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Fuel Cell Hybrid Electric Delivery Van Deployment Project

Final Report

A California Air Resources Board Zero- and Near Zero-Emission
Freight Facilities Project

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Submitted by: Center for Transportation and the Environment



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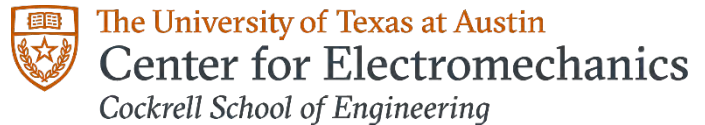


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Acronyms and Abbreviations

AC	Alternating Current
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AHJ	Authorities Having Jurisdiction
BOM	Bill of Materials
BAR	Bureau of Automotive Repair
CARB	California Air Resources Board
CEC	California Energy Commission
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CTE	Center for Transportation and the Environment
CHP	California Highway Patrol
DAC	Disadvantaged Community
DC/DC	Direct Current to Direct Current
DOE	Department of Energy

DMV	Department of Motor Vehicles
EDVR	Excluded Vehicle Diesel Reporting
ESS	Energy Storage System
EV	Electric Vehicle
FCHEDEV	Fuel Cell Hybrid Electric Delivery Van
FCTMS	Fuel Cell Thermal Management System
FEF	First Element Fuel
FHA	Functional Hazard Analysis
GHG	Greenhouse Gas
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HSP	Hydrogen Safety Panel
HSS	Hydrogen Storage System
HV	High Voltage
HYLA	Nikola hydrogen brand name
IPM	Internal Permanent Magnet
LCT	Low Carbon Transportation
LIDAC	Low-Income and Disadvantaged Communities
MD	Medium-Duty
MRI	Mitigation Risk Index
MRP	Manufacturing Resource Planning
NO _x	Nitrogen Oxides
NEC	National Electrical Code
NFPA	National Fire Protection Association
NMHC	Non-Methane Hydrocarbons
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
PSR	Project Safety Report
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SDI	Systems Development and Integration
SMR	Steam Methane Reformation
SOC	State of Charge
SoCalGas	Southern California Gas Company
SOF	State of Fill
SOPO	Statement of Project Objectives
SO _x	Sulphur Oxides
SR	Switch Reluctance
SSP	System Safety Plan
THC	Total Hydrocarbons
UES	Unique Electric Solutions
UNLV	University of Nevada Las Vegas
UPS	United Parcel Service of America, Inc.
UT-CEM	University of Texas Center for Electromechanics
VOC	Volatile Organic Compounds
WPO	Wilkins Process Optimization
WTW	Well to Wheels
WWW	W.W. Williams
ZANZEFF	Zero- and Near-Zero Emission Freight Facility

Executive Summary

The Fuel Cell Hybrid Electric Delivery Van (FCHEDV) Development and Demonstration final project report describes the development, build, and demonstration of a fuel cell hybrid electric delivery van supported, in part, by the California Air Resources Board (CARB). This report provides background for the project including objectives, implementation, technical results, hardships, and lessons learned to-date, as well as recommendations for relevant technologies going forward.

The goals of the project were to address the following technical objectives: 1) to substantially increase the zero-emission driving range, thereby reducing petroleum consumption and related emissions, and increasing the viability of these electric drive vehicles; 2) to accelerate the introduction and market penetration of electric drive transportation technologies; and 3) to respond to the growing demand to purchase electric drive vehicles, provided their operational priorities can be satisfied. By accomplishing these objectives, the project seeks to increase the commercial viability of hybrid battery and hydrogen technology. While these technical objectives certainly remained project goals, the Project Team knows much more now than when establishing these objectives in 2014, including the constraints of the technology and the challenges that come with demonstrating it. The Project Team aimed to operate vehicles in commercial package-delivery service and take the technology to its next stage of development.

In 2014, CTE designed a two-phase project. The first phase was for the design and build of a single hydrogen-fuel cell package-delivery van, and the second phase would produce fifteen more of the same vehicle to demonstrate them in package-delivery service. During the first phase of the project, from 2014 to 2019, the Project Team developed and demonstrated a viable zero-emission propulsion system kit that can be adapted to conventional Class-6 delivery vans. The prototype vehicle demonstrated that it met the range requirements for the vast majority of package-delivery routes and significantly outperformed its battery-electric counterpart. Additionally, this vehicle proved a cost-effective path to commercialization by means of retrofitting an aging diesel-powered chassis with a fuel cell hybrid electric propulsion system.

The valuable insights gained from the first phase of the project informed upgrades to the vehicle design at the system and component levels in Phase 2. The next iteration of vehicle design was intended to be demonstrated in a deployment of 15 additional vehicles throughout 2024. The primary challenges were the vehicles experienced various failures and inconsistencies surrounding fueling at local public hydrogen refueling stations. The Project Team overcame this issue and achieved the primary project goal of demonstrating a fuel cell hybrid electric delivery van that substantially increased zero-emission driving range. However, the full fleet of 15 vehicles was not deployed due to fueling and vehicle technology integration issues as well as the deterioration of the retrofit chassis.

Throughout this report, readers will learn about the results of the development of 15 fuel cell hybrid electric delivery vans (FCHEDVs). This report will discuss the technical barriers associated with the project, how the Project Team worked to overcome those barriers, and recommendations for the industry.

The Project Team acknowledges our project partnerships at the Department of Energy (DOE), South Coast Air Quality Management District (SCAQMD), California Energy Commission (CEC), Southern California Gas Company (SoCalGas), and CARB whose contributions to the project are very much appreciated.

Project Introduction

Background

The California Air Resources Board (CARB) is charged with protecting the public from the harmful effects of air pollution and developing programs and actions to fight climate change. From requirements for clean cars and fuels to adopting innovative solutions to reduce greenhouse gas (GHG) emissions, California has pioneered a range of effective approaches that have set the standard for effective air and climate programs for the nation and the world.

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). The statute authorizes CARB to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies.

On March 21, 2018, CARB issued the Zero- and Near Zero-Emission Freight Facilities (ZANZEFF) Project solicitation to support bold, transformative emissions reduction strategies that can be emulated throughout freight facilities statewide. In response to this solicitation, CTE developed an application in partnership with the University of Texas – Center for Electromechanics (UT-CEM), Unique Electric Solutions (UES), Accelera by Cummins, and United Parcel Service (UPS), collectively referred to as the “Project Team,” for additional funding to support the deployment of 15 fuel cell hybrid electric delivery vans (FCHEDVs). The awarded ZANZEFF funding built on the success of the first phase of the DOE-funded project and funded the Phase 2 deployment.

Electric drive vehicles drastically improve operational efficiencies over incumbent technologies by utilizing clean, safe, secure, affordable, and reliable energy from diverse domestic resources. Electric drive vehicles also provide the benefits of reduced consumption of resources, increased energy security, and reduced criteria pollutant and greenhouse gas emissions. A growing market for medium-duty (MD) electric trucks has developed in the delivery van market, where key players such as United Parcel Service (UPS), Federal Express, and Frito Lay have deployed hundreds of electric drive delivery vans. Although battery-electric drive powertrains have made great strides, these vehicles still have range limitations and typically can only provide service on select delivery routes. For example, an electric delivery van currently in use by UPS can only support about 70% of their existing delivery routes. By implementing a fuel cell range extender, it is possible to increase the range of a zero-emission delivery van and satisfy nearly all delivery routes supported by UPS or other delivery service providers.

At the time that the project title was developed, in 2014, fuel cell vehicles were not assumed to be hybridized. Currently, the industry assumes that all fuel cell vehicles also use batteries because fuel cells do not deliver energy at the rates required for vehicle operation. The fuel cell hybrid electric delivery vehicle design can achieve extended range through an optimal combination of energy storage and delivery using a fuel cell and batteries. By implementing a state-of-the-art, high-power capacity battery module, the team designed a vehicle that primarily uses hydrogen as its energy storage while the battery pack delivers the vehicle's power needs for locomotion.

During the first phase of the project, funded by the DOE, the team converted a UPS diesel-powered delivery van to an electric-drive van with a fuel cell range extender. The fuel cell hybrid van design was based on specifications for an existing UES battery-electric delivery van. The vehicle body was a 2006 Navistar that was repowered with a fuel cell electric propulsion system developed by UES. The vehicle stored a total of 9.8 kg of hydrogen in two 350-bar composite tanks, and range extension was provided by a 30-kW fuel cell provided by Accelera. The FCHEDV gets its energy for locomotion through electrical energy stored in the on-vehicle battery system, a 45-kWh high voltage lithium iron phosphate battery package.

Beginning in February 2019, UPS operated the vehicle out of its West Sacramento facility for five months then moved the vehicle to operate out of its Gardena facility for the remainder of the year. The vehicle was successfully fueled at the Iwatani and Shell hydrogen refueling stations in West Sacramento and Torrance, respectively.

The Project Team provided UPS personnel with written documentation on vehicle operation and maintenance, as well as conducted on-site training. The Project Team also coordinated the use of public fueling stations to fuel the vehicle. UPS personnel operated the vehicles in typical parcel delivery service including fueling the vehicles. UPS also performed basic maintenance on vehicle systems such as brakes and fluids. UES was responsible for maintaining the advanced powertrain componentry such as fuel cells and battery packs.

The Project Team collected vehicle performance data throughout the demonstration and distributed data sets to National Renewable Energy Laboratory (NREL) to compile, analyze, and report vehicle performance parameters. In Phase 1, the vehicles traveled a total of 507 miles and demonstrated an overall fuel economy of 12.0 miles per kg H₂ (equivalent to 13.5 miles per diesel gallon), which outperforms expected diesel equivalent vehicle fuel economies of 7.9 - 9.2 miles per diesel gallon.

The first phase concluded in October 2019, and Phase 2 was authorized by the DOE shortly after. The Project Team began seeking additional funding to support the phase two objectives and was awarded funding through the CARB ZANZEFF program.

Objectives

The overall objective of the project was to demonstrate a FCHEDV that substantially increases the zero-emission driving range over its battery-electric counterpart. This in turn, would reduce petroleum consumption and related emissions from these vehicles. In addition, the project aimed to accelerate the introduction and market penetration of electric drive transportation technologies and respond to the growing demand from commercial fleet customers willing to purchase electric drive vehicles.

In Phase 1, the Project Team carefully developed and fully validated (including in-service operation) a demonstration vehicle to prove its viability to project stakeholders, funders, and our commercial fleet partner, UPS. In Phase 2, the Project Team built and demonstrated a pre-commercial volume of the same vehicles. The fifteen vehicles were fully built by UES, operated by UPS, and operationally supported throughout the deployment by the Project Team. The Project Team carried out the project in close communication with each other, project stakeholders, and fueling station providers. By following this high-level plan, this project addressed every aspect of the DOE technical objectives:

1. To substantially increase the zero-emission driving range, thereby reducing petroleum consumption and related emissions, and increasing the viability of these electric drive vehicles;
2. To accelerate the introduction and market penetration of electric drive transportation technologies; and
3. To respond to the growing demand by commercial fleet customers that are willing to purchase electric drive vehicles, provided their operational priorities can be satisfied.

Partners and Roles

The project partners and roles are shown in Figure 1 and described below.

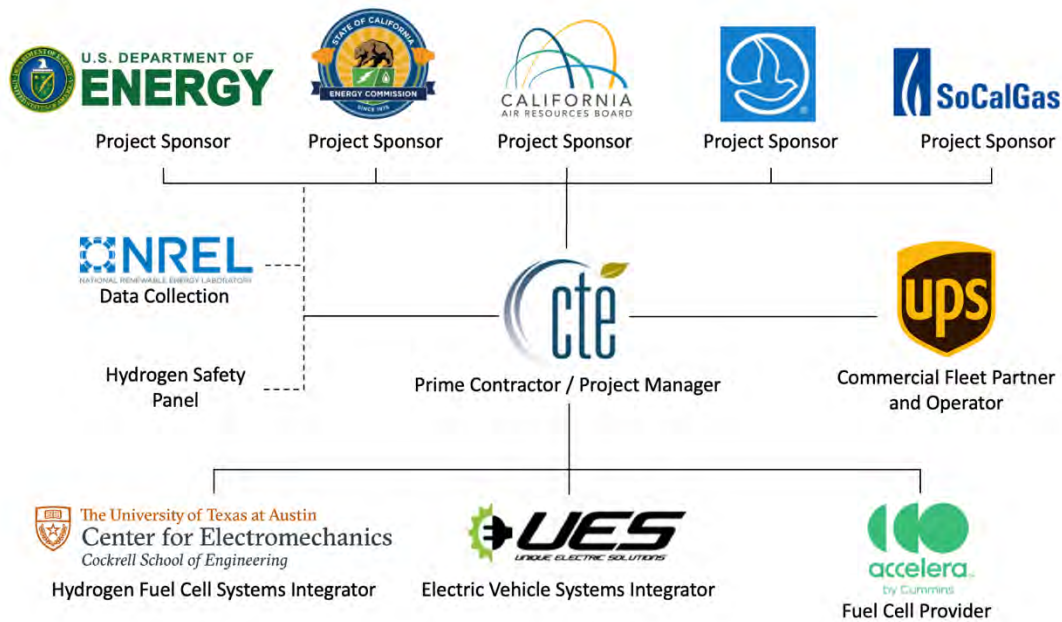


Figure 1: Project Organization Chart

Center for Transportation and the Environment (CTE) is a nonprofit, 501(c)(3) organization that leads technology development projects and implements solutions to achieve energy and environmental sustainability. CTE was the Grantee for this project. CTE was responsible for overall program administration and budget oversight; oversight of project partners; submitting project reports and disbursement requests to project partners; collection and submission of data requested; and coordination of project status update meetings. CTE also provided technical support and project management services to the team above and beyond the administrative activities highlighted above.

Unique Electric Solutions (UES), a subcontractor on the team, was responsible for the build, test, and validation of the fuel cell hybrid electric propulsion systems and integration into the delivery vans. UES provided full support during demonstration to ensure the vehicle operated reliably for the end user. UES also provided on-ground support at the UPS Ontario depot.

The University of Texas – Center for Electromechanics (UT-CEM), a subcontractor on the team, led the design and supported integration of the fuel cells and hydrogen storage systems during vehicle build and inspections. UT-CEM was also responsible for project support throughout the demonstration.

Accelera by Cummins, a subcontractor on the team, provided the 30kW fuel cell system and supported UES during integration and vehicle commissioning. Accelera provided service and support for the fuel cell systems throughout the demonstration.

United Parcel Service (UPS), a subcontractor on the team, operated and fueled the fuel cell delivery van in routine service, paid for the hydrogen fuel, and provided valuable fleet operator feedback throughout the demonstration.

Relevance and Outcomes

This project furthered California’s goals to reduce air pollution emissions that damage the environment and public health, especially in disadvantaged communities. It also closely aligned with three 2023 goals of federal clean energy investment programs through which the project was partially funded (DOE Systems Development

and Integration (SDI)¹, supporting the U.S. National Clean Hydrogen Strategy and Roadmap). Although national clean energy goals are numerous, below are three of the specific priorities and their relevance to the FCHEDV project:

1. Priority 1: The focus for heavy-duty transportation applications is to demonstrate and validate fuel cell durability and performance under real-world conditions.
 - a. Relevance and Outcome: Although the project objective is for medium-duty transportation applications, this project was set forth at a time when there were no commercially available hydrogen vehicles, and the vehicles that did exist were generally prototypes converted from diesel or gas vehicles. Currently, there are several purpose-built medium-duty hydrogen vehicles available in the market. This project built and tested UPS delivery vans to operate in package delivery service, thus addressing this national priority.
2. Priority 2: Projects will demonstrate and validate high-flow hydrogen fueling to support these transportation modes.
 - a. Relevance and Outcomes: Fuel cell electric vehicle technology has improved significantly over time allowing for a high-flow hydrogen fueling. While the FCHEDV project designed and demonstrated vehicles at 350 bar, the industry is trending towards 700 bar. The fueling data that was gathered will have limited application towards future development of this technology.
3. Priority 3: Analysis will be conducted to determine total cost of ownership and future targets needed to compete with incumbent technologies.
 - a. Relevance and Outcome: The project demonstrated that due to the high cost of fuel and the limited availability and supply of hydrogen at public fueling stations, the technology is not competitive with incumbent technologies. However, the team expects the economics to improve in the future with the introduction of the DOE Hydrogen Hubs, a program to accelerate regional networks of hydrogen producers and consumers and increase deployment of hydrogen technology.

Approach

General Approach

The following section discusses the methodology of the CARB funded Phase 2 of the project and the development and demonstration of the 15 FCHEDVs. Four tasks are planned for the project according to the schedule shown in Figure 2 and Figure 3 below.

- **Task 1 Vehicle Design and Build:** The Project Team builds, validates, and delivers fifteen fuel cell electric-drive delivery vans on time and at budgeted cost based on the designs developed in Phase 1 of the project. The Vehicle Design portion of this task includes incorporating engineering design updates in the delivery vans built in Phase 2.
- **Task 2 Training and Education:** The Project Team creates safety and operations manuals and provides operator, fueling, and maintenance training.
- **Task 3 Vehicle Operation, Support, and Data Collection:** The Project Team conducts a twelve-month vehicle demonstration for each vehicle which includes technical support as well as data collection as defined by the Project Sponsor.
- **Task 4 Project Administration:** The CTE team completes all administrative project requirements such as contracting, project kickoff and other meetings, project management plan, and reporting documents. This task includes coordinating the hydrogen fuel supply.

¹ <https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review23/2023-amr-08-systems-development-integration-0.pdf>

There were deviations from the planned objectives, including in the schedule, budget, and demonstration duration, which are elaborated on in the *Results* section of this report.

