CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

# Fuel Cell Hybrid Electric Delivery Van Project

Project ID: TA016


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Center for Transportation and the Environment (CTE)

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# Overview

## Timeline

Project Start: 7/15/2014
Project End: 04/30/2022

## Budget

| | |
|---|---|
| Total Project Budget: | $ 11,264,505 |
| Total Recipient Share: | $ 8,282,434 |
| Total Federal Share: | $ 2,982,071 |
| Total DOE Funds Spent: | $ 1,034,573* |

**as of Feb. 2019*

## Partners

**US DOE, CARB, 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 (15) 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 2018 – March 2019)

- 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 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 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 | 100% | Jan. 2019 |
| 2 | Training and Education | 100% | Feb. 2019 |
| 3 | Demonstration Vehicle Test and Evaluation | 10% | July 2019 |
| 4 | Project Management Phase 1 | 95% | July 2019 |
| **Go / No-Go Decision Point** | | | **July 2019** |
| | **Phase 2 Deployment** | | |
| 5 | Vehicle Build | 0% | May 2020 |
| 6 | Training and Education | 0% | Jun. 2020 |
| 7 | Vehicle Test and Evaluation | 0% | Apr. 2022 |
| 8 | Project Management Phase 2 | 0% | Apr. 2022 |

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

# Accomplishments and Progress

## Completed Vehicle Build and Delivered to UPS in West Sacramento

- ✓ Completed vehicle acceptance testing at UT-CEM in Austin, TX
- ✓ Performance test results were collected and are displayed in the table below
- ✓ UPS refurbished the vehicle's exterior prior to vehicle shipment
- ✓ Shipped the vehicle to the UPS West Sacramento Customer Care center

| Key Specifications | Fuel Cell Hybrid Van |
|---|---|
| Maximum Speed | 65+ mph |
| Range | >125 miles |
| Acceleration (0-60 mph) | 30 seconds at 23,650 lbs |
| Operating time | >12 hours |
| Gradeability | 9.0%: 0-20mph in 11 sec<br>13%: 0-20mph in 17.5 sec<br>15%: 0-20mph in 20 sec |


Table: CTE

Photo: CTE


THE LINDE GROUP
Linde
Hydrogen.
ups
Worldwide Services
139408
Fuel Cell Electric Vehicle
USDOT 021800

# Accomplishments and Progress

## Conducted operations, maintenance, and fueling training with UPS staff

- ✓ Conducted hydrogen test fills with Linde Gas in W. Sacramento
- ✓ Hosted a vehicle “show and tell” at California Energy Commission
- ✓ Executed a training plan for UPS operations and maintenance staff and notified local First Responders
- ✓ Started demonstration in Feb. 2019


Photo: CEC


Photo: CTE

# Accomplishments and Progress

## Awarded Additional Funds under CARB ZANZEFF

- Phase 2 cost share was originally 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 was required to cover cost increases from design changes and additional administration

- Resolution – Awarded additional funds under CARB ZANZEFF
  - CTE submitted a proposal to CARB to account for the scope of work and budget deficit for 15 Phase 2 delivery vans
  - CTE was selected as a Grantee and executed the Grant Agreement with CARB in late-Q1 2019
  - The project team expects to start work in Q3 2019

# Responses to Last Year AMR Comments

**"The project team should address whether it is feasible to switch to 700 bar hydrogen tanks for added range. … The team should encourage the integrator to commercialize the new/custom DC-to-DC converter."**

**"It is recommended that the project team accelerate testing and that UES prioritize solving issues with the custom DC-to-DC converter."**

- The Project Team has initiated several control measures to address these concerns and mitigate program risks regarding the DC-to-DC converter and overall vehicle design:
  - Design Updates and Manufacturing Plan deliverables moved from Phase 2 into Phase 1
  - Initiated a Corrective Action Plan to identify root cause and resolution of issues while continuing demonstration activity
  - Subcontractor is receiving quotes and delivery schedule estimates for off-the-shelf DC-to-DC converters in parallel with root cause analysis
  - Phase 2 vehicles will use 700 bar hydrogen tanks

