previous Year Reviewers Comments

- *This project was not reviewed last year.*

Collaborations



Remaining Barriers and Challenges

Issue - EV Manufacturer Involvement

- Original base EV Manufacturer experienced executive leadership turnover, lost direction for the project, and introduced significant cost increase (+$1.3M) for no change in scope.

Resolution – EV Manufacturer Replacement

- CTE released a competitive procurement to industry to source and select a replacement.
- Selection utilized a predetermined scoring criteria and a evaluation committee consisting of project team.
- Unique Electric Solutions (USL) was selected.
- Administrative and contractual requirements are currently being addressed to incorporate replacement.

Remaining Barriers and Challenges

Issue – Team Experienced Cost Increases

- Major component (battery/fuel cell) resizing from design optimization [+$526k]
- Other component (HSS/DC-DC Converter) downselection [+$330k]
- Additional administrative/PM/design labor burden due to unforeseen issues and updated estimates [+$433k]
- EV Manufacturer replacement variance [+$366k]

Resolution – Secure Outside Funding

- Securing additional funding from outside sources to cover increases. Proposal currently under consideration fro $980k.
- Limit vehicle development work until complete Phase 1 funding is secured. [+$500k]

[All cost increases above include both project phases - all 17 vehicles and for life of project.]

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.

Resolution – Manage Existing and Seek Additional Funds

- CTE to ensure Phase 1 (through go/no go decision) is fully funded with existing funds. Also ensure that all Phase 2 development and a significant quantity of vehicles remain funded with existing funds.
- Currently securing additional funding from outside sources.
- CTE to continue to monitor and seek remaining funding through multiple forthcoming state opportunities.

Remaining Barriers and Challenges

Issue: Fueling Station Compatibility at 350-bar LDV Stations

- Fills are current limited to 5 kg for most 350-bar light duty vehicle fueling stations.
- The stations utilize tables from SAE Standard J2601 to establish the protocol for non-communications fills. Tables limited to serve light duty market.

Resolution

- CTE and CEM are working with station/gas suppliers to address this potential issue through other station-side coding/protocol changes and avoid operational or vehicle-design concessions.

Proposed Future Work

Task 1 – Vehicle Build

- Complete design and hold final design review [3Q FY15]
- Order long lead components [3Q FY15]
- Build vehicle and validate battery-only operation [4Q FY15 – 1Q FY16]
- Integrate fuel cell and hydrogen storage system [2Q FY16]
- Validate vehicle [2Q FY16]

Task 2 – Training and Education

- Develop and complete training and education [2Q FY16]

Task 4 – Project Management

- Process subcontractor change [3Q FY15]
- Administer and complete safety hazard analysis [3Q FY15]
- Coordinate Ph 1 availability and compatibility [4Q FY15 – 1Q FY16]
- Monitor budget and schedule [3Q FY15 – 2Q FY16]
- Monitor identified risks and implement mitigation strategies if necessary [3Q FY15 – 2Q FY16]

Summary

Objective: To substantially increase the zero emission driving range and increase the viability of electric drive medium duty trucks with an eye toward commercialization.

Relevance: Fuel cell hybrid electric delivery van development, validation, deployment, and data collection project utilizing strong technical experience and commercialization resources. Performance objectives include meeting 125 mile range and over 95% of UPS routes.

Approach: Phased project for application-specific development, validation, deployment of prototype fuel cell hybrid electric delivery van, with follow on (go/no go dependent) manufacturing, deployment and data collection of additional 16 vehicles.

Accomplishments: Kicked off comprehensive scope of work with stakeholders to develop vehicles. Completed modeling simulation, and optimization of powertrain configuration utilizing extended-range, delivery van specific duty cycles.

Collaborations: Full project team dedicated toward commercialization of viable technology, including commercial fleet operator. Strong set of project sponsors leveraging federal, state, and private funding.

