Thirty-Six Month Evaluation of UPS Diesel Hybrid-Electric Delivery Vans

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Technical Report
NREL/TP-5400-53503
March 2012

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NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. VTP2.3001

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List of Acronyms and Abbreviations

AVTA	Advanced Vehicle Testing Activity
DOE	U.S. Department of Energy
FT&E	Fleet Test and Evaluation (NREL team)
GPS	global positioning system
mpg	miles per gallon
mph	miles per hour
MY	model year
NREL	National Renewable Energy Laboratory
PEC	power electronics carrier
UPS	United Parcel Service
VDC	voltage direct current

Executive Summary

This 36-month follow-up evaluation is part of a series of evaluations by the U.S. Department of Energy (DOE). Using an established and documented evaluation protocol, DOE—through the National Renewable Energy Laboratory (NREL)—has been tracking and evaluating new propulsion systems in transit buses and trucks for more than 10 years. The DOE/NREL vehicle evaluations are a part of the Advanced Vehicle Testing Activity (AVTA), which supports DOE's Vehicle Technologies Program.

The role of AVTA is to bridge the gap between research and development and the commercial availability of advanced vehicle technologies that reduce petroleum use in the United States and improve air quality. The main objective of AVTA projects is to provide comprehensive, unbiased evaluations of advanced vehicle technologies in commercial use. Data are collected and analyzed for operation, maintenance, performance, costs, and emissions characteristics of both advanced-technology fleets and comparable conventional-technology fleets that are operating at the same site. AVTA evaluations enable fleet owners and operators to make informed vehicle-purchasing decisions.

This report focuses on a parallel hybrid-electric diesel delivery van propulsion system currently being operated by United Parcel Service (UPS). The hybrid propulsion system is an alternative to the standard diesel system and allows for increased fuel economy, which ultimately reduces petroleum use.

Evaluation Design

This 36-month evaluation used six P70H hybrids and six P70D standard diesels that are located in two UPS facilities in the Phoenix, Arizona, area. Dispatch and maintenance practices are the same at both facilities. Global Positioning System logging, fueling, and maintenance records are used to evaluate the performance of these hybrid step delivery vans. This report is an update to the 12-month evaluation[1] .

Evaluation Results

The results and related discussions included here focus only on the selected facilities and the two P70 study groups.

Delivery Van Use and Duty Cycle

The hybrids had an average monthly mileage rate that was 18% less than that of the diesel vans. Miles per operational day were 16% lower for the hybrids than they were for the diesels, but this difference was not statistically significant. The hybrids were consistently driven a fewer number of miles throughout the evaluation period, but they also experienced extended downtime late in the first year as a result of an accident and Eaton calibration issues. The hybrids spent more time idling and operating at slower speeds than the diesels did, and the diesels spent slightly more time operating at greater speeds; this accounted for much of the hybrids' fewer monthly miles.

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[1] M. Lammert. 2009. "Twelve-Month Evaluation of UPS Diesel Hybrid Electric Delivery Vans." http://www.nrel.gov/docs/fy10osti/44134.pdf

Fuel Economy

The 36-month average fuel economy for the hybrid vans is 13.0 mpg, 23% greater than the diesel van group's 10.6 mpg. This is less than the nearly 29% reported after the first year and 31% to 37% shown during laboratory fuel economy testing. The diesels seemed to slightly improve their fuel economy over time while the hybrids did not. Figure ES-1 shows the average monthly miles per gallon for each van group and the cumulative average miles per gallon.

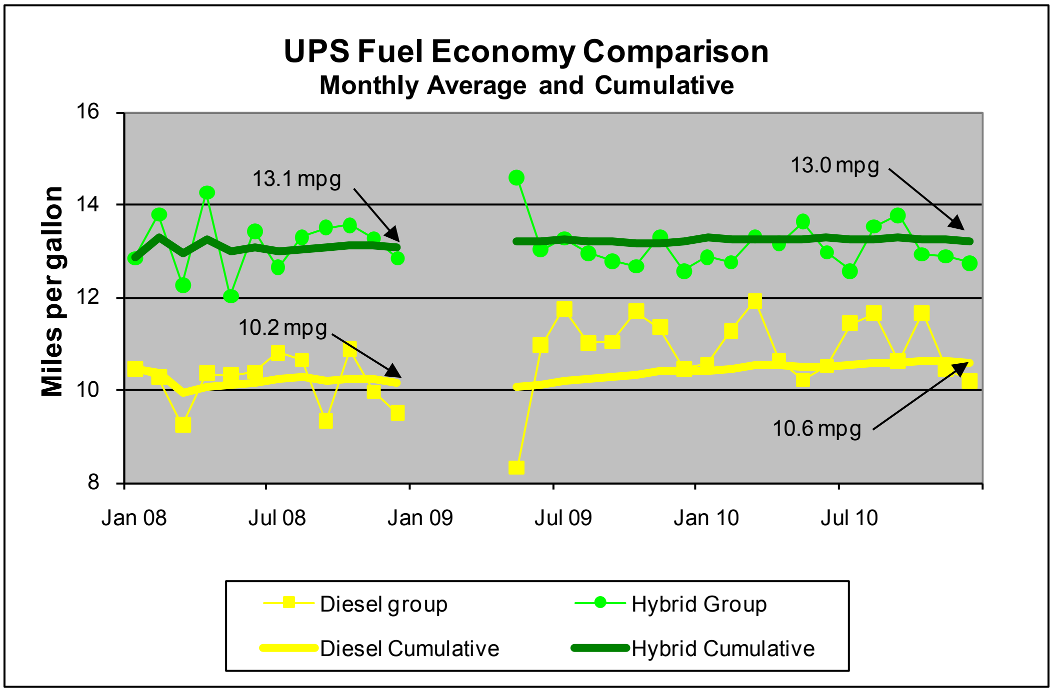

Figure ES-1. Average monthly and cumulative fuel economy

Maintenance Costs

The total maintenance cost per mile of $0.141 for the hybrid vans was 9% more than the $0.130 for the diesel vans. The propulsion-related maintenance cost per mile of $0.037 for the hybrid vans was 25% more than the $0.029 for the diesel vans. Using a t-test, researchers found neither difference to be statistically significant.