# Responses to Last Year AMR Comments



**"It is unclear whether the Linde Gases station in West Sacramento is ready to receive and facilitate the fueling of the first vehicle or if a number of steps still need to happen on the operational side (outside of training and fueling agreements)."**

- The Project Team has been coordinating closely with Linde Gas and conducted test fills at the fueling station when the vehicle arrived in West Sacramento
  - The station has capacity to facilitate fueling the Phase 1 vehicle, and Linde has local staff available to troubleshoot potential issues
  - UPS staff was able to participate in hands-on fueling training
- Phase 2 vehicles will be designed with 700 bar hydrogen storage tanks, and the Project Team and intends to utilize the Shell fueling station that is being built in Ontario, CA under the same CARB ZANZEFF program

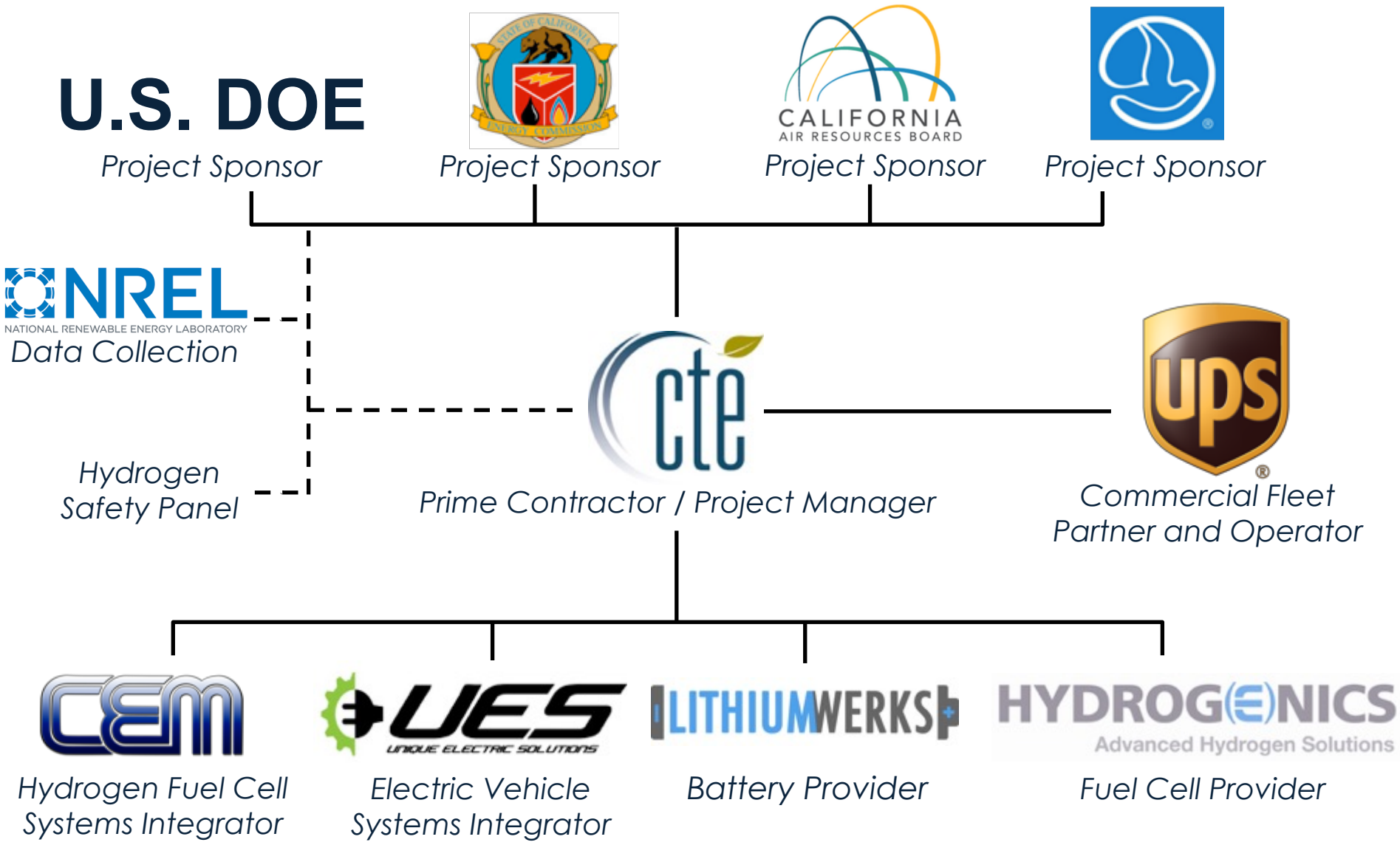
# Responses to Last Year AMR Comments

**“This is a highly relevant and potentially impactful project because of the increased understanding of the operational range limitations of battery electric options in last-mile delivery space for medium-duty vehicles.”**

**“The project still aligns well with DOE goals in supporting the development of fuel cell commercial vehicles.”**

- CTE agrees that this project maintains relevance in a highly attractive market for fuel cell propulsion system applications
- Project stakeholders believe “there is no silver bullet for package delivery” and that proving out a fleet of diverse fuels is as relevant as it ever has been
- There are multiple ongoing development projects in this space:
  - CARB awarded another UPS delivery van project under the ZANZEFF program (4 total fuel cell delivery vans)
  - Plug Power truck developed under DOE sponsored program
  - SCAQMD-sponsored fuel cell delivery van being developed with UES and others

# Collaborations and Project Partners



# 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 slowed vehicle build progress
- The custom DC/DC and its backup have failed during demonstration which has resulted in diagnostics and repair delays