Questions and Comments

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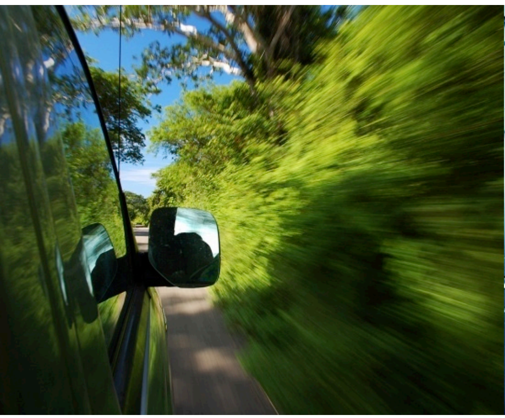


Technical Backup Slides

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

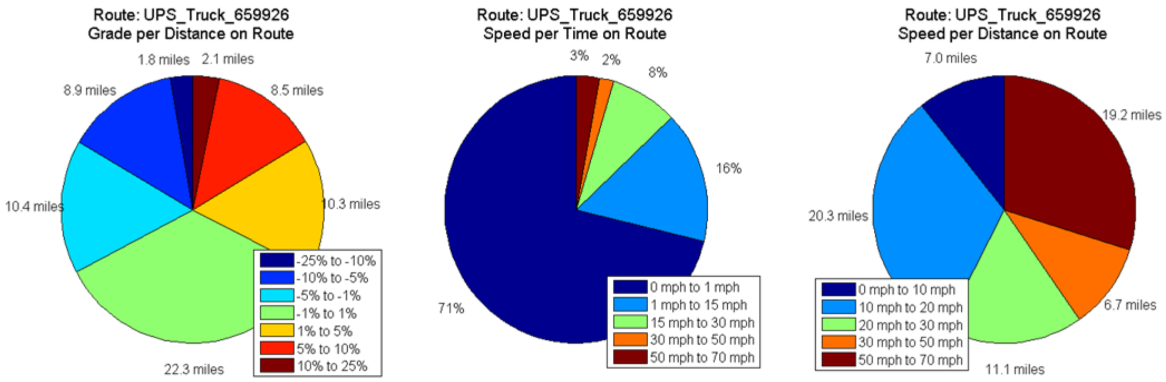
Route Data Collection

- Organized 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

Route Comparison

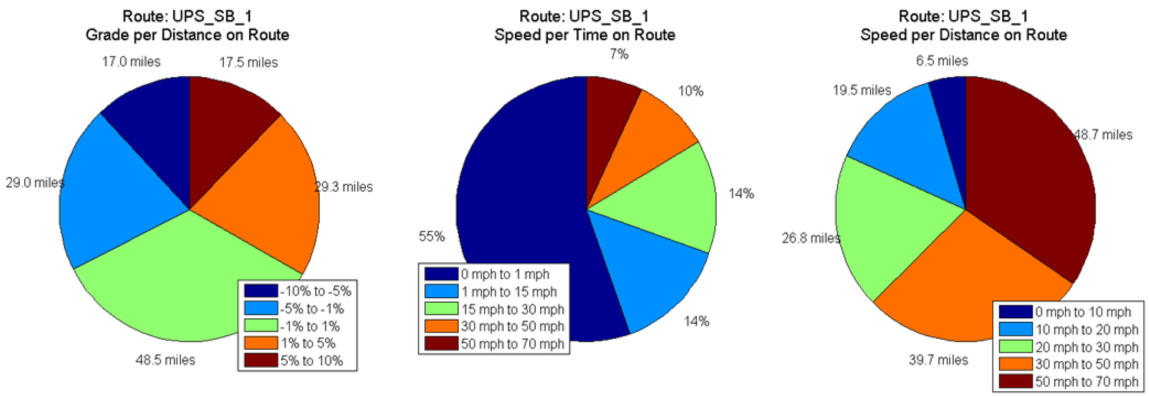
Oakland / Berkeley Hills



Oakland / Berkeley Hills

- 71% stopped
- 19 miles at highway speeds
- Significant grades
- 65 miles long

San Bernardino

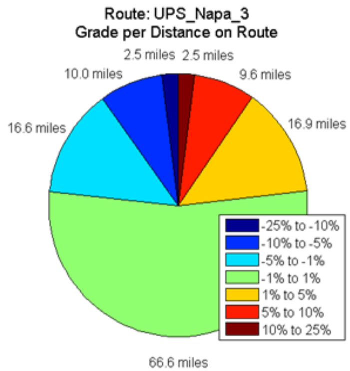