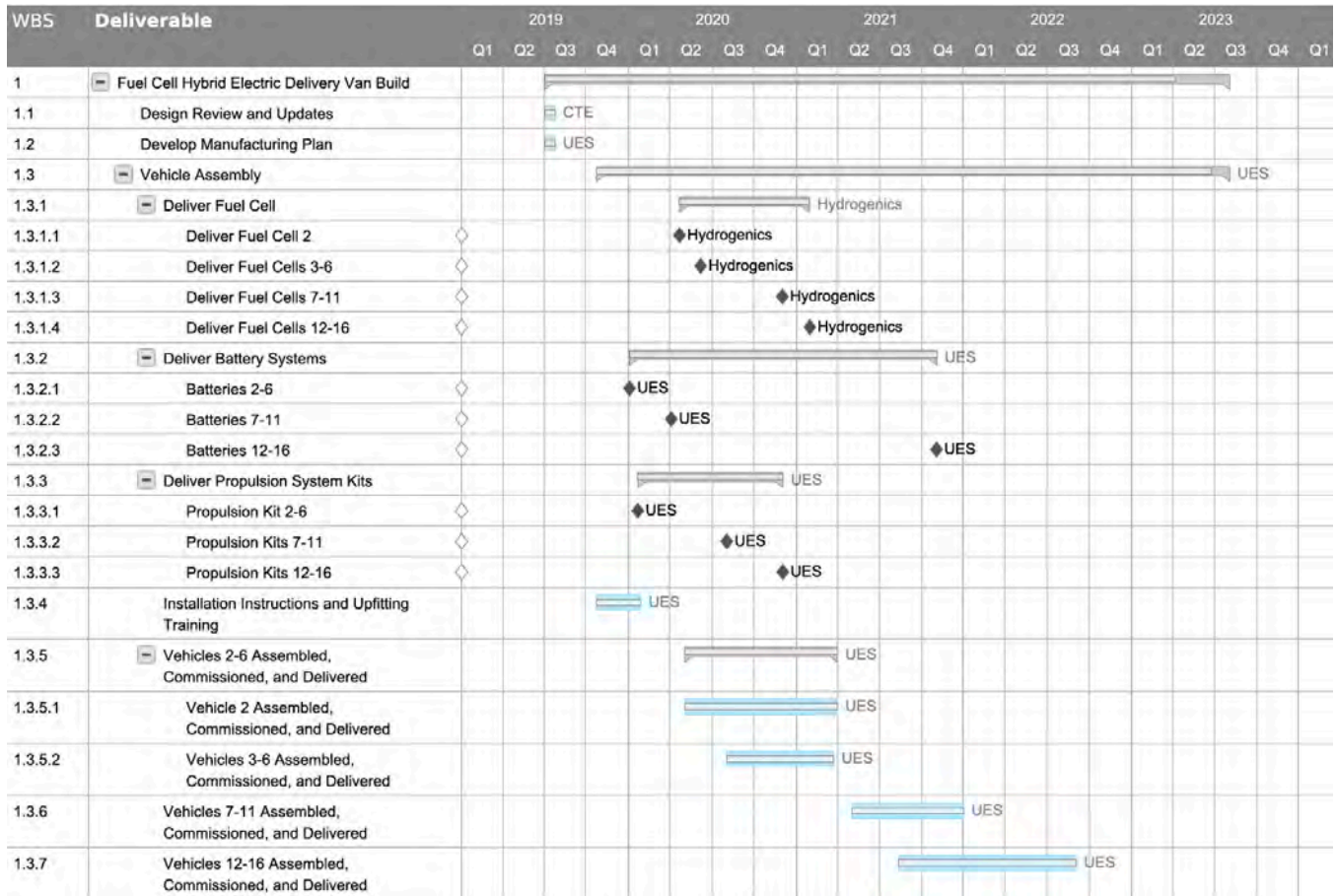


Figure 2: Phase 2 Project Schedule

Task 2 Training and Education

The Project Team delivers operations training for van drivers, support staff, and first responders over multiple sessions. The Project Team updates the training plan, training materials, operating manuals, and fueling training from the initial van demonstration based on lessons learned. CTE coordinates the training to ensure that it is efficient and effective.

Task 3 Vehicle Operation, Support, and Data Collection

The objective of Task 3 is to evaluate the effectiveness of the vehicles by operating in revenue service with UPS. To the extent possible, UPS operates the vehicles in package delivery service on routes in disadvantaged communities (DACs) near the facility. During the operations period, the team provides technical support to address any issues the vans may encounter. The team focuses on maintaining optimal reliability, efficiency, and performance. Throughout the deployment period, data is collected from the vehicles, refueling station, and maintenance charger. The data collection is automated using a transmission device onboard the vehicle. The team works with the fueling stations to collect appropriate fueling data. Vehicle operations and maintenance data is planned to be sent to NREL for analysis and reporting. The team uses the data to evaluate the vehicles' performance, compare operating parameters to the model, and assess any degradation in performance.

Task 4 Project Administration

The objective of Task 4 is to accomplish all routine and non-routine activities for managing the project. CTE conducts project management, including project oversight, administration, and reporting. CTE's centralized, structured management of the work program enables team members to concentrate on project goals and ensure the production of deliverables. CTE has a proven project management approach based on key principles that have emerged from its collective experience in managing large, technical, multi-partner contracts and cooperative agreements. The project management structure efficiently and effectively takes advantage of the consortium capabilities of the Project Team while delegating management of each task to the appropriate individual team members. Project Management includes administrative tasks such as execution of subcontracts with members of the Project Team, administration of a kickoff meeting, developing the Project Management Plan, administration of critical project review meetings, completion and submission of monthly and quarterly status reporting including the Final Report, identifying and obtaining required permits, and identifying and obtaining matching funds when necessary.

Results

Task 1 Vehicle Design and Build

Vehicle Design Review

Utilizing lessons learned from the Phase 1 vehicle assembly, commissioning, and deployment tasks, the Project Team incorporated the following engineering design updates in the delivery vans built in Phase 2:

- New energy storage system (ESS) design to facilitate packaging and cooling constraints
- New traction motor technology, switching from Switch Reluctance (SR) to Internal Permanent Magnet (IPM), to reduce system noise, decrease overall component size, and increase ground clearance
- Increased use of air-cooled components to decrease water coolant complexity
- Addition of rooftop solar panel on the vehicle to maintain low-voltage (12V) battery charge
- Upgrades to the driver interface for more informed operation of vehicle

- Improved fuel cell DC-to-DC converter design for higher reliability
- H2 storage system modification from 2 fueling receptacles to 1 fueling receptacle (a change made possible by updates to the SAE J2601 fueling protocol used at public hydrogen stations)
- Updated fuel cell mechanical enclosure to allow for easier service and maintenance to all the components

These design changes allowed the Project Team to repackage many components. The overall internal component layout was updated to increase ease of assembly and maintenance of components, the most notable changes are a) consolidation of the ESS in the engine bay, and b) relocation of the fuel cell to the transmission tunnel area, a space accessible through removable panels in the cabin floor. Finally, it was decided to leave the UPS body on the chassis during the repower (the Phase 1 vehicle removed the body during assembly) to decrease repower time and further prove the commercialization feasibility of the Phase 2 vehicles. To facilitate a body-on-chassis repower, certain mounting brackets were redesigned to allow the installation of components through the underside of the vehicle. The new component layout on the vehicle chassis is shown in Figure 4, below.

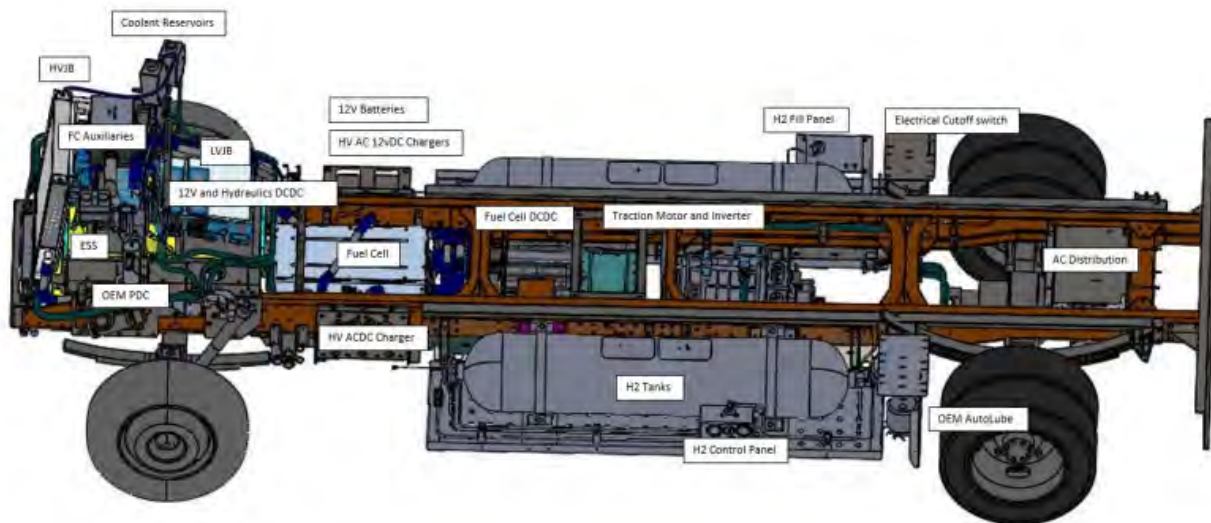


Figure 4: CAD Rendering of Phase 2 Component Layout on Chassis

This new Phase 2 design showed its success in the numbers. The Phase 2 design reduced curb weight by nearly 2,000 pounds; the Phase 1 vehicle weighed 14,210 pounds compared to the Phase 2 vehicle weighing 12,230 pounds. This decrease in curb weight translated to an increase in available cargo weight capacity for the fleet operator, UPS. The Phase 2 vehicle also achieved significantly better performance metrics and greater overall drivable range compared to the Phase 1 vehicle while still maintaining the same hydrogen storage capacity, high voltage battery capacity of 45 kWh, and fuel cell power output. The Phase 1 vehicle achieved a 120-mile range, while the Phase 2 vehicle achieved a 169-mile range during road-testing. The result of this extensive design review and update was a Phase 2 Fuel Cell Electric Vehicle repower kit that led to a more commercially viable vehicle that was easier to manufacture, operate, and maintain.

Manufacturing Plan

UES developed a Manufacturing Plan for the Phase 2 portion of the project. It consisted of several new documents to aid UES engineering and assembly technicians in initial training, vehicle assembly, process quality checks, and final commissioning checklists to ensure vehicles were built to the operational and safety standards developed by the Project Team during the Phase 1 vehicle design and in accordance with SAE guidelines for the vehicle technology. UES also planned and executed a partnership with a vehicle upfitter, W.W. Williams (WWW),

to provide the facility and assembly technicians for the Phase 2 build, which included office space for UES engineering, warehouse space for procured parts storage, and high bays with wheel lifts for vehicle teardown and assembly. UES also planned to strategically outsource contract manufacturers for vehicle wire harnessing, metal bracketry, and junction box enclosure assemblies to decrease overall build time and streamline the vehicle build and assembly. Lastly, UES planned to implement a manufacturing resource planning (MRP) software system to facilitate the management of all vehicle build activities, from creating purchase orders to issuing work orders needed to assemble the vehicle.

UES's vehicle assembly and manufacturing documentation was a critical aspect that facilitated smooth on-vehicle assembly with the vehicle upfitter WWW's supplied assembly technicians. UES completed initial training with an interactive slide show and videos showing the nature of on-vehicle steps needed to assemble the vehicle properly. UES then utilized a vehicle assembly manual with integrated quality control checks, which stayed with a vehicle throughout the assembly process and was used to audit the completion status of each vehicle. Lastly, UES engineering utilized vehicle commissioning and outbound vehicle checklist documents to consistently and accurately verify safe operation of the vehicle prior to delivery to UPS operators.

UES's partnership with the vehicle upfitter, WWW, proved to be a successful choice that allowed a streamlined vehicle assembly site with a short start-up time. Utilizing the above-mentioned training and assembly documents, UES trained the upfitter technicians on the specific vehicle assembly while providing education in fuel cell electric vehicle technology. UES used the upfitter site resources, such as forklifts and storage barns, to receive, warehouse, and kit-up parts for the vehicle assembly process. UES engineering was able to work onsite in an office setting on computers as needed to make engineering design and manufacturing updates in a timely fashion, which allowed consistent vehicle assembly.

UES outsourced the manufacturing of strategic vehicle sub-systems to maintain a focused vehicle assembly site. Wire harness manufacturing consists of thousands of wires and hundreds of connectors per vehicle and would take up a lot of manufacturing space and time. Outside contract manufacturing of these wire harnesses allowed the build site to be focused on pure vehicle assembly. On a similar note, UES contracted outside manufacturers for vehicle metal bracket kits and junction box sub-assemblies, again allowing the build site to remain focused on vehicle assembly.

UES's MRP software system was a huge success at facilitating and executing the Phase 2 vehicle repowers in an organized and timely manner. UES's MRP system housed the entire vehicle Bill of Materials (BOM) and managed the continuous purchasing of all major and minor parts by initiating purchase orders for a vehicle build based on current inventory levels at the production site. UES MRP allowed inbound parts and consumable items to be easily received and stored in live inventory with location tags. The UES MRP would produce work orders for vehicle pre-assembly kits and sub-assemblies that were organized and labeled to follow the Vehicle Assembly Manual, facilitating smooth and organized vehicle builds. Lastly, the MRP system would control and release revision updates to part numbers, part kits, sub-assemblies, and vehicle firmware, allowing UES engineering changes to the production vehicle repower kit to be documented and tracked on a per vehicle, as-built basis.

Lastly, UES planned the labor and time needed to complete the entire project and delivered this within the initial manufacturing plan. This consisted of planned labor coming from two full-time onsite UES employees, three full-time WWW assembly technicians, and UES providing program management and engineering support for the entire program. The time to complete vehicle assemblies was planned to be one month per vehicle.

Vehicle Assembly

In practice, the vehicle assemblies were completed at an average of 5 vehicles per calendar year, 2.4 months per vehicle. This extended vehicle assembly time was rooted in many factors across the program, ranging from procurement lead times, parts availability, labor availability, sub-assembly build times, and the creation and

implementation of new test fixtures and commissioning steps into the vehicle assembly flow to further increase the quality assurance of the finished vehicles. Regardless, the average rate of 2.4 months per vehicle was considerably faster than the 3 years it took to build the Phase 1 vehicle. This shorter manufacturing time provides a pathway for commercialization of a medium-duty FCEV repower kit-derived vehicle.

The average vehicle production rate of five (5) vehicles per year required considerable overtime effort by the onsite UES engineer while also managing and conducting the commissioning, deployment, and maintenance of completed vehicles in California. Vehicle assembly began in 2020 with one UES engineer and one WWW technician who was replaced halfway through the year. The 2021 vehicle builds saw the replacement of the second WWW technician and the addition of a UES-employed University of Nevada Las Vegas (UNLV) mechanical engineering student intern to assist with receiving, warehousing, and parts kit creation at the production facility. The WWW technician was replaced again in 2022. Two additional UNLV engineering interns and one new UES assembly technician were added to the production team in 2022. The overall workflow for the project was completed by batching five vehicles at a time, running most of the vehicle teardown, initial chassis preparation, and component installation in parallel, while the final commissioning and validation testing happened in series. Below in Figure 5, images show the FCEV repower kit in different stages of vehicle assembly. The image on the left is of a vehicle at 50% assembly completion. The top right image shows batch production of the ESS and FC sub-assemblies. The bottom right image is of a 100% assembled vehicle awaiting final commissioning steps at the Las Vegas, Nevada production facility.



Figure 5: Phase 2 FCEV Repower Kit Assembly

UES commissioned then proved the EV drivetrain operations with a 30-mile validation drive in Las Vegas. UES also did an H₂ line pressure check and fuel cell operation check on stationary vehicles using an auxiliary H₂ gas cylinder tank procured from a local gas supply vendor while the vehicle was in Las Vegas (no public H₂ fueling stations were available in Las Vegas). The vehicles were then transported to Gardena, California, to have the Hydrogen Storage System (HSS) tanks purged and filled using a public H₂ station in Torrance, California. A final 100-mile on-road full operation test was conducted per vehicle before delivery to UPS. H₂ commissioning steps

are shown in Figure 6, below. The image on the left is commissioning with H2 bottle gas in Las Vegas. The image on the right is H2 tank filling at a public H2 fill station in Torrance.



Figure 6: H2 System Commissioning, Las Vegas and Torrance

Procuring Equipment

Fuel Cells: At the heart of the FCEV is the fuel cell, an electromechanical device that turns the chemical energy of H₂ into electrical energy used to charge the vehicle's high-voltage battery ESS. The Accelera, previously known as Hydrogenics, fuel cells arrived on schedule which allowed vehicle assembly to stay on track. The first fuel cell arrived at WWC on April 20, 2020, and was immediately integrated into the vehicle called CTE-2. The next four fuel cells, for vehicles CTE-3 through CTE-6, arrived at the end of Q2 2020 due to delays in procuring some minor equipment. All remaining fuel cells for CTE-7 through CTE-16 vehicles arrived at WWC by Q1 2021.

Battery Systems: The FCEV gets its energy for locomotion through electrical energy stored in the on-vehicle battery system, a 45-kWh high voltage lithium iron phosphate battery package. Battery systems arrived on schedule which allowed vehicle assembly to stay on track. The first five battery systems, for vehicles CTE-2 through CTE-6, arrived at WWC in February 2020. The second batch of five battery systems, for vehicles CTE-7 through CTE-11, arrived at WWC in Q1 2021. The last batch of five battery systems, for vehicles CTE-12 through CTE-16, arrived at WWC in Q4 2021.

Propulsion System Kits: The FCEV delivers traction force to the wheels by use of an Internal Permanent Magnet (IPM) switched reluctance motor, accompanied by a high-voltage power inverter and a tail shaft assembly for a parking gear assembly with a driveshaft that connects to the vehicle OEM rear axle. This system of parts used to take electrical energy from the on-vehicle ESS to the traction force at the rear wheels is referred to as the propulsion system kit. Propulsion system kits arrived on schedule which allowed vehicle assembly to stay on track. The first five propulsion system kits for CTE-2 through CTE-6 arrived at WWC in February 2020. The second set of five propulsion system kits, for CTE-7 through CTE-11 arrived at WWC in Q1 2021. The final set for CTE-12 through CTE-16 vehicles arrived in Q4 2021.

Installation Instructions and Upfitting Training

UES's vehicle assembly and manufacturing documentation was a critical aspect that facilitated smooth vehicle assembly to occur with the vehicle upfitter WWC's supplied assembly technicians. UES completed initial training with an interactive slide show and videos showing the steps needed to assemble the vehicle properly. UES then utilized a vehicle assembly manual with integrated quality control checks which stayed with a vehicle

throughout the assembly process and was used to audit the completion status of vehicles. Lastly, UES utilized vehicle commissioning and outbound vehicle checklist documents to consistently and accurately verify the safe operations of the vehicles prior to delivery to UPS operators. UES developed and updated these documents during the assembly of CTE-2 through CTE-6 in the first year of project work in 2020 at the vehicle upfitter WWW in Las Vegas, Nevada. These updated documents were submitted to the Project Team in Q1 2021.