Fuel Costs

Fuel costs per mile for the hybrids were 19% less than those for the diesels and were found to be statistically significant (assuming $3.09/gal) (P value = 0.0048).

Operating Costs

Total operating costs per mile for the hybrids were 10% less than those for the diesels but were not found to be statistically significant (assuming $3.09/gal).

Reliability

The hybrid group had a cumulative average of 96.3% uptime over the 36-month study period, less than the diesel group's cumulative average of 99.0% uptime. The hybrids experienced troubleshooting and recalibration issues related to prototype components, which were primarily responsible for the lower uptime figures.

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Overview

Advanced Vehicle Testing Activity

The role of the Advanced Vehicle Testing Activity (AVTA) is to help bridge the gap between research and development and commercial availability for advanced vehicle technologies that reduce petroleum use and meet air-quality standards. AVTA supports the U.S. Department of Energy's (DOE's) Vehicle Technologies Program by examining market factors and customer requirements and evaluating the performance and durability of alternative-fuel and advanced-technology vehicles in fleet applications. The National Renewable Energy Laboratory's (NREL's) Fleet Test and Evaluation (FT&E) team conducts evaluations primarily with support from AVTA, but has also been supported by other DOE programs focused on non-petroleum-based and advanced petroleum-based fuels.

The main objective of FT&E projects is to conduct comprehensive, unbiased evaluations of advanced-technology vehicles. Data collected and analyzed include the operations, maintenance, performance, cost, and emissions characteristics of advanced-technology vehicles and comparable conventional technology in fleets operating at the same site. The FT&E evaluations help fleet owners and operators make informed vehicle-purchasing decisions. The evaluations also provide valuable data to DOE about the maturity of the technology being assessed.

The FT&E team has conducted several evaluations of advanced-propulsion heavy-duty vehicles (see Table 1). Information on these and other evaluations involving advanced technologies or alternative fuels, such as biodiesel and Fischer-Tropsch diesel, is available at www.nrel.gov/vehiclesandfuels/fleettest.

Table 1. FT&E Heavy-Duty Vehicle Evaluations

Fleet	Location	Vehicle	Technology	Evaluation Status
FedEx	Los Angeles, CA	Ford E-450 strip chassis	Gasoline hybrid electric parcel delivery trucks, Azure Dynamics	Completed in January 2011
UPS	Phoenix, AZ	P70 Delivery Van	Parallel hybrid, Eaton system	Completed in December 2009
Long Beach Transit	Long Beach, CA	New Flyer 40-ft low floor transit bus	Gasoline-electric series hybrid	Completed in June 2008
Metro	St. Louis, MO	Gillig 40-ft transit bus	Biodiesel blend (B20)	Completed in July 2008
New York City Transit	Manhattan, NY; Bronx, NY	Orion VII 40-ft transit bus	Series hybrid, BAE Systems HybriDrive propulsion system (diesel), order of 200 (Gen II); order of 125 (Gen I)	Completed in January 2008
New York City Transit	Manhattan, NY; Bronx, NY	Orion VII 40-ft transit bus	Series hybrid, BAE Systems HybriDrive propulsion system (diesel), order of 125; DDC S50G compressed natural gas engines	Completed in November 2006
Denver RTD	Boulder, CO	Gillig 40-ft transit bus	Biodiesel blend (B20)	Completed in October 2006
King County Metro	Seattle, WA	New Flyer 60-ft articulated transit bus	Parallel hybrid, GM–Allison EP 50 System (diesel)	Completed in December 2006
IndyGo	Indianapolis, IN	Ebus 22-ft bus	Series hybrid, Capstone MicroTurbine (diesel)	Completed in 2005
Knoxville Area Transit	Knoxville, TN	Ebus 22-ft bus	Series hybrid, Capstone MicroTurbine (propane)	Completed in 2005

Project Design and Data Collection

This report discusses a 36-month in-use evaluation of six model year (MY) 2007 Freightliner P70H hybrids that were placed in service in Phoenix, Arizona, during the second half of 2007. These hybrid vehicles are evaluated against six MY 2006 Freightliner P70D diesels that were placed in service in Estrella, Arizona, during the first months of 2007. The diesel vans were chosen by using United Parcel Service's (UPS's) database and comparing the average miles per day of the six hybrids to that of diesel vans that had the same size and cargo capability and that were located at the two facilities. All fueling and maintenance data were collected by UPS from its databases and were shared with NREL for this evaluation.

This report is an update to and continuation of the original 12-month in-use evaluation, which included laboratory dynamometer vehicle testing, published in December 2009 and available at http://www.nrel.gov/vehiclesandfuels/fleettest/pdfs/44134.pdf.