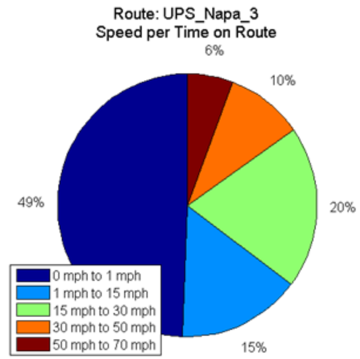
San Bernardino

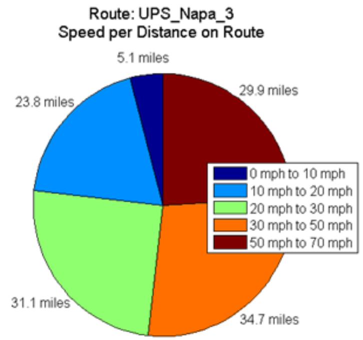
- 55% stopped
- 19 miles at highway speeds
- Extreme grades

Route Comparison

Napa

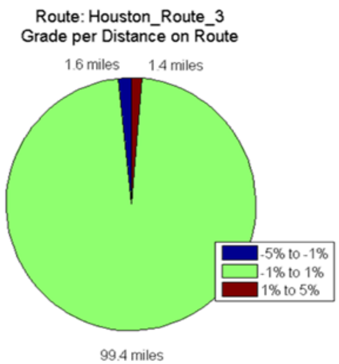


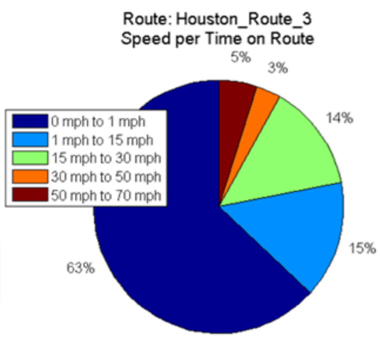


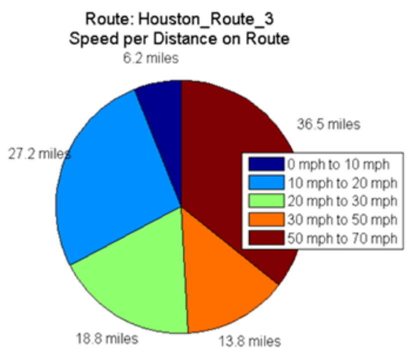


Napa
- 49% stopped
- 30 miles at highway speeds
- Significant grades
- 123 miles long

Houston







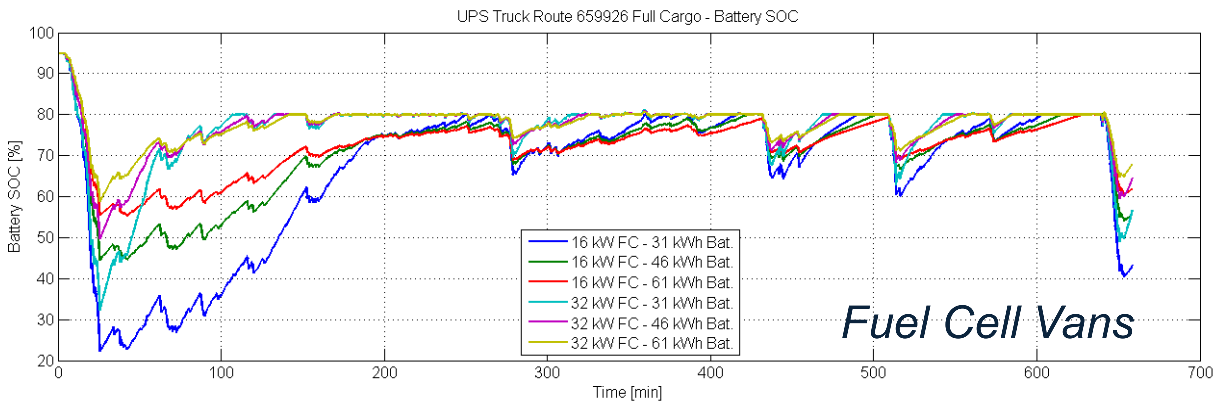
Houston
- 63% stopped
- 36 miles at highway speeds
- Little to no grade
- 100 miles long