Vehicle Assembly, Commissioning, and Delivery

The Project Team strategically approached the vehicle assembly, commissioning, and delivery by grouping the vehicles in sets of five. This way, the Project Team could utilize the lessons learned and efficiently execute the processes on the later sets of vehicles. Additionally, splitting up the milestones allowed for better cash flow to project partners. Once each set of five vehicles was assembled, commissioned, or delivered, the partners were able to invoice for the completion of the respective milestones. The vehicles were assembled, commissioned, and delivered, in the following groups, in this order: CTE-2 through CTE-6, CTE-7 through CTE-11, and CTE-12 through CTE-16.

The vehicle commissioning process is a critical phase in ensuring the safe and effective operation of the FCHEDVs. This process involves a series of validation and verification steps to confirm the performance of key vehicle systems, including the HV battery, drivetrain, and FC system. Based on the availability of hydrogen refueling infrastructure, commissioning was conducted in two phases: an initial phase in Las Vegas, where the base EV and stationary fuel cell system were tested, and a second phase in California, where full hydrogen tank commissioning and final vehicle testing were completed.

Las Vegas Commissioning

The first phase of commissioning took place in Las Vegas and focused on verifying the fundamental electric vehicle functionality. During this stage, the on-road performance of the HV battery and drivetrain was tested to ensure that the base EV systems were operating as expected. Additionally, initial stationary fuel cell system tests were conducted. Since hydrogen fueling was not available at this location, alternative methods were used to evaluate the integrity and function of the hydrogen piping and fittings. A 5,000 PSI nitrogen bottle was utilized to perform leak checks, ensuring the quality of the hydrogen piping connections. For the initial fuel cell system startup and operation verification, a 3,000-PSI hydrogen weld bottle was used, providing a controlled means of introducing hydrogen into the system for preliminary validation.

California Commissioning

The second phase of commissioning occurred in California, where access to hydrogen refueling infrastructure allowed for comprehensive FCEV testing. This phase began with hydrogen tank commissioning, which involved purging the onboard tanks with nitrogen, performing sequential hydrogen fills and vents, and conducting thorough leak checks on all hydrogen piping and fittings. Once the hydrogen system was fully validated, the vehicles underwent final commissioning, including system operation verifications, tuning, and full acceptance testing. The most extensive testing was conducted on the CTE-2 vehicle, which underwent in-depth acceptance procedures and a full-range validation test. The remaining vehicles completed 100-mile on-road operation verifications to confirm performance under real-world conditions.

CTE-2 – CTE-6

The Project Team began Phase 2 of the project by assembling CTE-2 through CTE-6. These FCHEDVs were used as the validation vehicles for the manufacturing plan. COVID-19 made the completion of these vehicles challenging due to temporary business shutdowns and supply chain delays. These delays moved the delivery of these vehicles to UPS into 2021. Below is a summary of significant activities organized by quarters in which the work was completed:

Q1 2020:

- UES identified five de-commissioned UPS vehicles with the Navistar chassis available for repower. One of these vehicles was located in Las Vegas and was delivered to WWW early in the quarter.
- By the end of the March 2020, UES had three chassis at WWW with an additional chassis available nearby in California.

Q2 2020:

- In early June 2020, CTE-2 completed high-pressure H2 testing successfully. The vehicle was driven to validate key components before shipping it to the UPS Olympic facility for painting.
- UES removed the gas engines from CTE-3 through CTE-6, completed chassis cleanup, and finished HV wire harness preparation work.

Q3 2020:

- By the end of September 2020, CTE-2 painting at the UPS Olympic paint shop was postponed due to other UPS projects.
- CTE-3 through CTE-5 completed commissioning in Las Vegas and were sent to California for final H2 and drive commissioning.

Q4 2020:

- CTE-6 encountered issues with the ESS HV batteries during the Las Vegas commissioning of the EV drive system. A battery module inside the ESS was identified as the root cause of the problem, and work to send and install a replacement began.

Q1 2021:

- CTE-2 completed a 169-mile range test in just under 14 hours with a payload of approximately 4,792 pounds. The payload was simulated by using dry concrete bags in the package storage area of the vehicle. The vehicle was then delivered and went into service at UPS-Gardena utilizing the Shell Torrance, California public H2 station for fuel while in package delivery service.
- CTE-3 through CTE-5 completed California H2 storage and operation commissioning and were delivered to the UPS-Ontario facility to be used in service.
- CTE-6 completed the battery module replacement and Las Vegas Commissioning. The vehicle was shipped to California where H2 storage and operation commissioning was completed and the vehicle was delivered to UPS-Ontario facility ready to operate in service.

By the end of March 2021, CTE-2 through CTE-6 were assembled, fully commissioned and delivered to UPS. UPS provided documentation of vehicle acceptance, and the vehicles were ready to be operated in package delivery service.

Below, in Figure 7, a collage of images from the CTE-2 range test and acceptance test are shown. The upper images depict the loadout of the 4,792 pounds of concrete bag payload. The bottom left image shows the 15% grade hill during the start of acceleration testing. The bottom right image shows the vehicle idling, to test the operation of the fuel cell using H2 to charge the ESS, during the range test of CTE-2.



Figure 7: CTE-2 Range and Acceptance Test Driving in California

It is of note that the CTE-6 Battery module failure during Las Vegas EV commissioning triggered the creation and implementation of a new sub-assembly into the vehicle assembly to further increase the quality assurance of the finished vehicles. UES created an ESS cycle fixture to allow the charge and discharge of the ESS HV batteries in a controlled stationary environment prior to installing the ESS in the vehicle to ensure assembled vehicles would properly operate after assembly completion. This cycle fixture and commissioning step was successfully utilized for the remaining CTE-7 through CTE-16 vehicles. The newly developed and implemented ESS cycle fixture for stationary commissioning of the ESS before vehicle installation is shown in Figure 8.



Figure 8: ESS Stationary Commissioning Cycle Fixture

CTE-7 – CTE-11

This second batch of five UPS chassis, CTE-7 through CTE-11, were procured and delivered to the assembly location by the end of 2020. The COVID-19 related supply chain challenges were, for the most part, overcome, and delivery of these vehicles to UPS was completed by the end of 2021. Below is a summary of significant activities that occurred during the assembly, commissioning, and delivery of CTE-7 through CTE-11:

Q4 2020:

- The chassis for CTE-7 through CTE-11 were delivered to WWW by the end of 2020.
- UES began the tear-down and engine removal process on CTE-7 and CTE-8 during the last quarter of 2020.

Q4 2021:

- CTE-7 through CTE-11 completed pre-delivery commissioning in Las Vegas and were sent to California to for the rest of the commissioning tests. After this, they were delivered to the UPS-Gardena facility.
- UPS completed minor body damage repair and painted the vehicles in the fourth quarter of 2021.

By the end of 2021, CTE-7 through CTE-11 were assembled, fully commissioned, and delivered to UPS. UPS provided proof of acceptance to the Project Team.

CTE-12 – CTE-16

This third and final batch of five UPS chassis were procured and delivered to the assembly location by the end of 2021 and were all repowered and delivered to UPS by early 2023. Below is a summary of significant activities organized by quarters of completion.

Q2 2022:

- CTE-12 and CTE-13 completed Las Vegas Commissioning and were sent to California for final H2 and drive commissioning. These two vehicles were fully commissioned and delivered to the UPS-Gardena facility on June 24, 2022. UPS completed minor repairs on the body and painted the vehicles. CTE-12 and CTE-13 were ready for service by the end of June 2022.

Q3 2022:

- CTE-14 completed Las Vegas Commissioning then was sent to California. The vehicle was fully commissioned and delivered to the UPS-Gardena facility during the quarter. UPS completed minor repairs on the body and painted the vehicle. CTE-14 was ready for service by the end of September 2022.

Q4 2022:

- CTE-15 completed pre-delivery commissioning in Las Vegas then was sent to California for the rest of commissioning. It was delivered to the UPS-Gardena facility on the week of December 5, 2022, for minor body damage repairs and painting. By the end of 2022, CTE-15 was ready for service.
- CTE-16 completed Las Vegas Commissioning then was sent to California the week of December 26, 2022, to complete commissioning.

Q1 2023:

- CTE-16 commissioning was completed then the vehicle was delivered to the UPS-Ontario facility to enter package delivery service.

By the end of March 2023, CTE-12 through CTE-16 were fully assembled, commissioned, and delivered. UPS provided documentation of vehicle acceptance.

Below in Figure 9, the nearly entire Phase 2 FCEV fleet of vehicles is seen awaiting start of delivery service at the Ontario, California UPS facility.



Figure 9: Phase 2 FCEVs Awaiting Delivery Service in Ontario, California

Fuel Cell Integration

The fuel cell performed well in the Phase 1 vehicle with a few upgradeable areas. One of the main challenges with the fuel cell on the Phase 1 vehicle was the ease of accessibility and serviceability. The Phase 2 vehicle was improved by putting the fuel cell in a more accessible location for installation and service repairs. Accelerera, which was called Hydrogenics at that time, also made internal mechanical updates to their fuel cell to increase the serviceability of the fuel cell. These updates proved successful by UES being able to conduct service and repairs with the fuel cell in the installed location on the vehicle.

Another engineering update that stemmed from Phase 1 vehicle operation data was the need for a better Fuel Cell Thermal Management System (FCTMS) and controls. An engineered radiator bypass valve was included on the Phase 2 vehicles to address the shortcomings of the Phase 1 vehicle's FCTMS. The net effect of this bypass valve was an improvement over the Phase 1 vehicle, but it was still not robust enough for all driving conditions. Under certain driving conditions, the FCTMS was unable to keep the FC warm enough for operation. The final engineering update to the system was to install a wind block panel to the front radiator grill. This wind block allowed the FCTMS to maintain acceptable fuel cell operating temperatures under all driving conditions.

Most of the issues faced with fuel cell integration were rooted in the new assembly location of the fuel cells. With manufacturing transitioned to the new Milpitas, California, facility, the first few fuel cell assemblies suffered from inconsistent quality. UES troubleshooted and fixed numerous issues in the units during stationary FC commissioning in Las Vegas that ranged from loose internal H₂ fittings to improperly or incorrectly terminated electrical connectors. These quality issues were readily diagnosed and fixed by UES engineering with the assistance of Accelerera. Below, in Figure 10, the ease of accessibility and serviceability of the fuel cell is shown, which showcased the commercialization feasibility of the Phase 2 vehicle redesign.



Figure 10: Fuel Cell Installed in Vehicle

Additionally, CTE-2 had the fuel cell hydrogen pump replaced twice during assembly due to the premature failure of the pumps. It was determined that the failure was caused by a supplier component with a high defect rate provided to Accelerera. It is of note that all Phase 2 FCs were assembled with H₂ pumps with subcomponents

from this high-defect rate batch which means this H2 pump failure had the potential to affect more vehicles if they had all gone into extended operational service like CTE-2. These parts were all replaced.

Overall, the Phase 2 vehicle Accelerera fuel cell power units performed as expected and allowed the vehicles to consistently finish their 100-mile on road commissioning drives, demonstrating the commercial feasibility of a FCEV repower kit-assembled vehicle.

UT-CEM assisted UES and the Project Team in the Phase 1 evaluation and the Phase 2 design updates. This included additional modeling and simulation activities during the redesign phase to assess performance benefits. As stated previously, the lighter Phase 2 vehicle had a significantly higher driving range, which was proven by vehicle modeling and simulation studies conducted prior to the Phase 2 vehicle builds. UT-CEM also lent their expertise to help update the H2 Storage system design specifications for the fueling port and the relocation and balance of parts needed for the new fuel cell mounting location in the vehicle.

UT-CEM assisted UES and the Project Team in Phase 2 vehicle final inspections and operations verifications. UT-CEM traveled to California to inspect and test the vehicles as they were delivered. Pre-deployment safety inspections were also performed at two separate times as outlined later in this report.

The Project Team submitted and was approved for a CARB experimental operating permit to allow the Phase 2 vehicles to be registered and operated within the state of California.

Task 2 Training and Education

In the Training and Education task, the Project Team delivered operations training for delivery van drivers, support staff, and first responders. The following section describes the development of the training plan, the execution of the training, and how the Project Team conducted a second set of training to better prepare UPS employees to operate the vehicles safely. This section includes the following subsections:

1. Training Plan
2. Initial Training
3. Additional Training

Training Plan

Throughout 2021, while the first set of five vehicles were being commissioned and the second set of five vehicles were being assembled, the Project Team developed a training plan. Training would be conducted over three days; each day would target different UPS staff groups (maintenance staff, on-road supervisors, and drivers) to ensure familiarity with vehicle technology, safety practices, and vehicle operation, including fueling. Due to the COVID-19 pandemic, training was delayed until it was safe to conduct in-person training, which was not until February 2022. CTE developed a Training Matrix to summarize the training plan, as shown below in Table 1.

Table 1: Training Matrix

	Maintenance Training	Onroad (Supervisor) Training	Driver Training
Scope	Ensure that UPS maintenance staff is familiar with vehicle technology and appropriate safety practices. This also includes vehicle operation and fueling of 2 vehicles.	Ensure that UPS onroad (supervisor) staff is familiar with vehicle technology and appropriate safety practices. This also includes vehicle operation and fueling of 2 vehicles.	Ensure that UPS drivers is familiar with vehicle technology and appropriate safety practices. This also includes vehicle operation and fueling of 2 vehicles.
Date(s)	- Monday, February 21, 2022 (May be 2 sessions for day/night staff)	- Tuesday, February 22, 2022	- Wednesday, February 23, 2022 - Additional days for ridealongs, as needed
Trainer	- Unique Electric Solutions	- Unique Electric Solutions	- Unique Electric Solutions
Required Attendees	- UPS Maintenance Staff - Unique Electric Solutions - Cummins	- UPS Onroad (Supervisor) Staff - Unique Electric Solutions - Cummins	- UPS Drivers - Unique Electric Solutions
Optional Attendees	- CTE - UT-CEM	- CTE - UT-CEM	- CTE - UT-CEM
Locations	- UPS Customer Center: 3480 E Jurupa St, Ontario, CA 91761 - Shell Hydrogen Refueling Station: 4325 E Guasti Road, Ontario, CA 91761	- UPS Customer Center: 3480 E Jurupa St, Ontario, CA 91761 - Shell Hydrogen Refueling Station: 4325 E Guasti Road, Ontario, CA 91761	- UPS Customer Center: 3480 E Jurupa St, Ontario, CA 91761 - Shell Hydrogen Refueling Station: 4325 E Guasti Road, Ontario, CA 91761
Timing	-2 Hours in "Classroom" -2 Hours On-Board Vehicle -1 Hour at Fueling Station	-2 Hours in "Classroom" -2 Hours On-Board Vehicle -1 Hour at Fueling Station	-2 Hours in "Classroom" -2 Hours On-Board Vehicle -1 Hour at Fueling Station Ridealongs as needed until proficient
Materials & Deliverables	- Vehicle Operation Manual - Vehicle Support Plan	- Vehicle Operation Manual - Vehicle Support Plan	- Vehicle Operation 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 training includes any manual data logging requirements (fueling reports, incident reports, maintenance reports...)

Initial Training Sessions

On Monday, February 21, 2022, a training session was conducted specifically for UPS maintenance staff to ensure they became familiar with the relevant vehicle technology, safety practices, and procedures for operating and fueling vehicles. The training was led by UES with support from Cummins representatives. The session was structured to include approximately two hours of classroom instruction, two hours of on-board vehicle training, and one hour of hydrogen fueling training at the fueling station. Participants were provided with a Vehicle Operation Manual and a Vehicle Support Plan. Additionally, the training emphasized the importance of the manual data logging requirements for the project data collection, such as fueling reports, incident reports, and maintenance reports.

On Tuesday, February 22, 2022, UPS on-road supervisors participated in a training session designed to familiarize them with vehicle technology, safety practices, and the operation and fueling of the vehicles. Like the maintenance staff training, this session was facilitated by UES, with support from Cummins representatives. The program included approximately two hours of classroom instruction, followed by two hours of on-board vehicle training and one hour at the fueling station. Materials provided during the session included a Vehicle Operation Manual and a Vehicle Support Plan. As with the maintenance training, there was a strong emphasis on ensuring that the training covered all necessary manual data logging requirements.

Lastly, UES conducted the UPS driver training session which took place on Wednesday, February 23, 2022. This training was focused on equipping UPS drivers with knowledge of vehicle technology, safety practices, and the procedures for operating vehicles, which included ride-alongs, as needed, to ensure proficiency. The training format consisted of approximately two hours of classroom instruction, two hours of on-board vehicle training, and one hour at the fueling station. Participants were given a Vehicle Operation Manual, and the training emphasized the importance of the manual data collection requirements, such as fueling reports, incident reports, and maintenance reports.

Additional Training Sessions

After the February 2022 training took place, the CARB training task and associated milestone payments were expended. As described in the *Project Safety Report (PSR)* section, UPS's insurer conducted a safety audit on the project in 2023. As a result of the safety audit, UPS and their insurance provider informed the Project Team that

the February 2022 training did not have a consistent and repeatable framework that could pass a legal discovery process in the unlikely scenario of a hydrogen event requiring an investigation. UPS requested that the Project Team conduct additional vehicle operation and maintenance training sessions and provide more thorough documentation of training. UPS required their insurance carrier to approve the plan for subsequent training and associated documentation.

The Project Team revised all training materials and developed detailed training sign-off sheets to document the transfer of knowledge to UPS operators. The training plan and all associated documentation were approved by UPS’s insurance carrier in March 2023. However, coordinating, updating, and developing the new material for additional training caused a significant strain on the project administration budget.

In late 2022, the Project Team developed the following guidelines and documents for the additional training sessions:

- There must be at least three drivers trained per vehicle.
- Additional training sessions will take place the week prior to the deployment of each vehicle.
- A driver-specific operation manual will be developed. During the first part of the additional training sessions, drivers will walk through this manual with the UES technician. After this, the driver and UES technician will operate the vehicle until the driver feels comfortable. At the end of the training the driver will be required to sign the Automotive Staff Training Sign-Off Sheet to confirm transfer of knowledge.
- The Project Team created additional documents to remind drivers how to fuel the vehicle and about the pre- and post-trip procedures.

In May 2023, UES trained 25 UPS staff members. Another five UPS staff were trained in June 2023. These sessions were broken down into automotive maintenance staff training, on-road management training, and driver training, using the agenda developed by the team. Table 2 summarizes the dates of the additional training sessions and the number of attendees.