At the time the decision was made to update the original 12-month study, the first 4 months of mileage and fueling data from 2009 had been erased from UPS's database. Maintenance records for the period were still complete. Therefore, only 32 months of fuel economy data are presented while the full 36 months of maintenance data are presented.

Figure 1. UPS hybrid van[2]

Table 2 presents additional details on Eaton Corporation's parallel hybrid system, and Figure 2 provides a schematic of the system.

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[2] This image is reproduced with permission of United Parcel Service of America, Inc. © 2011 United Parcel Service of America, Inc. All rights reserved. Photo from UPS, NREL/PIX 19821.

Table 2. Hybrid Propulsion-Related Systems

Category	**Hybrid Van Description**
Manufacturer/integrator	Eaton Corporation
Transmission	Fuller medium-duty automated manual 6-speed Prototype
Motor	Synchronous brushless, permanent magnet Continuous power, 26 kW Peak power, 44 kW
Energy storage	Lithium ion batteries 340 VDC 1.8 kWh total storage

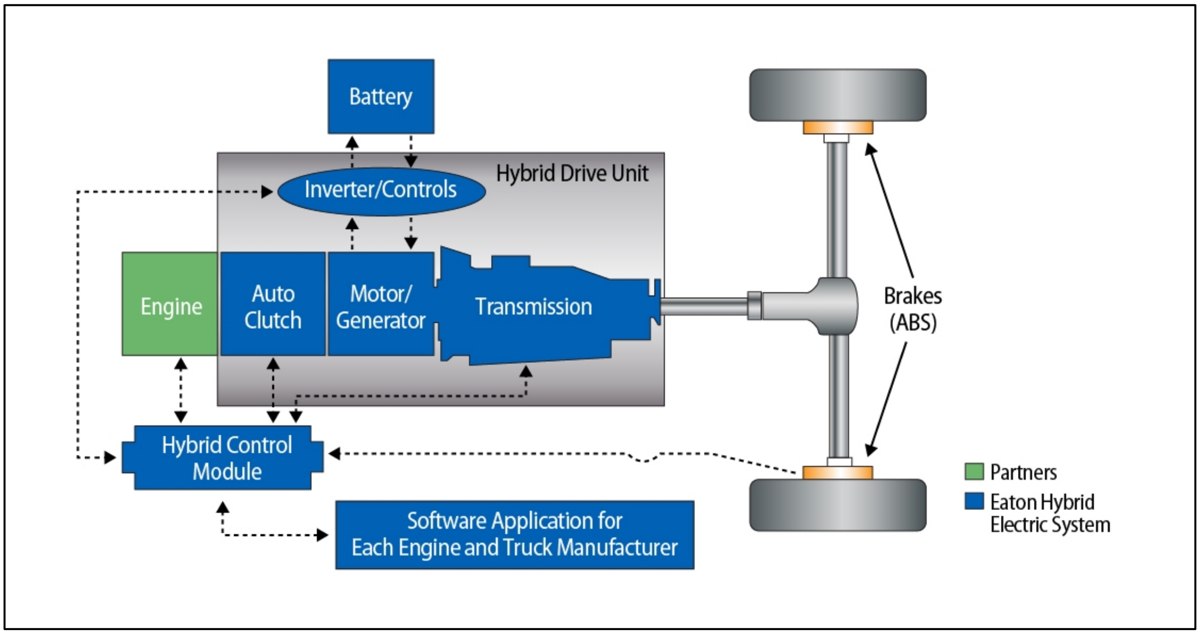

Figure 2. Eaton hybrid system schematic

Figure 3 shows the primary hybrid components in the Eaton system.

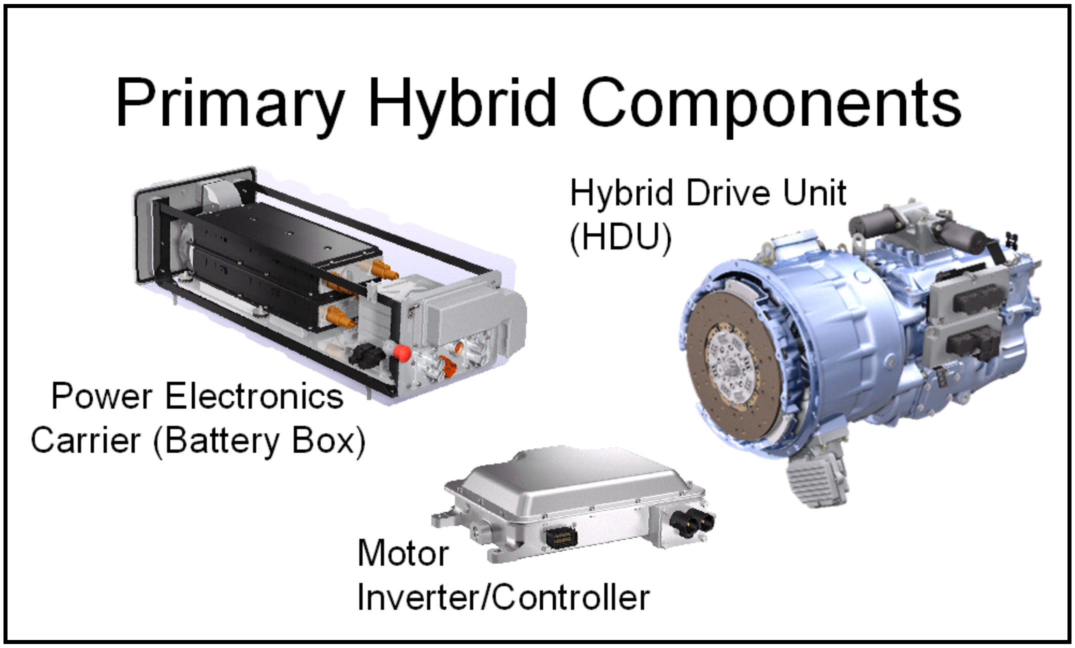

Figure 3. Eaton hybrid system components

Figure 4 shows the primary hybrid components arranged in the undercarriage of a UPS delivery van.