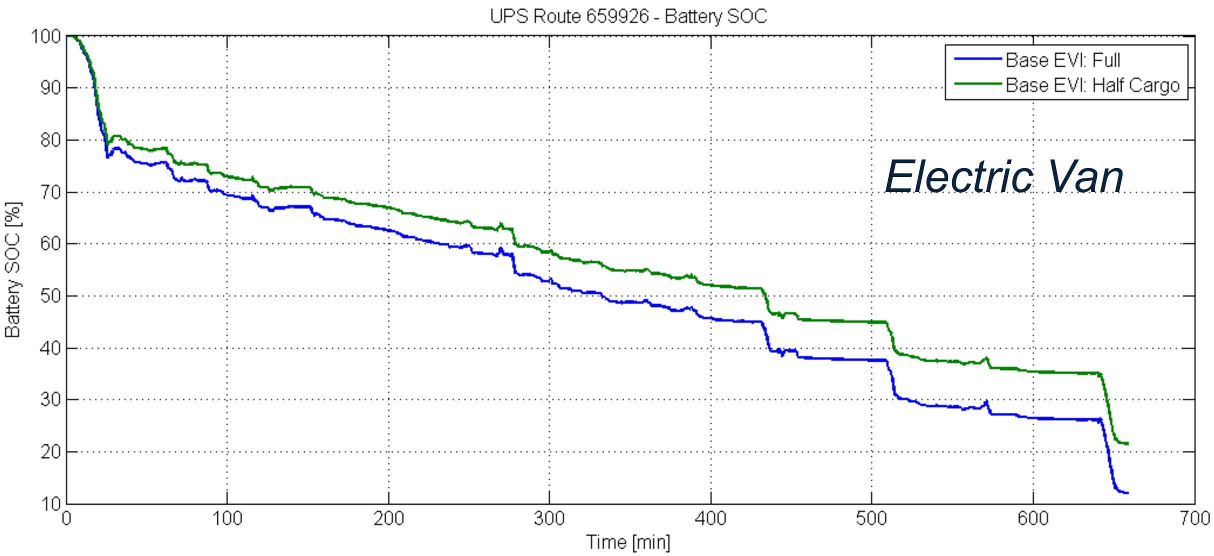
Vehicle Component Trade Study

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
  - 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