Table 2: Training Summary

Date	Training Session Type	Trainer	No. Participants
May 1, 2023	Automotive Mechanic Training	UES	5
May 2, 2023	Automotive Mechanic Training	UES	2
May 11, 2023	On-Road Management	UES	10
May 18, 2023	Driver	UES	5
May 25, 2023	Driver	UES	3
June 1, 2023	Driver	UES	2
June 15, 2023	Driver	UES	3

The fueling training was performed at the Ontario, California, Shell H2 Station. Pictures of the UPS Staff training are provided in Figure 11-Figure 13.



Figure 11: UPS FCHEDV Staff Training at Shell Ontario Station



Figure 12: UPS FCHEDV Staff Training at Shell Ontario Station



Figure 13: UPS FCHEDV Staff Training at Shell Ontario Station

Task 3 Vehicle Operation, Support, and Data Collection

The results of the Vehicle Operation, Support, and Data Collection Task are split into two sections: Pre-Deployment Activities and Deployment. The **Pre-Deployment Activities Section** describes how the Project Team prepared to operate the vehicles in revenue service in the following sections:

1. Hydrogen Facility Modifications
2. Functional Hazard Analysis
3. Project Safety Report
4. Pre-Deployment Fuel Coordination

The Deployment section of this report outlines how the Project Team provided technical and administrative support to address the issues encountered. The **Deployment Section** covers the following topics:

1. Deployment Plan
2. Initial Deployment
3. Deployment Hold and Problems Encountered
4. Data Collection

Pre-Deployment Activities

Hydrogen Facility Modifications

Fueling coordination for the Phase 2 demonstration began in Q3 of 2020. The Team needed to determine what facilities upgrades were needed to safely house and maintain hydrogen fueled vehicles at the UPS facility in Ontario, California. CTE procured services competitively in accordance with federal guidelines for an audit of the facility for hydrogen vehicle repair garage compliance with codes and standards. CTE selected Wilkins Process Optimization (WPO) to conduct the audit in November 2020. The audit took five months and cost UPS approximately \$11,000. WPO evaluated the feasibility and cost of adding hydrogen detection to the existing gas detection system at UPS Ontario. WPO assessed that the current ventilation system was compliant with National Fire Protection Association (NFPA) 2 requirements. WPO provided the Project Team with a report detailing the actions required to make the facility compliant with the City of Ontario regulations. Each of the actions was resolved by the Project Team, and the final audit report was issued by WPO in April 2021. CTE worked with UPS to upgrade the CNG facility and install the necessary equipment to safely maintain H2 vehicles.

Functional Hazard Analysis

Since the inception of the project, the Project Team held safety paramount. In December 2016, during the construction of the Phase 1 FCHEDV, CTE held a Functional Hazard Analysis (FHA) review with the full Project Team. The Project Team explored possible means of failure for each subsystem, assigned risk values based on severity and likelihood of each failure mode, and assigned risk mitigation actions. These documents were also submitted to the Hydrogen Safety Panel (HSP) for review and feedback. The safety hazards were codified into a single document that summarized and evaluated the hazards, mitigations, and related action items that were subsequently implemented.

The Project Team determined the Mitigation Risk Index (MRI) of each hazard using the severity and probability definitions shown in Figure 14.

Hazard Analysis Definitions

Severity		Probability	
I. Catastrophic	Death or permanent debilitating injury Facility or equipment damage above \$500,000 or total system loss Operation significantly compromised	A. Frequent	Happens regularly, occurrence would not be surprising
II. Critical	Disfiguring injury or lost time greater than three months Facility or equipment damage between \$50,000 and \$500,000 Operation moderately compromised	B. Probable	Will occur several times during the life of the system
III. Marginal	Lost time injury greater than one day Facility or equipment damage between \$5,000 and \$50,000 Minor operational interruption	C. Occasional	Likely to occur during the life of the system
IV. Negligible	No lost time injuries Facility or equipment damage less than \$5,000 Little or no operational interruption	D. Remote	Possible occurrence, but uncommon
		E. Improbable	Unlikely to occur, few or no documented cases

Figure 14: Hazard Analysis Definitions

Using the MRI and the Risk Severity Matrix in Figure 15, the Project Team determined if a hazard required further risk mitigation.

Risk Severity Matrix

Severity	Catastrophic	Critical	Marginal	Negligible
Probability				
Frequent				
Probably				
Occasional				
Remote				
Improbable				

	Requires mitigation
	Mitigation requirements to be discussed and agreed to
	No mitigation required. Recommend actions

Figure 15: Risk Severity Matrix

Shortly after delivering the Phase 1 vehicle to UPS, CTE reviewed the FHA documents with the full Project Team, including UPS. The objective of this meeting was to review the FHA and verify that all mitigating actions were implemented into the vehicle. The outcome of this meeting informed conversations between the Project Team and the owner of the public fueling station during initial fueling tests to ensure appropriate safety protocols.

Additionally, the Project Team developed an acceptance plan to ensure proper performance metrics and safety standards were met during testing and demonstration. The acceptance plan identified all relevant codes and standards at the system and component levels, as well as operational requirements defined by UPS. Of particular relevance, maintenance and service activities were delineated so that UPS would not be responsible for maintaining or servicing the high voltage or high pressure (hydrogen) systems.

Project Safety Report (PSR)

In Phase 2, UPS engaged their insurer to conduct a safety audit of the vehicles. The FCHEDVs could not be put into service until UPS's insurer completed a comprehensive safety audit. In response, CTE developed a Project Safety Report (PSR), a robust document that summarizes all project-level assessments. The appendix of the PSR includes more than thirty files detailing tests, certifications, specifications, confirmations, and approvals. Figure 16 below outlines the documents included in the appendix of the PSR.



Figure 16: Lists of Appendices from PSR

The first iteration of the PSR was submitted to UPS in April 2022. The Project Team published five iterations before receiving final approval from UPS to deploy the FCHEDVs in March 2023.

Five months after submission of the initial PSR, the insurer responded with a matrix of comments. The Project Team promptly made updates, as requested by the insurer, and addressed all comments within two weeks. Iteration two of the PSR was submitted to UPS on September 21, 2022. Six weeks later, the insurer responded with questions and comments about iteration two. CTE, UPS, and CARB reviewed the comments left by the insurer and developed a set of new deliverables to better document operator training. On December 2, 2022, CTE submitted iteration three of the PSR. The insurer responded with more comments and requested additional deliverables to help operators distinguish the differences between driving a regular diesel vehicle and FCHEDV. CTE submitted iteration four of the PSR on January 17, 2023. The insurer responded with comments about the new deliverables, then CTE submitted iteration five on February 6, 2023. In March 2023, nearly one year after the initiation of the safety report, the insurer and UPS approved the PSR, giving the Project Team permission to deploy the vehicles.

Figure 17 below, taken from the final iteration of the PSR, summarizes the series of updates and iterations required to get approval from UPS's insurer to deploy the vehicles.

FCHEDEV Project Safety Report



Deployment locations: Ontario, CA

Prepared by CTE

April 8, 2022

Update #1 on September 21, 2022

Update #2 on December 2, 2022

- 1) *Updated inspection results table*
- 2) *Addressed employee training signoff document in Operations, Maintenance and Training Section*
- 3) *Edited the Appendix to include automotive staff training sign off sheet and drivers training manual*

Update #3 on January 17, 2023

- 1) *Edited the Appendix to include fueling card and pre-trip & post-trip checklist*

Update #4 on February 6, 2023

- 1) *Updated fuel card*
- 2) *Updated pre-trip & post-trip checklist*
- 3) *Edited the Appendix to include driver and on-road management training sign off sheet*
- 4) *Created on-road management training signoff*
- 5) *Updated the automotive maintenance staff training signoff sheet to include additional signatures*
- 6) *Updated the driver training signoff sheet to include additional signatures*
- 7) *Edited the Appendix to include Issue Report Form*

Figure 17: Summary of PSR Iterations

The UPS Safety Audit resulted in a delay of over a year, and the development of the Project Safety Report significantly strained the project budget and made it challenging to adhere to the project schedule. It also impacted the health of the fuel cells, as described in the *Deployment* section of this report. However, the Project Team considers the Project Safety Report to be one of the greatest achievements of this program. The insurer's high level of engagement required the Project Team to develop a comprehensive set of documents that can be leveraged for hydrogen fuel cell safety planning and education for insurers and others.

Pre-Deployment Fuel Coordination

CTE planned to work with its partners in California, as well as UPS, to identify and select one or more sites for deployment. Before the project began, CTE estimated that each vehicle would require approximately five to seven kilograms of gaseous hydrogen per day. The station and vehicles had to accommodate J2601 fueling protocol at 35 MPa to adhere to UPS's demanding operating logistics and schedule. The State of California had provided funding to assist several major fuel suppliers with the construction of publicly accessible hydrogen fueling stations throughout California that met J2601 specifications. CTE would ensure that stations would be available in convenient proximity to UPS distribution centers when the fuel cell trucks would be deployed. There needed to be absolute compatibility between vehicles and fueling infrastructure, including the ability to provide redundancy should there be any disruption in the primary fuel supply. CTE planned to work with UPS to develop a deployment plan that would fully enable the movement of vehicles from one distribution site to another if for any reason a station was unable to provide fuel.

Throughout the project, leading up to demonstration, CTE was in contact with the Ontario, California Shell H2 Station. The station opening date was continually delayed. The first fueling by one of the vans occurred in December 2020 before the public opening of the station. CTE worked with Shell to be able to potentially fuel some of the FCHEDEVs before the public opening of the station which was pushed back to May and then July 2021; CTE also considered moving some vehicles back to UPS's Gardena facility, where Phase 1 demonstration had occurred, to utilize the Shell station near Gardena in Torrance. Moving vehicles to Gardena did not become necessary due to other delays in deployment including the hydrogen facility upgrades at the UPS Ontario facility.

The public opening of the station did not provide a complete fueling solution. The Shell management team was concerned that light-duty vehicles that require 700 bar fuel would use the 350 bar dispenser and damage the equipment, so Shell locked out the H35 dispenser that the project vehicles needed. After investigating alternatives that could be implemented at the dispenser, including adding a lock to the fuel door, updating the software to require a PIN to fuel, or modifying the dispenser hardware, Shell elected to update the dispenser hardware to prevent cross-compatibility between H70 and H35 fueling. This upgrade further delayed vehicle deployment by another year. Shell completed the upgrades and the fueling station was fully operational for the demonstration in Q2 of 2022.

Deployment

Deployment Plan

CTE developed a Deployment Plan to smoothly integrate the vehicles into UPS revenue service. The plan consisted of two phases, with six (6) vehicles entering service in phase 1 and the remaining nine (9) vehicles entering service in phase 2. This phased approach allowed the Project Team to ensure that the deployment was going smoothly before continuing. The Project Team developed gate conditions that needed to be met to enter the second phase, as shown below in Table 3.

Table 3: Deployment Plan Summary

	Phase I - Initial Deployment	Phase II - Secondary Deployment
No. Vehicles	6 vehicles	9 vehicles
Timing (start date, duration)	2 vehicles every other weeks Driver training on the off weeks Duration: 1.5 months	2 vehicles every other weeks Driver training on the off weeks Duration: 2 months
Route Selection	Start on low mileage routes (50-100 miles per day)	Full service routes (100+ miles per day)
Training	1. Driver training every two weeks 2. At least 18 drivers trained in phase I 3. Operator and maintenance staff training during phase I	1. Driver training every two weeks 2. At least 27 drivers trained in phase 2 3. Secondary operator and maintenance staff training occurs during phase II
Data collection	UES uploads performance data into google drive the week after vehicles have been deployed. CTE will pull up dashboard during meetings to show previous week performance as data gets added.	UES uploads performance data into google drive the week after vehicles have been deployed. CTE will pull up dashboard during meetings to show previous week performance as data gets added.
Operations and maintenance data	1. Austin to keep a log vehicle operation issues to share status update during calls (i.e. why a vehicle was out of service). 2. UPS provides cost share report to CTE.	1. UES log of vehicle operation and report any maintenance requests to project team. 2. UPS continue to provide cost share report to CTE
Gate conditions to move to next phase	1. Six vehicles in service 2. CTE has provided team with insightful performance data. 3. UPS has provided cost share data with team 4. UES has provided record of any maintenance, operations issues and any anticipated delays	1. All fifteen vehicles in service 2. CTE has provided team with insightful performance data. 3. UPS has provided cost share data with team 4. UES has provided record of any maintenance, operations issues and any anticipated delays.

During each of these two phases, the Project Team planned to switch between a week of training and a week of vehicle deployment to ensure that vehicles were smoothly integrated into UPS service, and that the driver training was fresh for the operators. Table 4 below details the events that would occur each week and the responsibilities of each member of the Project Team. The table also shows that the deployment dates we pushed multiple times due to the challenges described in the following section of this report.

Table 4: Full Deployment Plan Detail

Deployment Schedule and Responsibilities						
	Week 1	Week 2	Phase I - Initial Deployment		Week 5	Week 6
Date	1/23/2023 – 1/27/23	1/30/2023 – 2/3/23	2/6/2023 – 2/10/2023	2/13/2023 – 2/17/2023	2/20/2023 – 2/24/2023	2/27/2023 – 3/3/2023
Updated on 1/25	2/6/2023 – 2/10/2023	2/13/2023 – 2/17/2023	2/20/2023 – 2/24/2023	2/27/2023 – 3/3/2023	3/6/2023 – 3/10/2023	3/13/2023 – 3/17/2023
Updated on 2/1	2/13/2023 – 2/17/2023	2/20/2023 – 2/24/2023	2/27/2023 – 3/3/2023	3/6/2023 – 3/10/2023	3/13/2023 – 3/17/2023	3/20/2023 – 3/24/2023
Updated on 2/8	2/27/2023 – 3/3/2023	3/6/2023 – 3/10/2023	3/13/2023 – 3/17/2023	3/20/2023 – 3/24/2023	3/27/2023 – 3/31/2023	4/3/2023 – 4/7/2023
Updated on 2/22	3/6/2023 – 3/10/2023	3/13/2023 – 3/17/2023	3/20/2023 – 3/24/2023	3/27/2023 – 3/31/2023	4/3/2023 – 4/7/2023	4/10/2023 – 4/14/2023
Updated on 3/8	3/27/2023 – 3/31/2023	4/3/2023 – 4/7/2023	4/10/2023 – 4/14/2023	4/17/2023 – 4/21/2023	4/24/2023 – 4/28/2023	5/1/2023 – 5/5/2023
Events	Automotive Staff Training using CTE 4 (139777) & CTE 5 (139601) 6 UPS drivers present UPS Maintenance staff	CTE 4 (139777) and CTE 5 (139601) begin service out of UPS Ontario	Automotive Staff Training using CTE 8 (139295) & CTE 12 (139597) - 6 UPS drivers present	CTE 8 (139295) and CTE 12 (139597) begin service out of UPS Ontario	Automotive Staff Training using CTE 6 (139229) & CTE 7 (139748) 6 UPS drivers present	CTE 6 (139229) and CTE 7 (139748) begin service out of UPS Ontario
Gate conditions to move forward	CTE 4 (139777) and CTE 5 (139601) build matrix at 100%. Route/driver assignments ready for Monday morning. 6 trained UPS drivers. Mike Lewis has completed all vehicle inspections.	CTE 8 (139295) and CTE 12 (139597) build matrix at 100% by EOW		CTE 6 (139229) and CTE 7 (139748) build matrix at 100% by EOW		CTE 3 (139192) and CTE 13 (139486) build matrix at 100% by EOW 18 UPS drivers trained (CTE has roster and UPS has 18 sign off sheets). UPS maintenance staff have been trained.
UPS	1. Coordinate 6 drivers for training 2. Determine routes and driver schedule for weeks 1 and 2 on CTE 4 (139777) and CTE 5 (139601) 3. UPS provide cost share report to CTE		1. Coordinate 6 drivers for training 2. Determine route and driver schedules for weeks 3 and 4 on CTE 4 (139777), CTE 5 (139601), CTE 8 (139295), CTE 12 (139597) 3. UPS provides cost share report		1. Coordinate 6 drivers for training 2. Determine route and driver schedules for weeks 5 and 6 on CTE 6 (139229), CTE 7 (139748) 3. UPS provides cost share report	
UES	1. Conduct automotive staff training 2. Confirm there is no outstanding work for CTE 4 (139777) and CTE 5 (139601) 3. UES provide cost share report to CTE	Complete outstanding work on CTE 8 (139295) & CTE 12 (139597)	Conduct automotive staff training Provide data for vehicles in service	Complete outstanding work on CTE 6 (139229) and CTE 7 (139748)	Conduct automotive staff training Provide data for vehicles in service	Complete outstanding work on CTE 3 (139192) and CTE 13 (139486)
CEM						
CTE	1. Finalize data reporting workflow			Provide project team with performance data on first two vehicles		Provide project team with performance data on first month of deployment

Initial Deployment

The Project Team was faced with various challenges that delayed the deployment of the fleet and hindered the Team’s ability to adhere to the Full Deployment Plan, as illustrated in Table 4. Due to being Department of Motor Vehicle (DMV) registered and the most recently built, CTE-16 was in the best state for immediate deployment.

Deployment was scheduled to begin on May 26, 2023. However, the night prior to deployment, the emergency stop button on CTE-16 was actuated. This caused a short in the DC/DC converter which had to be resolved by replacing the converter in CTE-16 the morning of May 26, 2023. UES explained that CTE-16 was left in its keyed-on mode on May 25, 2023, meaning the fuel cell was still running. Instead of allowing the fuel cell to shut off according to the instructions displayed in the cab, an automotive technician mistakenly used the emergency off switch rather than keying off the vehicle.

The Project Team responded by updating the training manual to provide more information about when to use the emergency stop and included this incident as an example of when not to use the emergency stop button. CTE also created an incident report form to increase communication between the operators and the Project Team. This incident report form was accessible by scanning posters with a QR code hanging around the UPS maintenance facility.² After replacing the DC/DC converter in CTE-16, the team was finally able to deploy CTE-16 in package delivery service starting May 26, 2023, as shown in Figure 18, Figure 19, and Figure 20, below.

The first day of service went smoothly and the team received positive feedback from the driver. The vehicle was operated on a short route, therefore it did not need to be refueled at the Shell Ontario station at the end of the day. During the summer of 2023, the vehicle traveled 286 miles on routes around the Ontario depot. See the *Data Reporting* section for details about the operation of CTE-16 during the initial deployment.