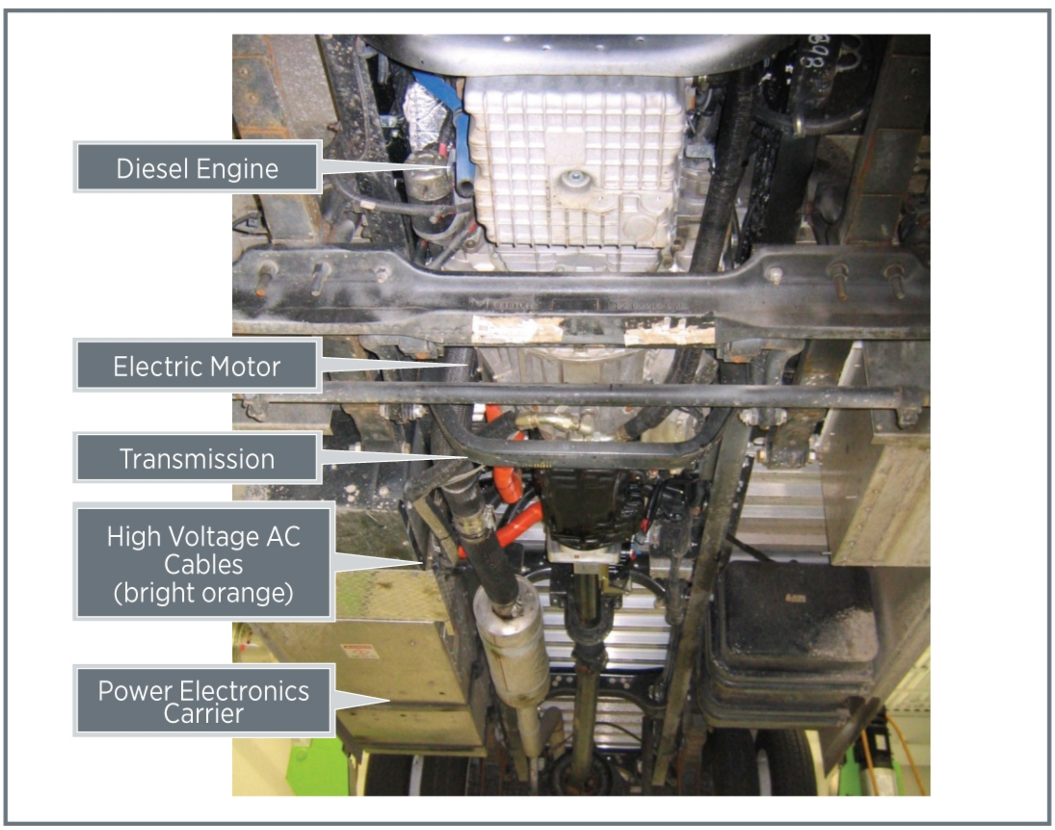

Figure 4. Eaton hybrid system components on UPS undercarriage

UPS has custom delivery vans built to the company's specifications. The P70 vehicles in this study are manufactured by Freightliner for UPS. Table 3 provides brief descriptions of the vehicle systems.

Table 3. Vehicle System Descriptions

Van Specification	Hybrid Electric Vans	Diesel Vans
Van manufacturer	Freightliner Corp.	Freightliner Corp.
Van model	P70H step van	P70D step van
Van model year	2007	2006
Engine manufacturer and model	Mercedes-Benz MBE 904 4 cyl MY 2006	Mercedes-Benz MBE 904 4 cyl MY 2006
Emissions equipment	No DPF[a]	No DPF
Retarder/regenerative braking	Regenerative braking	None
Air conditioning type	None	None
Gross vehicle weight	15,200 lbs	14,360 lbs

[a] DPF = diesel particle filter

Host Site Profile—UPS, Phoenix, Arizona

The host site consisted of the two UPS Arizona facilities—Phoenix and Estrella. Estrella is an expansion facility located about five miles west of the main Phoenix facility. It became necessary as the Phoenix facility outgrew its footprint. Figure 5 shows the locations of the two facilities in the greater Phoenix area. The vehicles used for this evaluation are six hybrids from the Phoenix facility and six standard diesels from the Estrella facility. It was not necessary to modify the Phoenix facility in any way to implement the hybrid vehicles into the fleet. Drivers were given training on the operation of the hybrids, but no restrictions or special accommodations were made for their use; however, UPS did assign them to urban routes rather than rural routes to make the best use of the hybrid drive train. Dispatch and maintenance practices are the same at both facilities.

To assess fuel usage in these two groups of vehicles at the two locations, fueling records from driver logs were utilized at both facilities. In both groups the drivers need to log their fueling events on their electronic tablets, and the records are uploaded to a central database. In some instances, failure to log a fueling event led to some months from each study group being left out of fuel economy calculations due to inaccurate fueling data and is discussed below.