## Resolution

- Component, system, and vehicle level testing yielded positive results before demonstration began
- Subcontractor has purchased and maintains backup spare components and hardware including a second DC-to-DC converter
- Subcontractor is coordinating a design review with UT-CEM staff to occur in Q2 2019 that will evaluate component- and system-level vehicle design
- Subcontractor is receiving quotes and delivery schedule estimates for off-the-shelf DC-to-DC converters

# Remaining Barriers and Challenges



**Issue – CARB funding has shared milestones but has a fixed end-date**

- CARB scope of work is the entirety of DOE Phase 2 scope of work
- All CARB work must be completed prior to the funding sunset date of March 31, 2021, including at least one year of demonstration for one Phase 2 vehicle
- Work must start immediately to meet CARB deadline, but DOE go/no-go decision is currently scheduled for July, 2019

**Resolution**

- Proactively communicating with all project Sponsors so everyone is aware
- No resolution identified but multiple options to consider

# Proposed Future Work (Next Year)

**Task 3 – Demonstration Vehicle Test and Evaluation**

- Demonstrate and evaluate vehicle in UPS fleet service [1Q – 3Q 2019]
- Data collection and reporting [1Q – 3Q 2019]
- Design review and updates [1Q – 2Q 2019]
- Develop manufacturing plan [1Q – 3Q 2019]

**Task 4 – Project Management**

- Coordinate Phase 1 H2 fueling availability [1Q – 3Q 2019]
- Monitor budget, schedule, risk, and mitigation [1Q – 3Q 2019]

**Go / No-Go Decision Point** [3Q 2019]

**Kickoff Phase 2** [3Q 2019]

**Task 5 – Phase 2 Vehicle Build**

- Vehicle assembly [3Q 2019 – 2Q 2020]

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

- UES has incorporated lessons learned from NYSERDA all-electric truck development into this DOE project

- UES is incorporating lessons learned from the DOE truck development into the development of the fuel cell truck for SCAQMD


Photo: CEC

# 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 15 additional vehicles. Each phase includes training and end-user education tasks.