² [FCDV Incident Reporting Form](#)



Figure 18: UPS Driver Delivering Package Using CTE-16 on May 26, 2023



Figure 19: CTE-16 FCHEDV Stationary During First Day of Service



Figure 20: CTE-16 FCHEDV in Service in Ontario

Deployment Hold and Problems Encountered

Due to the challenges described in the following section of this report, CTE-16 was the only vehicle successfully deployed during the summer of 2023. The following section describes the challenges, chronologically, that led to placing the demonstration on hold. These challenges include:

1. Weak Fuel Cells & Fuel Cell Rehabilitation
2. Fuel Cards
3. General Vehicle Repairs
4. Fuel Availability
5. Permitting and Registration
6. Vehicle Preventative Maintenance

After these initial challenges were resolved, the Project Team continued their efforts to resume the demonstration.

Challenge #1: Weak Fuel Cells & Fuel Cell Rehabilitation

Throughout May, June, and July 2023, while CTE-16 was in service, the Project Team worked on getting the remaining 14 vehicles in the fleet into service. By June 2023, the older vehicles (CTE-2 through CTE-6) had been sitting idle for approximately two years. This was due, in part, to COVID-19 pandemic business shutdowns and supply chain issues, delays in opening the Shell public fueling station, and interruption in order to develop and obtain approval of the PSR. As a result of sitting idle, the vehicles had issues with the fuel cells being unable to reach maximum power. UES observed low voltage from the fuel cell stacks. UES could only get the fuel cells to operate at lower power (approximately 7 kW). If the vehicles had been put into service with the weakened fuel cells, the drivers would have seen errors like low state of charge (SOC) and startup faults. The Accelera and UES teams determined that the fuel cells may have been exposed to residual moisture or contaminants in the storage area since their delivery in 2021, leading to cell degradation.

As a result, UES and Cummins developed a procedure to rehabilitate the fuel cells by slowly ramping up their power over many hours. The UES and Accelera teams successfully applied this solution to CTE-6 which took approximately 5-10 hours and achieved a partial recovery. To rehabilitate the other vans, CTE-7 through CTE-16, UES and UPS technicians drove each vehicle for about 20 miles and then left the vehicle in its key-on state for about 10 hours to allow the fuel cell to operate at low power.

On August 28, 2023, CTE formalized this rehabilitation process by developing and distributing a fuel cell rehabilitation plan to remediate the fuel cells in the other vehicles, CTE-3 through CTE-6. UES planned to begin the rehabilitation process for CTE-3 through CTE-6 in September 2023, however, CTE-5 was out of hydrogen and could not be refueled due to the Ontario station being offline, and CTE-4 required additional repairs.

Challenge #2: Fuel Cards

Each vehicle was to be equipped with a fuel card. The fuel cards function like credit cards and would be used by UPS operators to pay for hydrogen fuel at the Shell station. The fuel cards would capture data such as the cost of fuel, the kilograms of hydrogen purchased, the vehicle being fueled, and the time and duration of the fueling session. Once a fuel card was activated, the vehicle would be marked as active in the UPS internal tracking system. This would automatically flag any vehicles that are not in operation for maintenance and would affect employee metrics. As a result, UPS could not activate the fuel cards until the vehicles were ready to go into repeatable in-revenue service.

Keeping separate fuel cards for each vehicle was important to track the amount and cost of hydrogen fuel, but this was not possible until each vehicle was ready for operation and the fuel cards were activated. Additionally, the data was collected by a third-party provider, so gathering fuel card data was not as simple as downloading a report internally. Since the vehicles were not in regular in-revenue service, it did not make sense to activate a fuel card for each vehicle. As a result, the same fuel card was used to pay for hydrogen fuel for the entire fleet.

UPS worked with their supplier, Comdata, that ultimately provided cost data to the Project Team for January through June 2023. This Comdata report was used to show UPS's match share contribution towards the project.

Challenge #3: General Vehicle Repairs

In August 2023, the Project Team noticed various issues with CTE-2, CTE-4, and CTE-16.

Despite rehabilitation efforts, CTE-2's weak fuel cell was unable to turn on due to the extended idle period without running described in Challenge #1. As a last resort, UES recommended that the fuel cell in CTE-2 be replaced. Accelera shipped two spare fuel cell units on September 19, 2023 for CTE-2; however, they could not be installed due to the lack of hydrogen fuel beginning in September 2023.

On CTE-4, the dashboard displayed an icon, which alerted the Project Team that there was a ground fault issue. This meant that there was an issue with the device that monitors high-voltage isolation. The high-voltage and low-voltage DC systems need to maintain minimum isolation between them. The issue may have been caused by inadequate installation between the DC systems or a malfunctioning device with a poor connection. This issue was not resolved due to the lack of hydrogen fuel beginning in September 2023.

On CTE-16, the SOC on the battery was not reading accurately. UES connected CTE-16 to a wall charger, but this did not resolve the issue. As a result, the UES electric software team made changes to the code and updated the software. This software update resolved the SOC issue on CTE-16.

Challenge #4: Hydrogen Availability

On July 17, 2023, the Project Team was notified that the Shell Ontario station was offline and unavailable for fueling. UPS was forced to pull CTE-16 out of service. The Project Team continued to monitor the Hydrogen Fuel Cell Partnership website for status updates on the station. During the week of July 24, 2023, the Ontario station came back online.

On September 21, 2023, the Project Team learned that the Shell station would be offline again due to a disruption with the primary hydrogen supplier, affecting hydrogen availability at the three heavy-duty refueling stations operated by Shell in the area. The lack of fueling options would, again, halt CTE-16 and all other vans from deployment. Shell confirmed on November 10, 2023 that hydrogen deliveries to its Ontario H2 station were projected to resume in January 2024.

CTE took steps to investigate the issue and analyzed the risk associated with significant downtime of the fueling station. CTE investigated other fueling alternatives, which are summarized below:

1. Alternative Fueling Options Near Ontario

The goal of this analysis was to locate hydrogen fuel dispensers that were located near the UPS Ontario facility, so that operators could fuel on their way back to the depot. The dispensers must be able to dispense fuel at 350 bar using a TK16 dispenser.

- a. CTE reached out to Iwatani, a hydrogen station operator, to see if the Iwatani Riverside light-duty fueling station could provide fuel. The Iwatani Riverside Station had limited supply and required reservations. Since the supply was insufficient to fuel the entire fleet, the Project Team decided not to pursue this option.
- b. CTE met with a Project Manager from Nikola Hyla, a hydrogen refueling provider, on December 13, 2023 to discuss the possibility of fueling the UPS vans at the Hyla site near the Ontario Airport. At the time, the Nikola fuel cell trucks were fueled by a mobile refueler, but the system pressure was incompatible with the UES vans. Additionally, the Hyla station would not be open until much later in 2024. This option did not work out for the project.
- c. CTE met with the director of the California State Los Angeles University fueling station, but it was determined that fueling station was not in operation and was approximately 45 miles away from the UPS Ontario depot, making it impractical for UPS to use for fueling.
- d. CTE met with Foothill Transit to discuss utilizing their hydrogen fueling station, but Foothill Transit did not want to take on the liability of fueling the trucks at their private station.
- e. The Project Team discussed permitting a mobile refueler; however, this option had a 6-to-8-month lead time and would require additional funding for permitting, site preparation, and re-training UPS personnel.
- f. CTE met with Air Liquide on December 13, 2023. Air Liquid had a 400 kg trailer available, but the capacity exceeded the fleet's requirement. This would burden the project with excess additional costs and was therefore not pursued.
- g. CTE met with First Element Fuel (FEF) on December 19, 2023. FEF has four light-duty stations that dispense fuel at 350 bar (Fountain Valley, Mission Hills, Sherman Oaks, and Studio City); however, there was limited capacity at certain times of the day. FEF would only consider fueling part of the fleet at a single location and the available locations are prohibitively far from UPS Ontario, so FEF was not a viable option.

2. Alternative Demonstration Site

The Project Team considered moving the vans to an alternate UPS facility that was closer to an operational hydrogen station. CTE assessed compatible, operational hydrogen stations versus proximity to UPS facilities and presented options to the Project Team. Hydrogen stations were limited because the vehicles require H35 fuel with a TK16 dispenser. A new demonstration fueling station needed to be no more than 35 miles away from the depot to be viable. CTE plotted the results from Figure 21 and presented them to the Project Team, as shown in Figure 22. UPS did not have any additional facilities in California that utilized hydrogen. Therefore, facility modifications, including a new gas detection and safety system, would be required at any new UPS demonstration site; facilities that did not already support CNG vehicles would require extra gas detection systems. Additionally, a new site would require a new safety audit. The Ontario facility audit took five months and cost the project approximately \$11,000. Further, a new site would require re-training UPS personnel, which would cost approximately \$40,000. The fleet would need to be shipped to the new site at additional cost. The multi-month extension would create additional project management costs, upwards of \$35,000. Due to the time and additional costs, the team did not further pursue moving the project fleet. UPS and UES were supportive of moving to an alternative demonstration site, but doing so would not meet the requirements of the project sponsors, require a significant amount of additional funds, and extend the duration of the project.

San Jose/Santa Clara		1245 Hammett	1999 S 7th St	251 Sylvania	1355 Adams	5588 Cushing	22290 Hathaway	657 Forbes Blvd	8400 Pardee	4500 Norris Canyon Rd, San Ramon, CA 94583				
		UPS Sunnyvale	UPS San Jose	UPS Santa Cruz	UPS Menlo Park	UPS Fremont	UPS Hayward	UPS SF Forbes	UPS Oakland	UPS San Ramon				
337 E. Hamilton	FEF - Campbell - E. Hamilton	13.1	7.3	26.6	21.7	16.8	31.7	44.9	38.6	38.8				
1296 Sunnyvale	FEF - Sunnyvale	6.1	12.1	34.6	13.4	17.4	30.1	34.1	37.7	43.5				
West Sacramento		1380 Shore St 2275 Sierra Meadows Dr, Rocklin, CA 95677												
		UPS West Sacramento	UPS Rocklin											
1515 S Riverfront	Iwatali	2.5	26.1											
		505 Pine Ave, Goleta, CA 93117												
Santa Barbara		UPS Goleta												
150 S La Cumbre	FEF Santa Barbara	4.8												
Riverside		3480 E Jurupa 1391 Spruce 1457 E Victor 20799 Kramel 25283 Sherman Rd, Romoland, CA 92585												
		UPS Ontario	UPS Riverside	UPS San Bernardino	UPS Riverside		UPS Romoland							
8095 Lincoln	Iwatali Riverside	14.7	7.8	15	8.6	21.6								
Los Angeles/Anaheim		22 Brookline	1331 S Verno	16301 Trojan	13233 Moore	1100 Baldwin	1800 N Main	950 Blaine St	1430 N McKim	17115 S West	10690 Santa Fe	16000 Armin	12745 Arroyo	1501 Rancho
		UPS Aliso Viejo	UPS Anaheim	UPS La Mirada	UPS Cerritos	UPS Baldwin	UPS LA N Main	UPS LA Blaine	UPS LA McKim	UPS Gardena	UPS LA Santa Fe	UPS Van Nuys	UPS LA Arroyo	UPS Newbury
18480 Brookline	FEF Fountain Valley	16.9	13.6	17.7	18.7	34.6	x	x	29.8	27.1	x	x	x	x
3780 Cahuen	FEF Studio City	x	x	28.7	27.1	25.2	11.1	10	21.4	23.5	10.5	11.8	14	x
14478 Ventura	FEF Sherman Oaks	x	x	x	x	36.5	16.9	15.8	28.3	26.9	8.5	6.4	14.1	30.7
15544 San Felipe	FEF Mission Hills	x	x	x	x	x	28.8	22.5	x	x	17.7	5	4.6	36.8
** Ignoring UC Irvine station														

Figure 21: Potential Site Relocation Assessment



Figure 22: Potential Site Relocation Map

In March 2024, DOE met with Shell and secured a promise to re-open the Shell Ontario station. The Shell Ontario station was opened for refueling only for the FCHEDV project on March 20, 2024. This resolved the hydrogen fueling barriers to the demonstration. CTE-16 was successfully fueled on April 3, 2024.

Challenge #5: Permitting and Registration

To operate the vehicles, UES was granted a permit from CARB for experimental testing of the fleet. The Experimental Permit expired on April 21, 2022, and due to the delays caused by the PSR, the permit was not

immediately renewed. When the vehicles were closer to being ready to enter service, the Project Team began the renewal process. CTE-16 did not immediately re-enter service when the Shell Ontario station briefly re-opened in July 2023 as the Project Team was waiting on an updated Experimental Permit from CARB. The Experimental Permit from CARB was approved on August 16, 2023, and CTE-16 re-entered service on September 8, 2023.

In addition to the CARB Experimental Permit, each vehicle needed an active license plate and DMV registration. In summer 2023, the Project Team concluded that only four of the fifteen FCHEDVs had active plates and registration. UPS was working to register and plate the eleven unregistered vans. On September 7, 2023, UPS went to the DMV to register the remaining eleven vehicles. However, Vehicle Identification Number (VIN) verification was unsuccessful. The DMV was unable to verify the VINs on 11 of the 15 vehicles due to their scrap titles and previous registration as vehicles with diesel engines. Having this scrap title triggered an additional inspection from the California Highway Patrol (CHP).

On October 2, 2023, CARB notified CTE that they were working internally with UPS on the VIN verification issue. CARB spoke with their Excluded Vehicle Diesel Reporting (EDVR) contact, and they reported that the EDVR process would be the best solution for conducting VIN Verification for the remaining 11 vehicles. UPS completed new weight verifications for the vehicles on November 30, 2023. UPS then went to the DMV which redirected UPS to the Bureau of Automotive Repair (BAR) for registration. The BAR told UPS that they would need permission from CARB to register the vehicles. This cyclical process presented a challenge and the Project Team could not get a clear answer on how to resolve the issue. The Project Team continued to work towards registering the vehicles while the demonstration was also paused due to the lack of fuel.

In April 2024, CTE called the EDVR process hotline to assess what steps were blocking vehicle registration. At a meeting on April 3, 2024, CTE told UPS that they needed to find the certificate from the EDVR process they completed previously to go to the DMV. On April 10, 2024, UPS reported that they were in the process of re-submitting pictures for the EDVR process but had not found or received new certification packages. Ultimately, CTE-2, CTE-4, CTE-5, and CTE-16 were the only vehicles that had active plates and registrations.

Challenge #6: Preventative Maintenance

In December 2023, UES agreed to prepare the fuel cells for long term storage, due to the lack of hydrogen available at that time. This preventative maintenance procedure removes moisture out of the fuel cell stack to prevent freeze damage. However, this preventive maintenance procedure was never completed by UES, despite requests throughout January and February 2024, due to budget concerns.

Efforts to Resume Demonstration

The demonstration was put on hold in September 2023 while the Project Team worked to resolve the challenges facing the project. In March of 2024, DOE encouraged Shell to re-open the Ontario station for the demonstration. Shell agreed to open only for the demonstration but would not be open to the public.

Once it was clear fuel would become available, the team evaluated the necessary steps to restart the demonstration. There were two major barriers: vehicle repair and registration status. The issues encountered and resolutions attempted during this period are explained below.

Challenge #7: Vehicle Remediation

On March 12, 2024, UES committed to supporting vehicle repair to restart the demonstration, given they would be provided adequate funds in a timely manner. UT-CEM believed that the rehabilitated fuel cells should perform adequately for the less strenuous delivery routes, but there was concern from DOE and UT-CEM that the poor performance would hurt the project and industry more than help. Therefore, the team agreed to prioritize nine vehicles for registration and recommissioning that were most recently inspected in 2023 and were not already known to have fuel cell issues. These nine vehicles are shown in the red box in Figure 23. Of these vehicles, CTE-16 was the only van that was already plated and was most recently operated. UPS noted

several body damage issues on CTE-8 through CTE-16 including damage to rear overhead doors and turn signal switches. UPS committed to handle vehicle body repairs but noted that it would be difficult to get parts due to being an older vehicle model. The team decided to prioritize getting CTE-16 fueled and operating as soon as the Shell station was operational.

CTE No.	UPS No.	Registration Status	Fuel Cell Status	Notes
2	139131	Complete	Requires replacement	Candidate for new FC
3	139192	Incomplete	Requires rehabilitation	Candidate for new FC
4	139177	Complete	Requires rehabilitation	Ground fault issue, candidate for new FC
5	139601	Complete	Requires rehabilitation	Candidate for new FC
6	139229	Incomplete	Rehabilitated in May 2023	FC did not reach full power after rehabilitation
7	139748	Incomplete	Requires rehabilitation	Incomplete third-party inspection
8	139295	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	EDVR packets needed from UPS
9	139583	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	EDVR packets needed from UPS
10	139322	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	Outstanding collection blocking registration
11	139452	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	EDVR packets needed from UPS
12	139597	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	EDVR packets needed from UPS
13	139486	Incomplete	No issues as of 3 rd party inspection (5/23/2023)	EDVR packets needed from UPS
14	139770	Incomplete	No issues as of 3 rd party inspection (2/3/2023)	EDVR packets needed from UPS
15	139759	Incomplete	No issues as of 3 rd party inspection (5/23/2023)	EDVR packets needed from UPS
16	139408	Complete	Functional	Not operational due to lack of hydrogen



Figure 23: Vehicle Status Summary as of March 2024 with Priority Vehicles Boxed in Red

On March 20, 2024, the team learned that the Shell Ontario station was open for the project. However, the state of the vehicles was still unknown; UES said they would go to Ontario to conduct a baseline inspection but did not provide an exact date. In the meantime, UES instructed UPS to startup CTE-16 while UES was on the phone for remote support. However, UES told UPS that the remaining vehicles should not be started without prior inspection due to the possibility of damaging them. UES also agreed to develop a plan for vehicle inspection and remediation.

On April 3, 2024, UES and UPS reported that due to a miscommunication, CTE-10 had been started instead of CTE-16. Later that day, UPS and UES coordinated to startup CTE-16 and assess its state of health. UES reported that the vehicle could drive, but the fuel cell did not run. The H2 SOF was 16%. UPS began to drive CTE-16 to the Shell station for fuel, but the truck lost power. After pulling over, the UPS operator restarted the truck and was able to drive to the Shell station, as shown in Figure 24 below.



Figure 24: First Attempted Refueling at the Shell Ontario Station in April 2024

On April 9, 2024, UPS drove CTE-16 on a short route around Ontario and reported the following issues:

- The truck turned off frequently while driving (drivetrain shutdown, but brakes and steering still worked) on every driving attempt.
- The truck had a power surge or stutter in all pedal positions which caused a jerky ride.
- The drive systems took a long time to initiate, which would cause too many delays for in-service operations.