Figure 5. UPS Phoenix site map

Evaluation Results

Van Use

Figure 6 shows the average monthly miles driven per van for each van group with ±95% confidence interval lines. An accident involving one hybrid van affected mileage accumulation during August and September 2008, and this van's data have been removed from the figure and subsequent calculations. The width of the 95% confidence interval gives some idea about how uncertain we are about the average of the population. Few points in a sample group or points spread apart decrease confidence and increase the width of the confidence interval. Many data points closely grouped will bring the confidence lines close to the sample average, indicating strong confidence about the population mean. Van average usage did not change significantly during the evaluation period; the hybrids consistently were driven fewer miles throughout this period because of their shorter, more urban routes. In October and November 2008, the hybrid group showed a dip in average usage and an increase in the 95% confidence interval due to Eaton calibration issues for three vans; as a result, these vehicles were not available for service for extended periods of time of two to three weeks each.

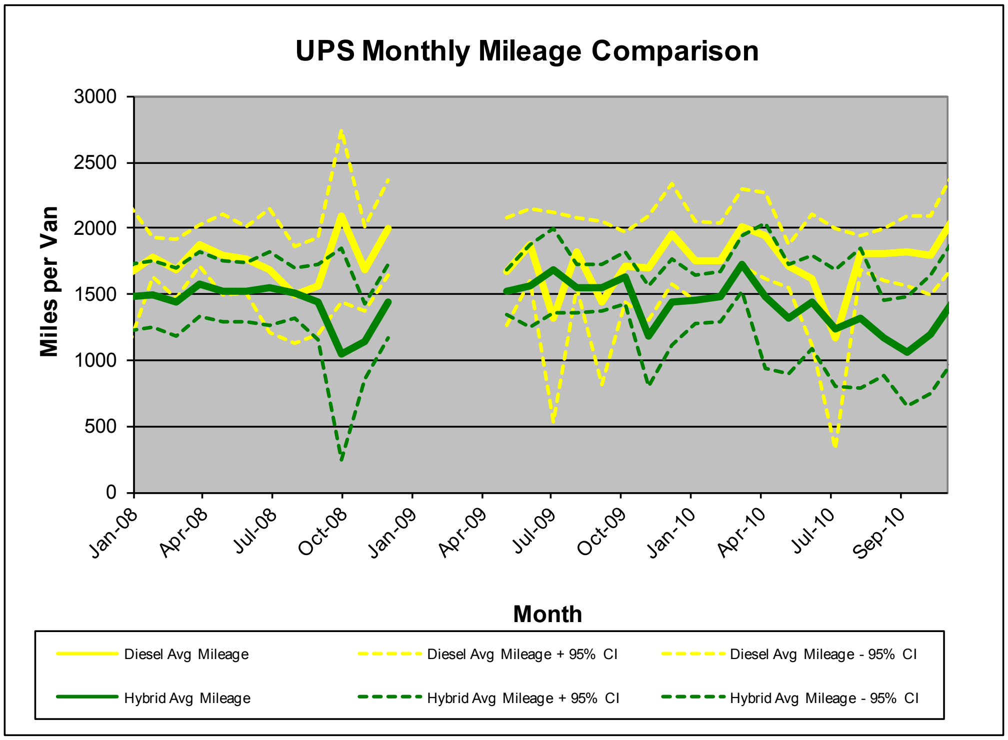

Figure 6. Hybrid and diesel monthly mileage per van

Figure 7 shows the cumulative monthly miles driven by each van study group. As shown here, despite the missing driver-logged odometer readings, van use did not change significantly over time. It is clear that the van average miles per month did not change during the period of missing data.