**Accomplishments:** Completed vehicle acceptance testing, delivered the vehicle to West Sacramento, conducted operator, maintenance, and fueling training, coordinated hydrogen fueling, began Phase 1 demonstration, obtained additional funding to complete full scope of original Phase 2.

**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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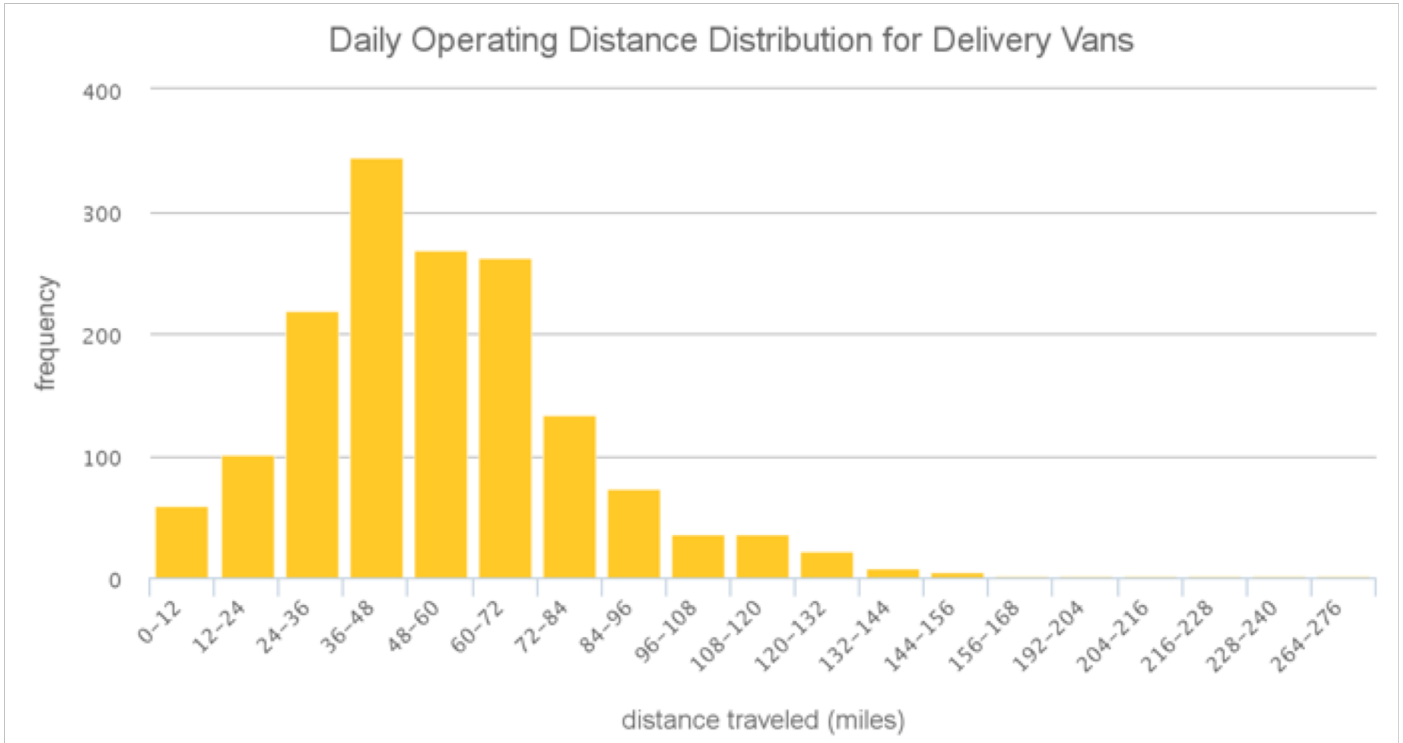
# *Technical Backup Slides*

# 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 |