These issues had to be resolved for CTE-16 to return to delivery service. UES sent a laptop and CANBus dongle to the Ontario site for diagnosis which arrived on April 10, 2024. Due to the remediation budget, which is discussed in the following section, the issues were not diagnosed. UPS also reported that the other vehicles were able to move upon startup with battery-only power because the solar panels had kept the batteries charged.

Challenge #8: Remediation Budget

The Project Team realized that the remaining budget would not be sufficient to repair the entire fleet for package delivery service. DOE mentioned the possibility of providing some small amount of additional funding to allow the Project Team to complete the demonstration successfully. CTE developed a proposed budget and action plan to successfully complete the scope of work.

In March 2024, CTE requested an estimate from UES for the additional budget required to support the remediation of the nine prioritized vehicles and complete the demonstration. On March 21, 2024, UES provided a cost estimate of approximately \$77,000 per month, for twelve months, to support remediation and demonstration. This estimate assumed one full-time technician and three half-time engineers and managers dedicated to the project. UES had already expended approximately 70% of its demonstration budget and requested an additional million dollars to complete its scope.

Furthermore, on March 15, 2024, UPS noted that they would need another inspection of the building for gaseous hydrogen detection systems since it had been more than six months since the operation of the vehicles. This would be an additional cost that the project would have to incur.

CTE worked with partners to assess remaining funds and developed an additional funding request for DOE to help finish the demonstration. In late April 2024, CTE met with DOE to discuss the feasibility of further funding the project to finish the demonstration. Unfortunately, DOE could not provide additional funding for the project,

and the Project Team began discussing how to best close out the program. CTE, CARB, and DOE discussed how to meet the contractual requirements to close out the project without incurring further costs that exceeded the budget. The Project Team decided not to pursue further demonstration.

Data Collection and Reporting

Data collection was accomplished through a number of methods including manual logging of the H2 fueling events which included the date, time, fuel amount (kg); the onboard UES data collection system which provided vehicle data such as fuel economy (kWh/mi); and the Geotab device which is owned and monitored by UPS and provided GPS tracking information. CTE created a comprehensive online data reporting application entitled “UES FCHEDV KPI Dashboard” that allows for easy searching of events by date and vehicle(s) selected. The CTE dashboard captures all operational data including vehicle inspection testing dating back to January 21, 2021. Over the lifetime of the project, the full fleet drove a total of 3,453 miles as shown in Figure 25.

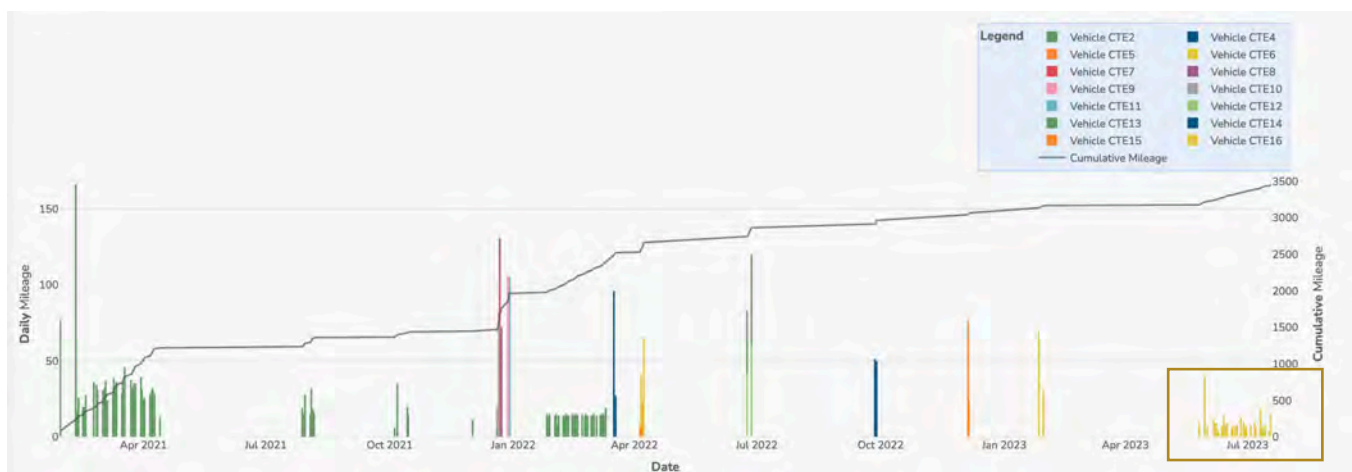


Figure 25: Daily and Cumulative Mileage of the FCHEDV Fleet over the Project Lifetime.

Vehicle Specifications

The Key Performance Specifications were developed around the existing UPS Delivery Van Fleet requirements for the State of California. The UPS routes studied included city, rural, and mixed routes. One of the key specifications was determining an adequate range to meet a significant number of the UPS routes, including what was called the “Napa” route consisting of fairly significant changes in elevation. A summary is provided in Table 5 below.

Table 5: FCHEDV Key Specifications

Key Specifications	Fuel Cell Hybrid Van
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/ 220VAC
Battery Life	1,500 Cycles / 5 Years
Motor	AC Permanent Magnet
Continuous Power	120 kW
Peak Rated Power	210 kW
Maximum Torque	900 Nm
Transmission	2 Speed Automatic Manual Transimission (AMT)
Fuel Cell	Hydrogenics HD30
Rated Power	32 kW continuous
Peak Efficiency	55%
Hydrogen Storage	Luxfer W205 (x2)
Capacity	9.78 kg
Pressure	350 bar

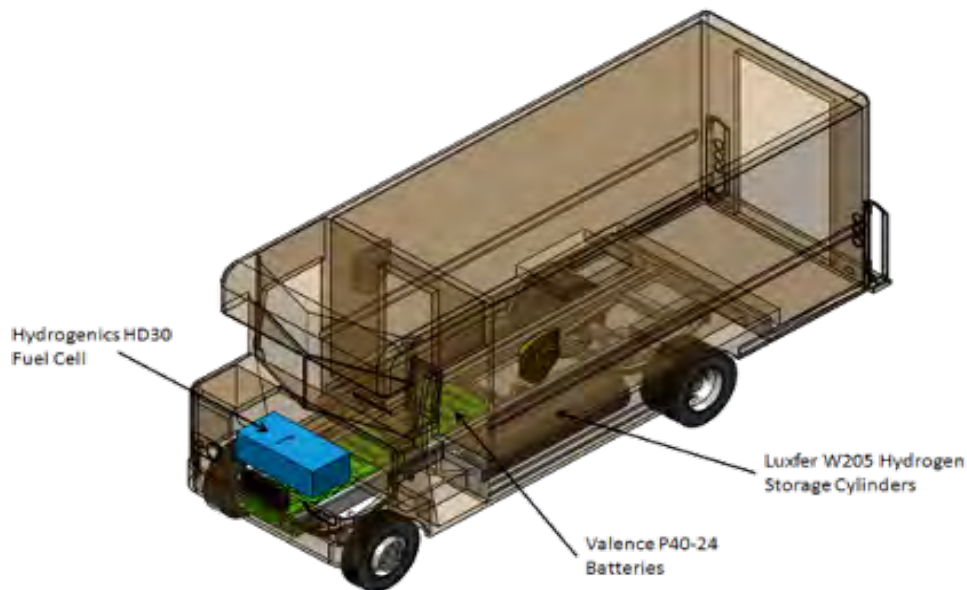


Figure 26: FCHEVDV Model

Figure 26 above shows the general layout of the FCHEVDV. Because all the components were below the chassis and under the hood, the cargo space was not impacted by the conversion.

Operation & Performance

The following data report analyzes the performance of only CTE-16 during its intended operation of package delivery service from May 26, 2023 to July 18, 2023, as shown above in Figure 25.

Description of Daily Use of Vehicles: The FCHEDV was operated by UPS in their typical daily delivery routes which included a mix of city and rural driving around Ontario, California. Below, Figure 28 and Figure 27 show some key parameters including distance driven, speed, fuel cell stack power, State of Charge (SOC), and State of Fill (SOF) over two example service days on June 22, 2023 and July 18, 2023.

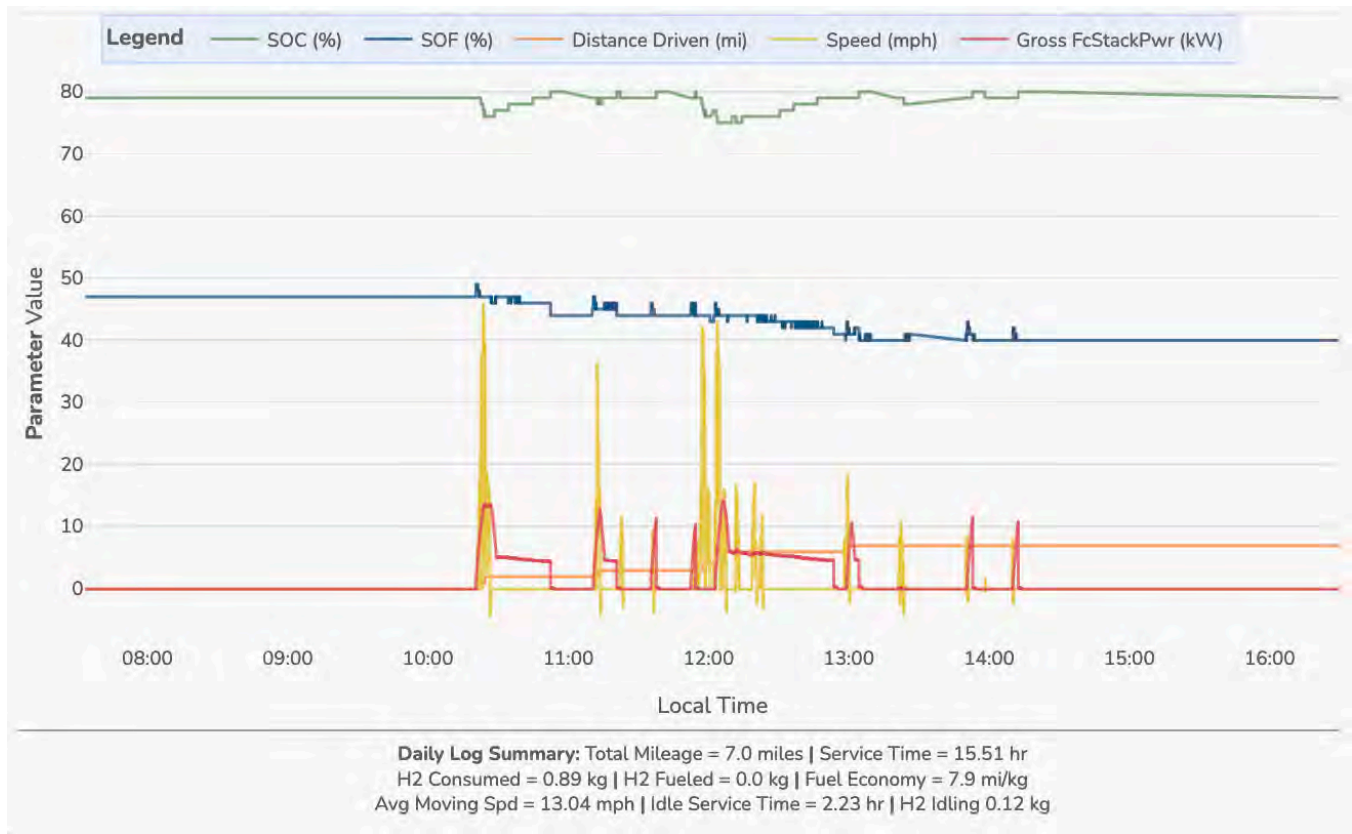


Figure 27: CTE-16 Operation on June 22, 2023

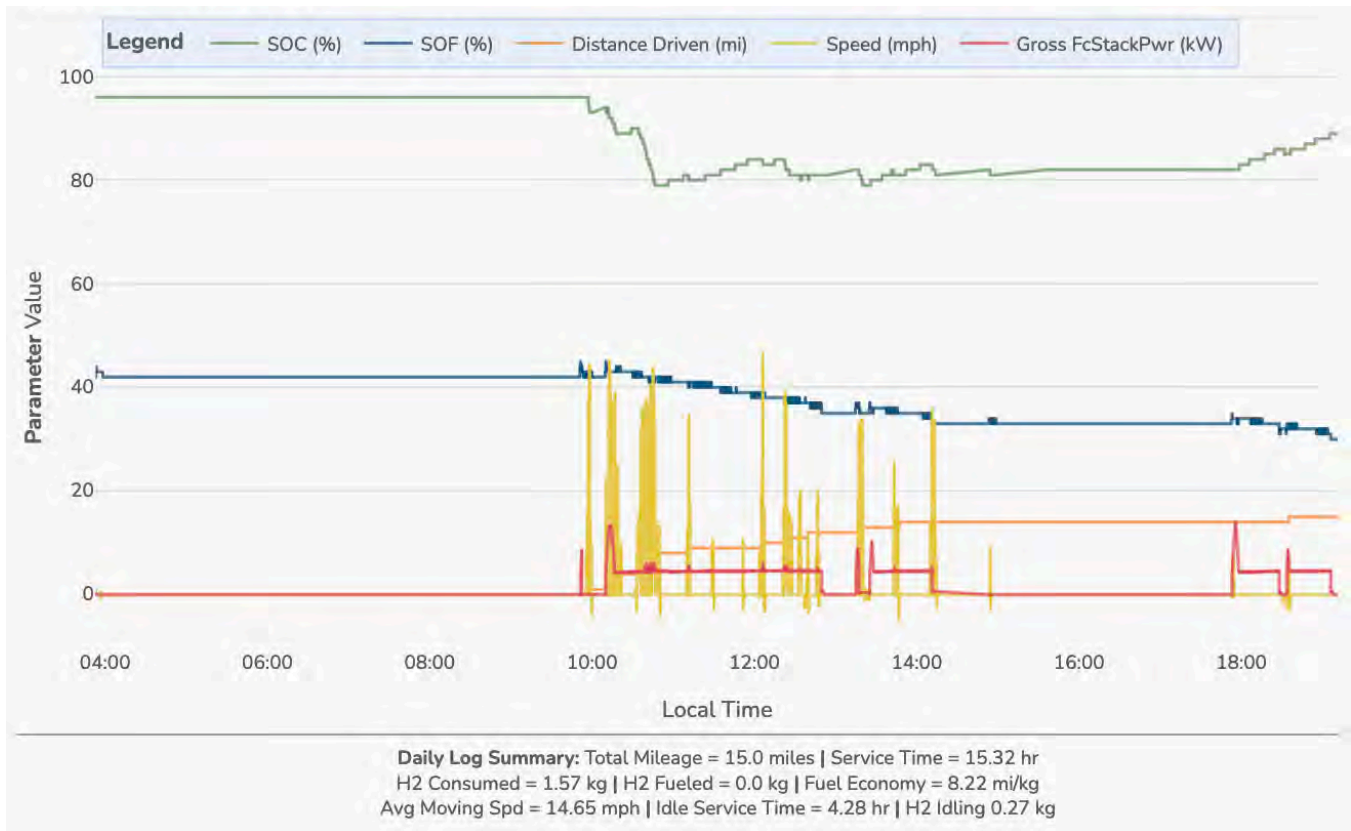


Figure 28: CTE-16 Operation on July 18, 2023

Vehicle Usage: CTE-16 was operated in delivery service for a total of 30 days over 286 miles, 38% of which was idling due to the start-and-stop nature of package delivery service. Table 6 provides key metrics.

Table 6: Summary of In-Service Vehicle Usage

		Mileage	Fuel Economy	Fuel Consumption	Idling Time Percentage	Service Time	Uptime
CTE-16	Daily Average	10 miles per day	--	1.2 kg per day	---	8.5 hours per day	--
	Total over In-Service Demonstration	286 miles	7.9 miles per kg H2	36 kg	38%	255 hours	66% of business days during demonstration

Origin and Destination: The origin and final destination of all routes for the FCHEDVs was the Ontario UPS Depot where the vehicles were domiciled. Various routes were utilized in and around the Ontario area.

Distance Traveled: The distance traveled in delivery service was between 4 and 40 miles per day. The average distance traveled was 10 miles per day.

Average Speed: The average speed during package service was 13 miles per hour, and Figure 29 shows the daily average speed.

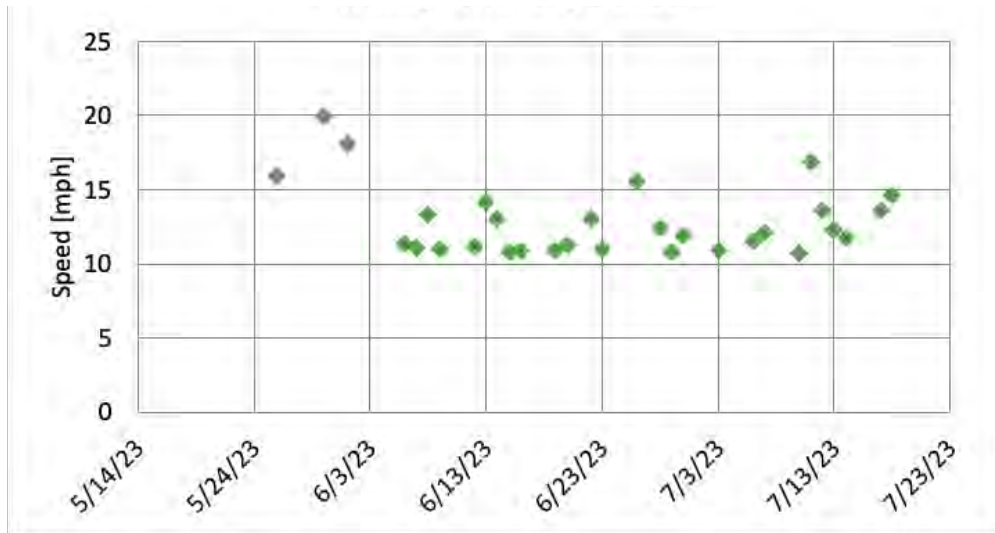


Figure 29: Daily Average Speed for CTE-16

Idling: During package delivery service, delivery vehicles drive for several hours and make frequent stops to deliver packages which results in frequent idling. The total idling time during demonstration was 79 hours, or 38% of the total service time. Daily service hours, split by idling and driving, are shown in Figure 30.



Figure 30: Daily In-Service Hours, Idling and Driving, for CTE-16

Weight of Load: The vehicles are rated for a maximum load of 7,000 pounds; specific daily package loads are not recorded by UPS.