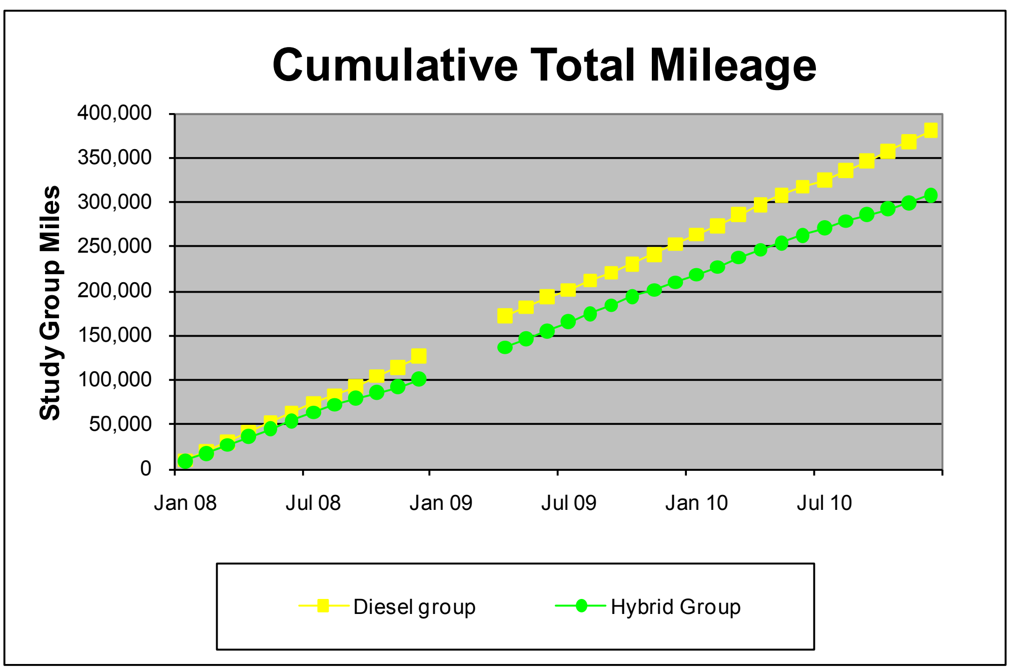

Figure 7. Hybrid and diesel cumulative mileage per group

Table 4 presents the average monthly mileage per van during the evaluation period for the two groups of vans. The hybrid vans monthly mileage accumulation rate is 18% less than that of the diesel vans (1,437 miles versus 1,761 miles). The majority of the difference is due to the routes they are assigned to; the miles per actual delivery day were 16% less for the hybrid group (71 miles per day versus 84 miles per day). The average monthly rate was also affected by downtime because four hybrid vehicles had a combined 7 months of operation during the first year due to extended downtime as described above. This downtime is responsible for the remainder of the lower monthly mileage not explained by the routes. Based on each individual vehicle's average miles per day and actual number of missed days, the diesel group missed 3,961 miles while the hybrid group missed 13,736 miles: the hybrids missed over 4% of their possible assigned miles due to downtime and the diesels only missed 1% of their possible assigned miles for that reason.

Table 4. Average Van Miles Driven per Month by Study Group

Van Number	Start Mileage	End Mileage	Evaluated Miles	Miles per Delivery Day	Miles per Month
663982	59,305	117,780	58475	77.0	1,624
665020	42,559	108,559	66000	87.3	1,833
665044	30,682	89,800	59118	78.9	1,642
665086	32,085	102,698	70613	95.4	1,961
665087	43,875	112,534	68659	91.3	1,907
665150	32,335	89,750	57415	76.2	1,595
Diesel Total			**380,280**	**506**	**10,563**
Diesel Average	**40,140**	**103,520**	**63,380**	**84**	**1,761**
Diesel Stdev	**10,976**	**11,735**	**5,742**	**8**	**160**
666131	11,813	52,817	41004	57.4	1,139
666132	15,711	75,357	59646	81.0	1,657
666133	15,598	74,921	59323	79.5	1,648
666139	15,899	69,692	53793	76.1	1,494
666142	14,212	60,984	46772	65.5	1,299
666145	13,732	63,601	49869	67.5	1,385
Hybrid Total			**310,407**	**427**	**8,622**
Hybrid Average	**14,494**	**66,229**	**51,735**	**71**	**1,437**
Hybrid Stdev	**1,583**	**8,777**	**7,317**	**9**	**203**
Avg Difference	**25,646**	**37,292**	**11,646**	**13**	**323**
% Difference	**64%**	**36%**	**18%**	**16%**	**18%**

Van Duty Cycle

Global Positioning System (GPS) data loggers were installed in two vans from each study group to obtain detailed information on the type of driving they were assigned to and ensure a more accurate comparison. Data were collected for one week of operation, providing 10 days of "typical" operation for each vehicle group. The data are not representative of the entire UPS fleet but only of the P70 vehicles operating out of these two depots. These data were reanalyzed for this update. Figure 8 shows a GPS visualization of the routes of the four logged vans. The red and orange traces each show one day of the diesel vans operations out of the Estrella depot. The blue and purple traces each show one day of the hybrid vans operations out of the Phoenix depot.

The exact routes vary daily, but the depictions are meant to show a typical of a day of operation for that van, as captured by the GPS loggers.