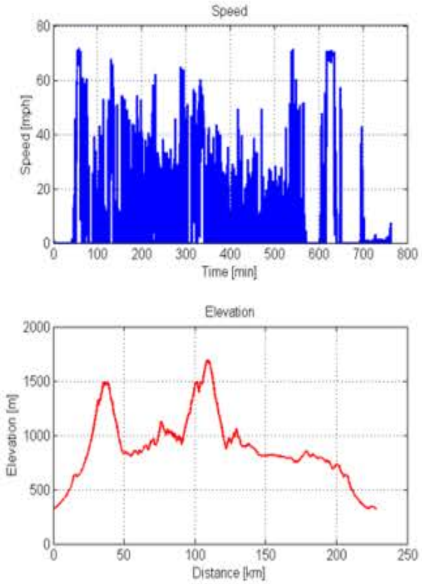
Results – Oakland / Berkeley Hills

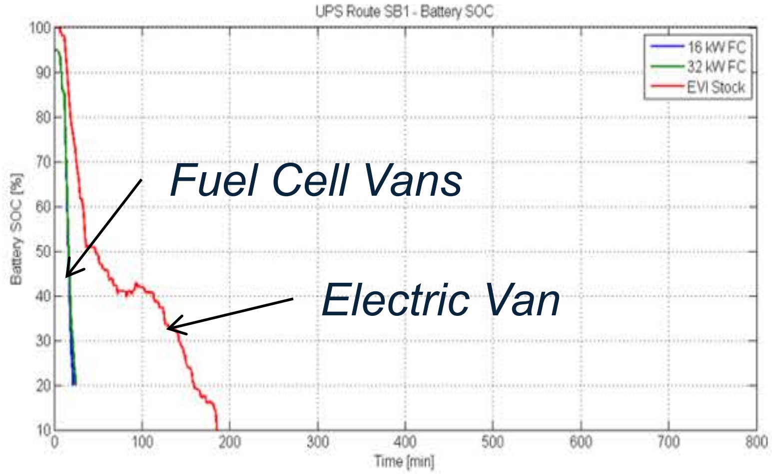




- 65 miles in length with significant grades
- All fuel cell vehicle configurations make the route
- 16 kW fuel cell with 30 kWh battery is marginal
- All-electric van is marginal in completing the route
- Requires 8 kg of hydrogen storage