Fuel Cell Efficiency: The daily fuel cell efficiency was measured according to the hydrogen energy input versus the fuel cell energy output. The daily average is shown in Figure 31. A majority of in-service days had a net efficiency of less than 50% and the daily average was 38% efficiency.

Vehicle Performance

Road Calls: No road calls were necessary for CTE-16 during package delivery operations.

Vehicle Availability: Out of the 45 business days between May 22 and July 23, 2023, CTE-16 operated on 30 days for an uptime of 66%. UPS did not operate the vehicles on the weekends.

Vehicle Zero-Emission Range: Using the total distance traveled by CTE-16 in delivery service and the amount of fuel consumed for the duration of the demonstration, the calculated average fuel economy is 7.9 miles per kg. By multiplying this value by 9.8 kg (the on-board hydrogen storage capacity), the predicted range of the vehicles in package delivery service is 77.4 miles (Figure 32). This is 47.5 miles less than the target range of 125 miles, though the vehicles were validated during testing to be capable of 169 miles of zero-emission range. Higher idling time, HVAC operation, and the specific duty cycles used on the demonstration routes may contribute to the lower fuel economy and estimated range.

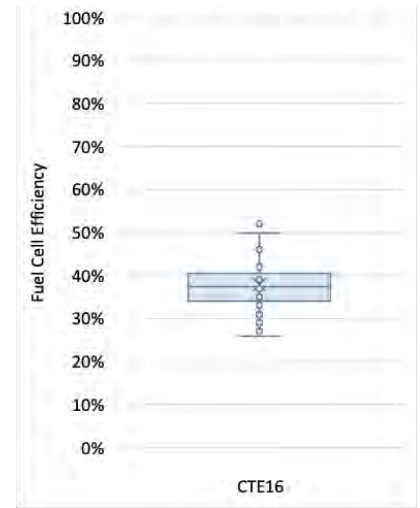


Figure 31: Daily Fuel Cell Efficiency for CTE-16

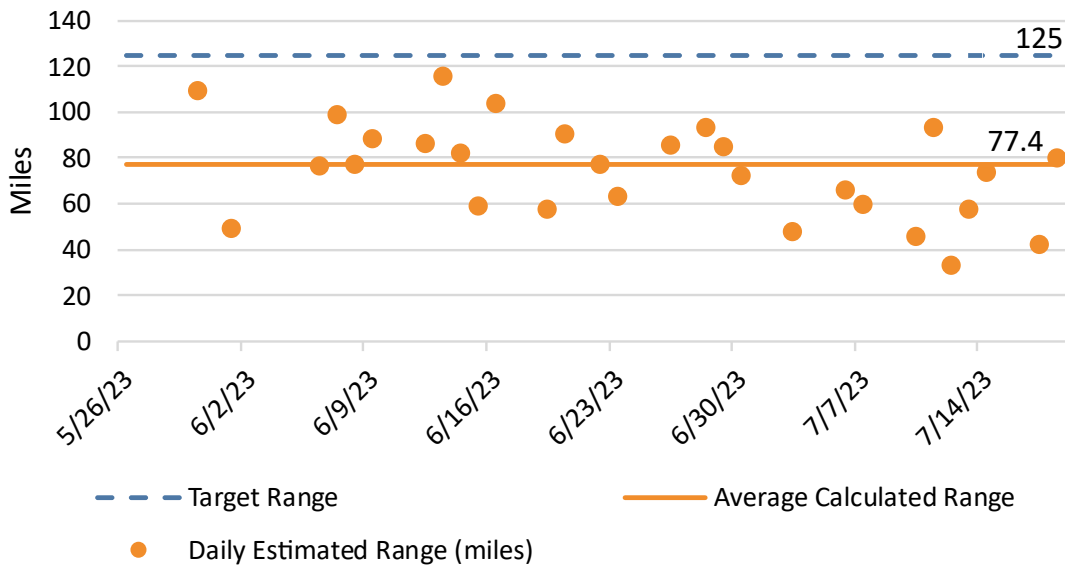


Figure 32: Estimated Zero-Emission Range in Package Delivery Service based on CTE-16 Daily Estimated Range

Fuel/Energy Consumption

Amount of Fuel, Date, and Fuel Price per Unit: The Project Team collected hydrogen fueling data from various sources. UPS provided receipts from fueling sessions at Shell. These receipts show the amount of fuel purchased, the unit price of hydrogen, and the total cost of each fueling session. However, UPS was unable to provide the Project Team with all receipts. As a result, the Hydrogen Purchased column in the table below captures only those fueling sessions where receipts were provided to the Project Team. Fueling sessions were also captured by UES data logs; however, it appears that not all fueling sessions were captured by the loggers. Thus, the combination of UPS fuel cards and UES data was used to estimate fuel purchased.

The fuel filled over the course of the demonstration for package delivery service is summarized in Table 7. In total, CTE-16 consumed 36 kg of hydrogen in package delivery service according to the UES vehicle data, but the vehicle data only includes 19 kg of fueled hydrogen. Based on the receipts provided to the Project Team, UPS purchased 41.4 kg of hydrogen and spent \$988.19 for the hydrogen fuel during the demonstration. The average

price per unit was \$23.15. Note the fuel purchased by UPS does not include all fueling sessions and some fuel may have been purchased for other vehicles and used in non-service driving.

Table 7: Fuel Purchased over the Demonstration

Date	Fuel Purchased Source: UPS Fuel Cards	Fuel Filled Source: UES Vehicle Data	Unit Price (\$/kg) Source: UPS Fuel Cards	Total Cost (\$) Source: UPS Fuel Cards
05/25/2023	1.0		\$20.34	\$20.69
05/25/2023	7.4		\$23.39	\$176.08
05/25/2023	5.1		\$23.39	\$121.36
06/01/2023	6.0		\$23.71	\$144.69
06/01/2023	5.3	5.5	\$23.76	\$128.11
06/13/2023	5.8	5.8	\$23.40	\$138.08
06/15/2023	3.3		\$23.66	\$79.42
06/27/2023	7.5		\$23.56	\$179.76
7/11/2023		7.7		
Total	41.4	19.0		\$988.19

Refueling Frequency: The FCHEDV was refueled six times during the demonstration, or approximately every five days of operation. Figure 33 shows the fueling events and amount according to the UES vehicle data and the UPS fuel cards which are not always aligned. External battery charging was not used during the demonstration, and vehicles were plugged in only for diagnostics or maintenance.

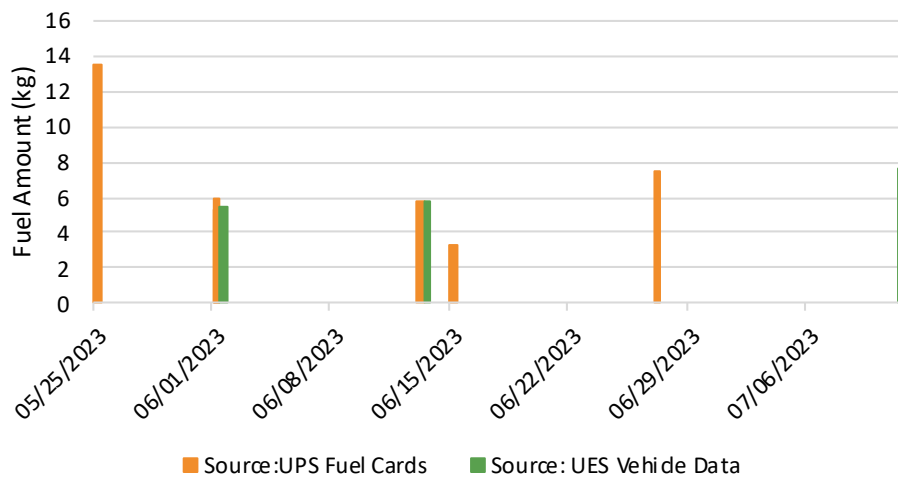


Figure 33: Fuel Filled during Demonstration for CTE-16

Fuel Consumption While Idling: The hydrogen fuel consumed while idling was 4.6 kg, or 13% of the total fuel consumed over the demonstration as shown in Figure 34. Electric vehicles do not idle because the motor does not need to consume power when the vehicle is stationary, unlike an internal combustion engine which continues to run and burn fuel while stationary. However, a fuel cell electric vehicle sometimes consumes hydrogen fuel while idling because the fuel cell charges the batteries until they reach a set SOC. During the demonstration period, 13% of the total fuel consumed was used during idling periods.

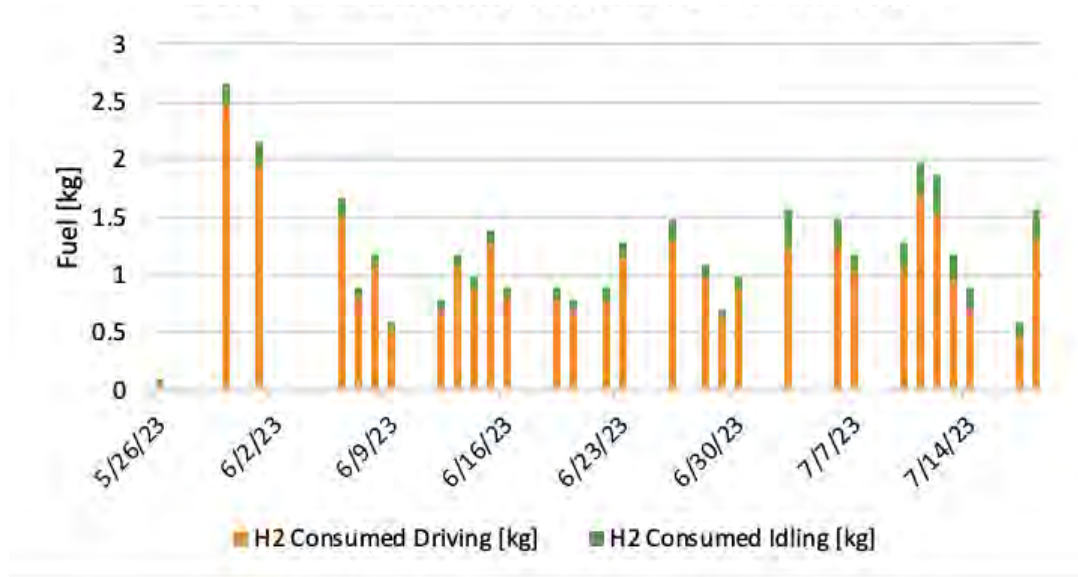


Figure 34: Daily Fuel Consumption while Idling and Driving for CTE-16

State of Charge: The battery SOC was typically maintained around 60-80% by the fuel cell during operation as shown in the example daily graphs, Figure 28: CTE-16 Operation on July 18, 2023 and Figure 27: CTE-16 Operation on June 22, 2023.

Refueling Source and Distance Traveled to Refuel: The vehicles were refueled exclusively at the Ontario Shell H2 Truck Station located at 4325 E Guasti Rd, Ontario, CA 91761. This is approximately 3.6 Miles from the UPS Ontario Facility.

Fuel Efficiency: The average fuel efficiency during package delivery service was 7.9 miles per kg (or 8.7 miles per diesel gallon equivalent), though the daily averages ranged from 3.5 to 11.8 miles per kg (Figure 35). UPS reported that the standard fuel economy for UPS package delivery vans is 9.0 miles per diesel gallon.

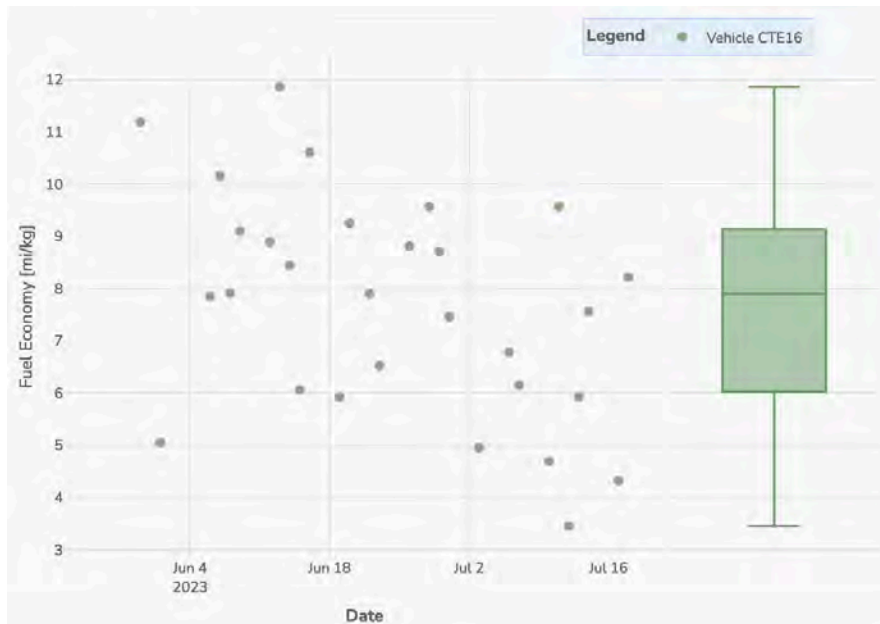


Figure 35: Fuel Economy for CTE-16

Service Calls

No service calls were reported during the testing period. Service was completed by UPS mechanics on the baseline technology systems such as the vehicle body, cabin systems such as heating and fans, and low voltage battery replacements. All advanced technology systems services were completed by UES or Accelera technicians and engineers.

Safety

Description of any Accidents or Incidents: There were no safety incidents throughout the delivery service demonstration.

Emissions Testing

CTE-16 operated for 255 hours and 286 miles over the demonstration, using 36 kg hydrogen. CTE compared the emissions of the FCHEDV to an equivalent diesel delivery van over 286 miles based on the 2023 AFLEET On Road Footprint³ tool and the emissions data from a diesel delivery van provided by UPS (see Methodology, Appendix A). Overall, the well-to-wheels (WTW) emissions for the hydrogen consumed by the FCHEDV were estimated to be 400 kg of greenhouse gasses (GHGs). While there are no tailpipe emissions from a FCHEDV, there are emissions created during hydrogen production (Table 8). In comparison, the diesel delivery van also emits 400 kg of GHGs from WTW. The lack of GHG savings is due to the constraints in the hydrogen supply chain during the demonstration, namely that the majority of hydrogen is currently produced via steam methane reformation, which caused the upstream emissions of hydrogen production to be equal to the WTW GHG emissions of the diesel van.

Table 8: Well-to-Wheels GHGs

	WTW GHGs (metric tons)
FCHEDV	0.4

³[AFLEET 2023, Argonne National Laboratory](#)

Diesel Delivery Van	0.4
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A diesel delivery van releases harmful air pollutants from the vehicle itself. However, deploying the FCHEdVs, which have no tailpipe air pollutants, prevented 310 grams of carbon monoxide (CO), 403 grams of Nitrogen Oxides (NO_x), 1 gram of particulate matter under 10 micrometers (PM₁₀), 1 gram of particulate matter under 2.5 micrometers (PM_{2.5}), 18 grams of Volatile Organic Compounds (VOCs), and 2 grams of Sulphur Oxides (SO_x) from being emitted during operation in the community. These pollutants have negative health and environmental impacts on a community (Table 9).

Table 9: Tailpipe Air Pollutants

	CO (g)	NO _x (g)	PM ₁₀ (g)	PM _{2.5} (g)	VOC (g)	SO _x (g)
FCHEdV	0	0	0	0	0	0
Diesel Delivery Van	310	403	1	1	18	2

The pollutants associated with the FCHEdVs come from the upstream production of electricity and hydrogen. While the upstream pollutant emissions of FCHEdVs are relatively higher than those of the diesel delivery van (shown in Table 10), they are still less than the tailpipe emissions of the diesel van.

Table 10: Upstream Air Pollutants

	CO (g)	NO _x (g)	PM ₁₀ (g)	PM _{2.5} (g)	VOC (g)	SO _x (g)
FCHEdV	189	227	15	11	63	86
Diesel Delivery Van	51	78	6	5	31	21

Please see the Emissions Calculations Methodology in Appendix A for details of calculations.

Operating and Maintenance Costs

Maintenance Costs: UPS provided labor and parts expenses for the full fleet over FY 2022 and FY 2023 as shown in Table 11. Labor expenses are calculated at a rate of \$125 per hour. The UPS maintenance costs were relatively low because UES and Cummins provided most maintenance and support. The total costs for UPS maintenance and labor over the course of the program were \$160,974 or an average of \$10,731 per truck.

Table 11: UPS Maintenance Costs

Unit #	Vehicle #	FY 2023	FY 2023	FY 2023	FY 2022	FY 2022	FY 2022
		Labor Hours	Labor Exp @ \$125	Parts, Tires, OSS Exp	Labor Hours	Labor Exp @ \$125	Parts, Tires, OSS Exp
139131	CTE 2 (139131)	17.96	\$ 2,245	\$ 1,133	15.46	\$ 1,932.50	\$ 65
139192	CTE 3 (139192)	14.57	\$ 1,821	\$ 21	1	\$ 125.00	\$ 2,201
139229	CTE 6 (139229)	27.66	\$ 3,458	\$ 5,365	1.5	\$ 187.50	\$ 2,201
139295	CTE 8 (139295)	18.96	\$ 2,370	\$ 824	112.68	\$ 14,085.00	\$ 1,076
139322	CTE 10 (139322)	15.11	\$ 1,889	\$ 938	52.32	\$ 6,540.00	\$ 101
139408	CTE 16 (139408)	23	\$ 2,875	\$ 1,089	0	\$ -	\$ 119
139452	CTE 11 (139452)	20.51	\$ 2,564	\$ 937	41.55	\$ 5,193.75	\$ 56
139486	CTE 13 (139486)	146.19	\$ 18,274	\$ 1,088	7.08	\$ 885.00	\$ 2,209
139583	CTE 9 (139583)	9.83	\$ 1,229	\$ 786	67.36	\$ 8,420.00	\$ 111
139597	CTE 12 (139597)	18.74	\$ 2,343	\$ 60	68.61	\$ 8,576.25	\$ 2,400
139601	CTE 5 (139601)	18.69	\$ 2,336	\$ -	24.91	\$ 3,113.75	\$ 2,471
139748	CTE 7 (139748)	19.23	\$ 2,404	\$ 1,526	79.24	\$ 9,905.00	\$ 226
139759	CTE 15 (139759)	87.73	\$ 10,966	\$ 1,365	0.92	\$ 115.00	\$ -
139770	CTE 14 (139770)	80.54	\$ 10,068	\$ 2,065	3.71	\$ 463.75	\$ -
139777	CTE 4 (139777)	9.32	\$ 1,165	\$ 2,390	2.49	\$ 311.25	\$ 2,293
		528.04	\$ 66,005	\$ 19,587	478.83	\$ 59,854	\$ 15,528

Costs for Facility Safety Systems Related to Hydrogen and Fuel Cells: Due to the robust CNG buildout at the Ontario maintenance facility, the upgrades required to prepare the facility for the FCHEDVs were minimal. In August 2021, WPO completed a facility safety audit to ensure that the maintenance bays were compliant with hydrogen safety codes and regulations. WPO concluded that the UPS parking garages do not require any special safety equipment beyond what is required for traditional fuels. No changes were recommended for the package loading areas. However, WPO recommended installing hydrogen gas detection sensors in repair garages and following defueling requirements for any work on high voltage or hydrogen systems. UPS installed hydrogen gas detection sensors in the Ontario facility in as described in Task 2.