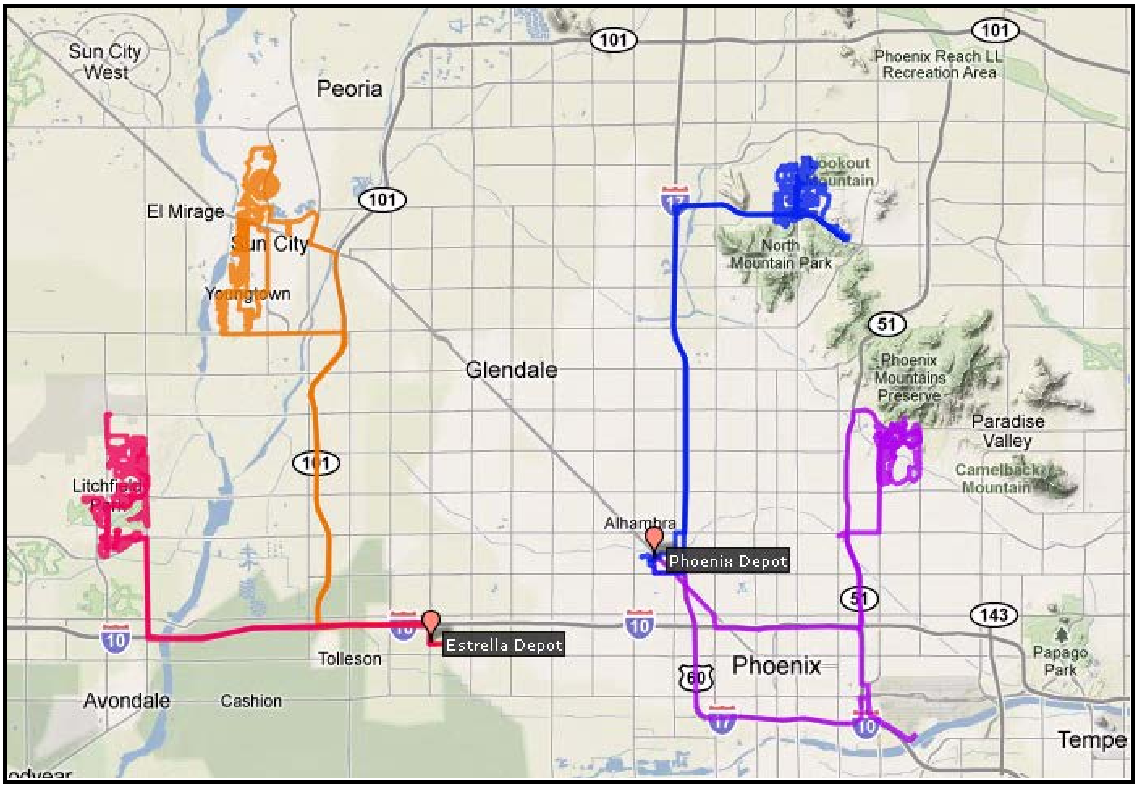

Figure 8. Hybrid and diesel route visualization

Figure 9 shows the average time (as a percentage) that vans with GPS loggers spent at different vehicle speeds. The hybrids spent more time at zero speed and operating at slower speeds than the diesels did, and the diesels spent slightly more time operating at higher speeds.

- The hybrid vans spent 15% of their time at zero speed, nearly twice the zero speed time spent by the diesels (8%).
- The hybrid vans spent 21% of their time in the 0 to 10 mph range, 15% more than the diesels did (18%).
- The hybrid vans spent 17% of their time in the 20–35 mph range, 29% less time than the diesels spent there (24%).
- The hybrids spent 7.4% of their time in the 50–65 mph range, twice as much as the diesels did (3.5%).
- The diesels spent significantly more time above 65 mph (4% vs. 1% for the hybrids). This was because the hybrids are speed-limited while the diesel vans are not.

The greater time spent by the hybrids at slower speeds could be an indication of a more urban duty cycle; or it could be an indication of slower accelerations, which lead to more time at those speeds. Both groups spent about 70% of their driving time (speed greater than zero) at speeds less than 35 mph, indicating that both groups were on city/residential delivery routes. Both groups spent about 8% of their driving time at speeds above 50 mph, indicating they had similar distances to travel from the depot to the delivery zone.

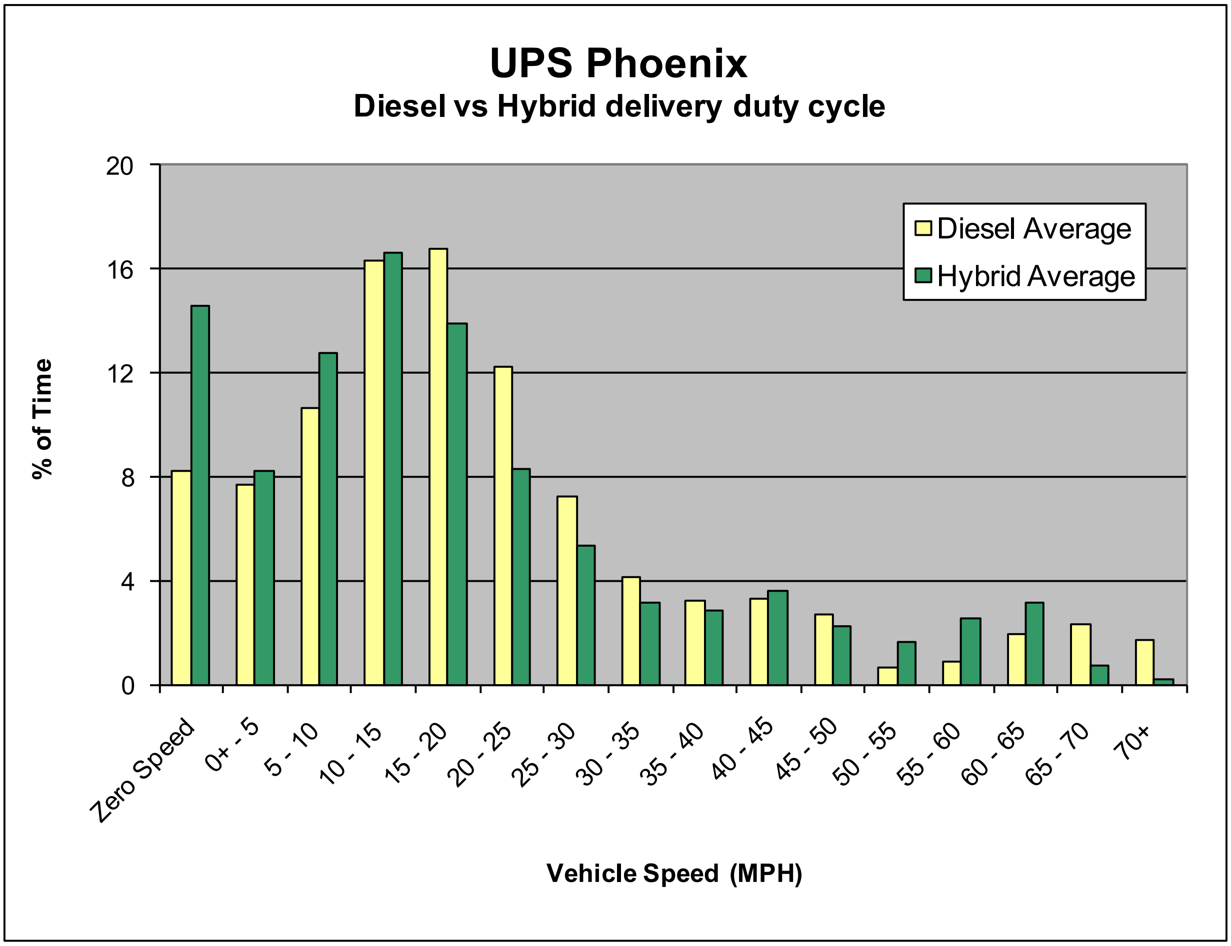

Figure 9. Hybrid and diesel duty cycle breakdown by time %

Figure 10 shows the average distance (as a percentage) that vans with GPS loggers drove at different vehicle speeds. This distance-based chart highlights a different breakdown of the routes.