Results – San Bernardino

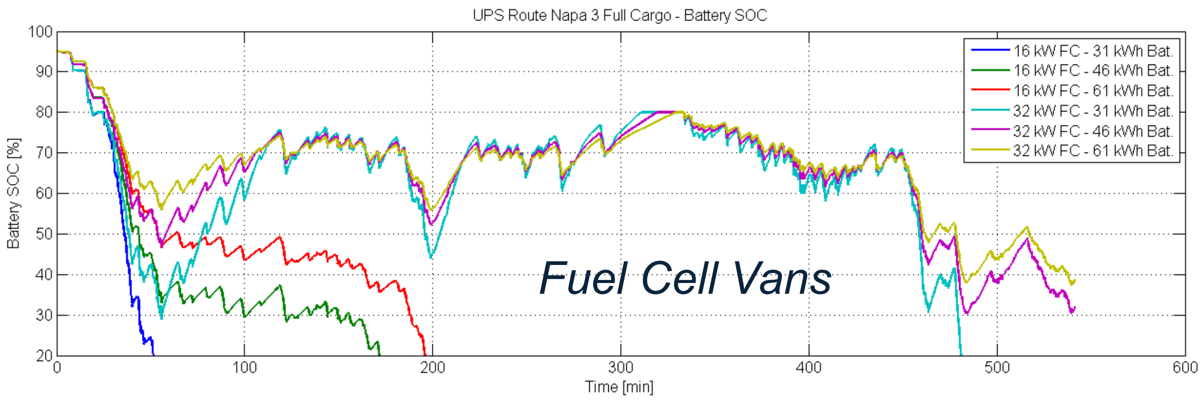


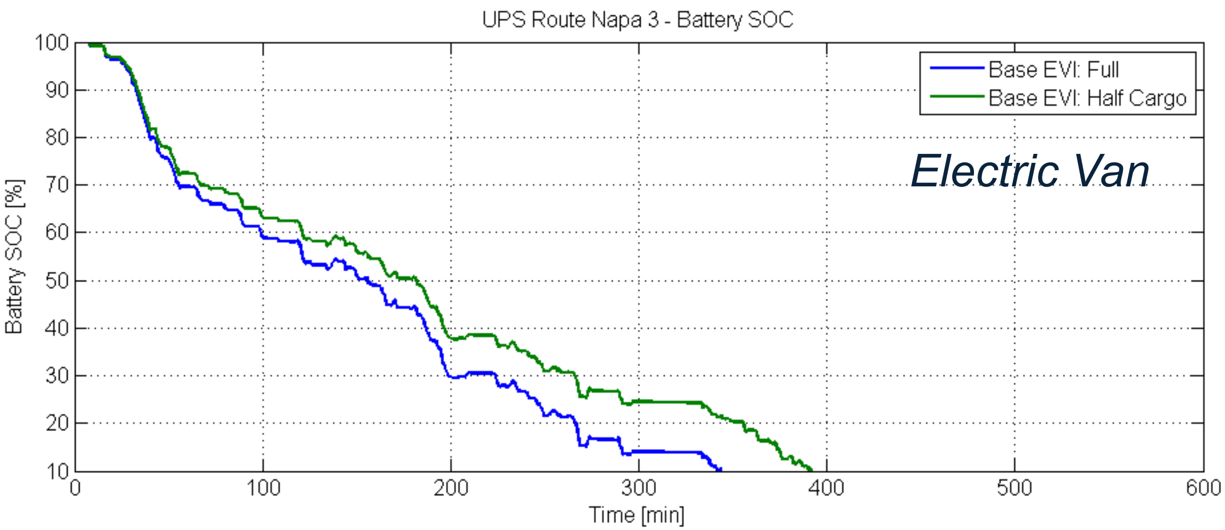


- No vehicles make the route.

- Initial climb at highway speeds requires a larger fuel cell that can sustain the tractive motor power. Hydrogenics Celerity may be an option for future commercial development.

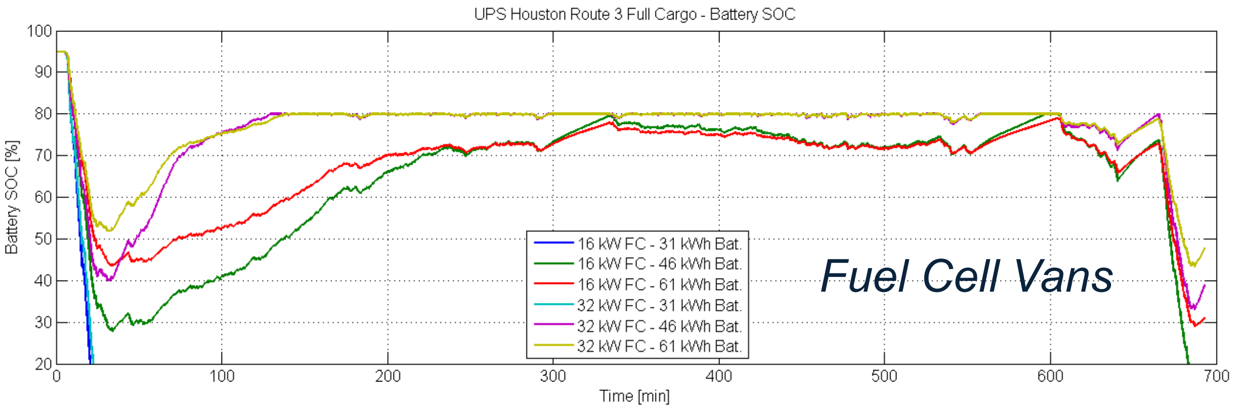
Results – Napa





- 123 miles in length with significant grades
- 16 kW fuel cell vehicles do not make the route
- 32 kW fuel cell vehicle almost makes the route with 30 kWh battery, requires 45 kWh or larger
- Battery electric vehicle cannot make this route
- Requires 15 kg of hydrogen storage

Results – Houston



- 100 miles in length with little to no grade
- All initial highway cycle requires 45 kWh or more of battery, no matter 16 kW or 32 kW fuel cell
- 16 kW fuel cell with 45 kWh battery is somewhat marginal
- All-electric van falls just short of completing the full route.
- Requires 10 kg of hydrogen storage

Simulation Results Summary

- To obtain 125 mile range, as proposed, the vehicle must travel 30+ miles at highway speeds given time spent delivering packages
  - 45 kWh battery with 32 kW fuel cell provides this capability
  - 30 kWh battery is limited to about 20 miles at highway speeds

- 125 mile range requires 10 kg of hydrogen for relatively flat routes, or up to 15 kg if significant grades are required