Conclusion

Broader Acceptance of Technology

Understanding the perspectives of both drivers and fleet operators is crucial for evaluating the effectiveness and practicality of the FCHEDVs. Feedback from vehicle operators highlighted issues such as long start times. On the other hand, UPS, one of the key participants in the demonstration, chose not to continue using the trucks post-demonstration due to high operational costs, fueling challenges, and reliability concerns. These insights highlight significant areas for improvement as the market for hydrogen-powered vehicles evolves. Additionally, the broader market perspective underscores the ongoing challenges in scaling hydrogen infrastructure and the potential impact of new initiatives in the future. The following sections delve into these perspectives in more detail.

Driver Perspectives: Drivers generally found the hydrogen fueling to be a positive experience and faster than CNG fueling. The drivers felt that driving the vehicles was smooth, based on feedback from training sessions; however, the lack of advanced technology in the cabin due to the retrofit of old scrap chassis did not improve the driver experience.

Fleet Operator Perspective: UPS chose not to continue operating the trucks after the demonstration period ended due to the high cost of ownership in comparison to their baseline diesel vehicles. The cost of fuel

averaged \$29.99/kg of hydrogen over the demonstration which made driving the trucks a larger operating expense in comparison to diesel at \$5.35/gal throughout the demonstration.⁴ Additionally, the uncertainty of hydrogen fuel availability made the operations challenging and unreliable. Finally, the compounded vehicle maintenance issues, including fuel cell degradation and general vehicle body damage on the older vehicles lowered UPS' confidence in the retrofit vehicles.

Broader Market Perspective: The hydrogen and fuel cell vehicle markets are developing rapidly. The design of the retrofit FCHEDVs in this project has already become obsolete due to fueling system technology updates: the industry is trending towards 700 bar, rather than 350 bar, fueling. Due to the protocols and equipment at stations, pressure compatibility already proved to be an issue when looking for alternate fueling stations for the demonstration.

Hydrogen has become more accepted and available since the inception of this project six years ago in 2019; however, as the 2023 CARB Annual Evaluation of Hydrogen Fuel Station Network Development shows, there are challenges in rapidly scaling up hydrogen stations, and the number of stations is not growing as quickly as previously projected.⁵ Shell exited the light-duty hydrogen fueling station market in February 2024; however, they were committed to MD/HD hydrogen vehicles. As a show of their commitment, Shell resumed operations at the Ontario station one month after pulling out of the light duty market. There is still a gap to close in the market for broad hydrogen adoption.

Community Impact

The City of Ontario, as well as the greater region within the South Coast Air Basin, has some of the worst air quality in the nation due to high PM2.5 and ozone levels, causing public health problems such as asthma, respiratory and cardiac diseases, and cancer.⁶ Additionally, the area has high freight traffic volume and transportation noise levels due to I-10 and the Ontario airport.^{7,8} Approximately 50% of emissions in the region are due to on-road transportation, which has a disproportionate impact on low-income and disadvantaged communities (LIDAC). Zero-emissions goods movement alleviates public health concerns like diesel pollutants and traffic noise in these communities. The community has prioritized solving these problems via the regional Priority Climate Action Plan published in March 2024 by the Riverside-San Bernardino-Ontario metropolitan statistical area.⁹ One of the three region-wide priority measures is “Goods Movement Decarbonization,” which was selected based on community stakeholder support, magnitude of impact, feasibility, and potential for co-benefits. This measure states that the adoption of zero-emission goods movement fueled by electric or hydrogen fuel cell technology would be “transformative” for the region, specifically in medium-duty and heavy-duty vehicles. The FCHEDV project fit into the community’s vision by providing a demonstration of goods delivery via a zero-emission medium-duty fuel cell delivery van fleet, contributing to the transformation of the goods-movement industry in the region.

A major success of the FCHEDV project was the zero-emission workforce development at the UPS Ontario site. The Project Team conducted several trainings and ultimately 30 UPS employees were trained in driving, fueling, and maintaining the vans, resulting in a commitment of more than 150 employee training hours. Experience with next-generation zero-emissions technology is a valuable skill, and the UPS mechanics who were closely supporting UES and Accelera had many hands-on learning opportunities with the technology.

⁴ [Energy Information Administration, Retail Diesel Prices in California](#)

⁵ [2023 CARB Annual Evaluation of Fuel Cell Electric Vehicle Deployment](#)

⁶ [Climate and Economic Justice Screening Tool](#)

⁷ [Freight Flows by Highway, Railway, and Waterway, Bureau of Transportation Statistics, 2018](#)

⁸ [National Transportation Noise Map, Bureau of Transportation Statistics, 2018](#)

⁹ [Riverside-San Bernardino-Ontario Priority Climate Action Plan \(2024\)](#)

As shown in Figure 36, the UPS facility in Ontario is in an area with a CalEnviroScreen4.0 score of 65 and a pollution burden in the 88th percentile. Areas with higher scores have greater environmental justice needs. The black circle indicates the location of the UPS customer center at 4280 Jurupa St, Ontario. The tailpipe emissions reductions of the FCHEDVs versus traditional diesel-powered delivery vans and training for UPS personnel provided a benefit to the disadvantaged communities around the UPS facility.

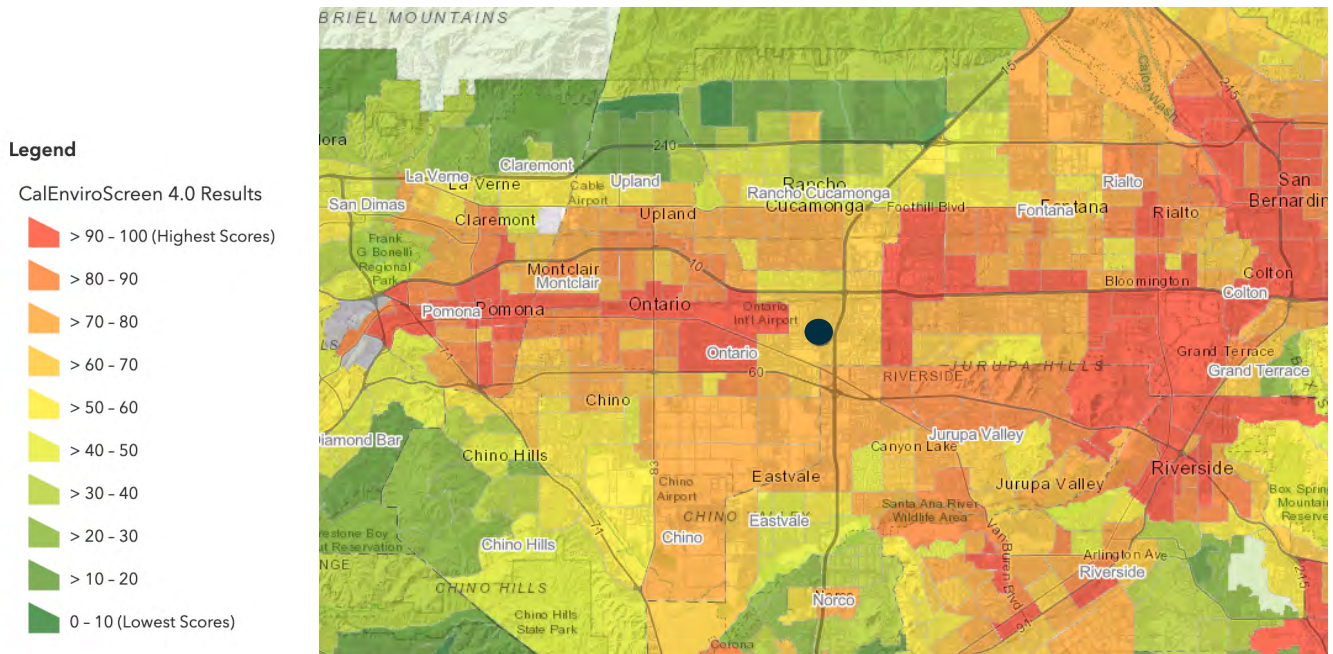


Figure 36: DAC Zones in Ontario According to CalEnviroScreen4.0¹⁰

Lessons Learned, Commercialization Challenges, and Recommendations

To ensure the successful adoption and implementation of FCHEDVs, several barriers must be overcome. The public perception of hydrogen safety remains a significant challenge, necessitating comprehensive education and safety training for end-users. Additionally, the current reliance on public hydrogen fueling stations led to operational delays and high costs, highlighting the need for more mature and reliable fueling infrastructure. Furthermore, demonstrating the scalability of hydrogen technology is crucial for its adoption by large commercial fleet operators. Moreover, retrofitting older vehicles that had been previously scrapped led to unexpected problems with registration and less desirable driving experiences that may prevent widespread commercialization of retrofits. The following recommendations summarize the barriers and potential solutions the industry must tackle to introduce class-6 retrofitted fuel cell delivery vans to the market:

Recommendation 1: Hydrogen Safety Education

There are continual challenges with the public perception of hydrogen. For mass adoption of FCHEDVs, there must be a comprehensive structure in place to educate end-users about hydrogen. Though the Project Team engaged extensively in safety planning throughout the lifetime of the project, hydrogen safety and training should be a larger focus of funded projects.

UPS's insurer encouraged safety training and the development of hydrogen safety documentation, which became the Project Team's focus for an entire year, leading to significant project delays. Ultimately, the FCHEDV project succeeded in developing a comprehensive set of documents that can be leveraged for the development

¹⁰ [CalEnviroScreen 4.0 Results](#)

of future FCHEDV demonstrations. However, the additional hydrogen safety education work that took place during the one-year delay was not included in the project plan at the onset of the project.

To overcome this barrier and mitigate delays on future projects, technology development and demonstration projects must incorporate a greater emphasis on community engagement and hydrogen safety education into their scope of work. Elements from the project's Safety Plan, such as the training sign-off sheets, fueling cards, and training agenda, should be used as a blueprint for training material and safety planning for future commercial fleet operators of FCEVs.

Recommendation 2: Reliance on Public Fueling Stations

Initially, the Project Team felt that an advantage for this FCHEDV project, and for the medium-duty market in general, was taking advantage of public fueling infrastructure. Mobile fueling infrastructure adds cost, time, and risk that can be justifiable for a temporary demonstration but detracts from the cost-reduction goals afforded by mass deployment. If an end-user does not invest in on-site fueling infrastructure, they are dependent upon public hydrogen fueling stations for their fueling needs; however, some public stations currently limit the fill pressure and amount of hydrogen available, which can be inconvenient for a medium-duty fuel cell vehicle operator trying to maximize zero-emission range.

Sourcing hydrogen fuel from a public fueling station was one of the barriers, among others, that prevented the vehicles from operating on a daily basis. Regular preventative maintenance for fuel cells requires the operator to run the full cell weekly; with longer delays in fuel availability and general operation, the fuel cells required more extensive maintenance to rehabilitate and reach full power.

Public hydrogen fueling infrastructure in California has not reached sufficient maturity to support regular delivery van operations. Demonstration projects need to plan for redundancy in fueling options, such as coordinating with multiple fuel providers. For a fully commercialized and large-scale fleet, private, on-site ("behind-the-fence") infrastructure will provide greater fueling reliability. Continued investments by state and federal agencies will improve the reliability of hydrogen supply, distribution, and public fueling in the coming years.

Another barrier to market adoption and vehicle technology expansion is the high cost of hydrogen fuel. As for-profit transportation companies, many medium- and heavy-duty truck operators are sensitive to fuel costs and will select technologies that allow their businesses to operate at the highest profit margin. A primary method of mitigating this risk is to encourage rapid and widespread deployment of hydrogen-fueled vehicles through various vehicle deployment programs and relationships with hydrogen fuel providers (such as Iwatani, Shell, and Air Products). Increasing the volume of hydrogen consumption will help decrease fueling infrastructure and hydrogen production costs, with the goal of providing an economical alternative to diesel. The economics from the demonstration concluded that this particular FCEV technology is not currently competitive with the incumbent technologies due to the high cost, the unpredictable availability, and the limited supply of hydrogen fuel at public fueling stations in 2024. However, it is expected that the economics will improve in the future with the introduction of the DOE Hydrogen Hubs.

Recommendation 3: Demonstrating at Scale

Large commercial fleet operators must have evidence of the scalability of a technology before incorporating it into their operations. To move Class 6 FCHEDVs forward in the market, investing in large-scale demonstrations is essential. The challenges of scaling battery electric charging infrastructure (e.g., the physical space and power needs for a large fleet of chargers) are becoming more apparent, but there is growing interest in scaling hydrogen infrastructure, which is able to support a larger fleet by increasing the capacity of the station with a relatively small additional area and equipment upgrades. Pilot and small scale demonstrations of zero-emission vehicles have become much more common across the freight movement industry during the ten years of the FCHEDV project. Demonstrating a large fleet of fuel cell vehicles would provide evidence of scalability and confidence to commercial fleet operators, proving that a full transition to a fleet of hydrogen vehicles is possible.

Recommendation 4: New vs. Retrofit Vehicles

An outcome of the demonstration for the operator was an overall preference for new FCHEDVs rather than retrofit vans. While both new and retrofit FCHEDVs provide zero-emission operation with advanced technology, the driver experience with a retrofit van is diminished due to the pre-existing wear on the chassis and lack of advanced features in the cabin. Additionally, the maintenance needs for an older chassis become prohibitively expensive as well as the increasing difficulty of finding replacement parts. Finally, the project experienced significant challenges with DMV to register the retrofit vehicles due their scrap titles and the change of powertrain. For further consideration of retrofit vehicles, a mechanism for easily registering repowered vehicles is needed. For these reasons, the Project Team recommends prioritizing new designs of FCHEDVs over retrofits for future demonstrations and commercialization.

Recommendation 5: Preventative Maintenance for Storage

The demonstration highlighted the necessity of vehicle storage preparation and preventative maintenance on fuel cell and hydrogen systems when the prolonged demonstration delays led to weak fuel cells on many of the FCHEDVs. The team created fuel cell rehabilitation plans that could be utilized but ultimately recommends prevention over rehabilitation to save time and effort. The team recommends defining fuel cell storage protocols and acting on proper storage procedures for any period of vehicle inoperability for fleet operators, just as combustion engines are prepared for storage.

Summary

This project demonstrated the build of 15 FCHEDVs using scrapped UPS chassis, Accelera HD30 fuel cells, and Valence Technology battery systems. This project built on information obtained during the prior initial Phase 1 project which built one fuel cell delivery van. Despite cascading challenges from safety planning and hydrogen availability, the team delivered 15 vans to UPS for demonstration in Ontario, California. Overcoming hurdles with hydrogen availability in the region and ongoing maintenance challenges, CTE-16 was demonstrated in package delivery service for a total of 255 hours and a total of 286 miles. The vehicle demonstrated an average fuel economy of 7.9 miles per kilogram and an estimated range of 78 miles in package delivery service. This range meets the needs of some UPS delivery routes. However, UPS will not continue to operate the vans due to the high cost of hydrogen at public fueling stations and the dynamic state of the hydrogen availability.

There is no immediate plan for the commercialization of a fuel cell delivery van by the project partners, but the project provided important lessons including the need for resilient fuel supplies, committed operating partners, and thorough safety planning and education.

Disclosures

Technology Showcases

1. The Project Team created and submitted posters for the CARB LCT Symposiums in 2019 and 2020. The 2020 Symposium was canceled due to COVID-19.
2. The Project Team presented at the August 2022 H2IQ webinar hosted by DOE.
3. The Project Team presented to the 21st Century Truck Partnership in October 2021.
4. The project presented at DOE Annual Merit Reviews from 2019-2024.

Publications

During the Phase 2 project in 2020, the team published *Model Validation and Demonstration of a Hydrogen Fuel Cell Parcel Delivery Truck* ([OSTI link](#)).

Appendix

Appendix A: Emissions Estimate Methodology

1. Estimate emissions from FCHEDV during demonstration, well-to-wheels (WTW)
 - I. Summed total mileage, idling hours, and hydrogen consumed.
 - II. Input the demonstration location (San Bernardino County, CA).
 - III. Assumed hydrogen is produced offsite through steam methane reformation (SMR). In California, 33% of hydrogen is required to be from renewable sources, defined as SMR with renewable natural gas, biomethane, or wastewater treatment gas, or via electrolysis with renewable electricity; however, compliance by most companies in California is generally achieved with out-of-state renewable energy credits.¹¹ The AFLEET model options for hydrogen production include Offsite SMR, Onsite SMR, and onsite electrolysis. None of these options account for potential renewable methane sources, which would still include emissions from the SMR process. Additionally, even if the 33% of renewable hydrogen came from off-site electrolysis, the onsite electrolysis modeled option would not include the emissions from transporting the hydrogen to the terminal. Thus, to be conservative, offsite SMR with no renewable components was modeled for the purposes of the AFLEET tool in order to calculate upstream emissions.
 - IV. Used AFLEET 2023 On Road Footprint to estimate WTW greenhouse gasses (GHGs) and criteria pollutants.
1. Estimate emissions from equivalent diesel delivery van, well-to-wheels
 - I. Estimated GHG tailpipe emissions (pollutants and GHGs) and diesel consumption based on UPS emissions data for a diesel delivery van (model year 2019). UPS provided a rate of 9.0 diesel mpg for standard operation. This is more appropriate than using AFLEET because it is specific to the operations of a UPS van.
 - II. The AFLEET Tailpipe Air Pollutants are calculated based on vehicle model year, not the fuel consumed, so the criteria pollutant emissions are not specific to a UPS van.
 - III. The upstream emissions of the diesel production and the total WTW Petroleum Use were estimated with AFLEET 2023.

Appendix B: Data Report (attached to pdf)

¹¹ [Assembly Committee on Natural Resources, 2023](#)