- The hybrid vans drove 6.8% of their miles in the 0 to 10 mph range, 32% more than the diesels did (5.2%).
- The hybrid and diesel vans both drove 24% of their miles in the 10–20 mph range.
- The hybrid vans drove 23% of their miles in the 20–35 mph range, 20% fewer miles than the diesels drove in that range (29%).
- The hybrids drove 23% of their miles in the 50–65 mph range, more than twice as much as the diesels did (10%).
- The diesels drove significantly more miles above 65 mph (13% vs. 3% for the hybrids). This was because the hybrids are speed-limited while the diesel vans are not.

If the duty cycle is split into three speed zones representative of different types of roads, the vans had nearly the same percentages. The hybrids drove 54% of their miles at residential speeds (below 35 mph); the diesels drove 58% of their miles at those speeds. The hybrids and diesels both drove 19% of their miles at arterial speeds (35 mph to 50 mph). The hybrids drove 27% of their miles at highway speeds (above 50 mph); the diesels drove 23% of their miles at those speeds. The hybrids would offer more advantage with fewer highway miles, but the locations of the depots may limit those choices.

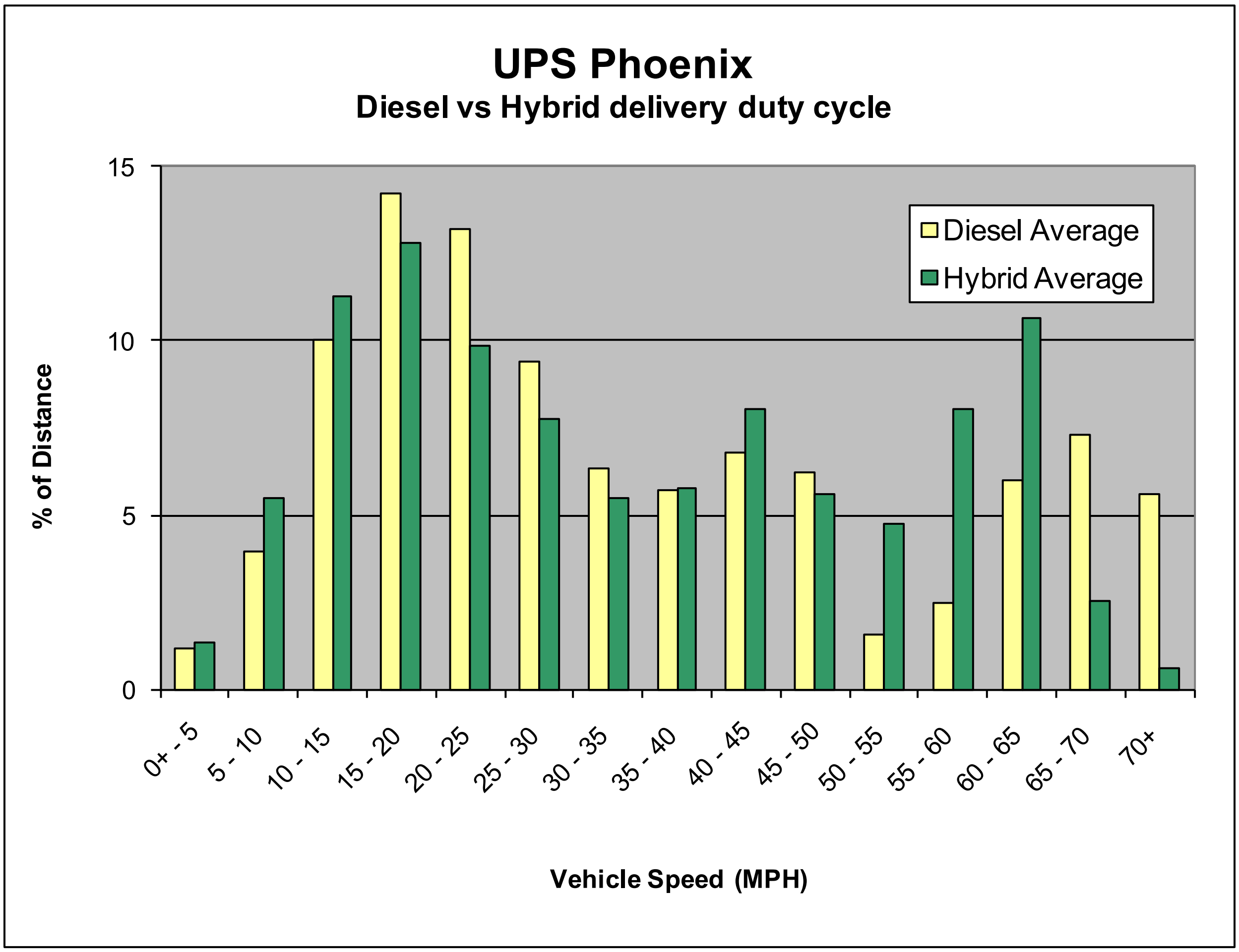

Figure 10. Hybrid and diesel duty cycle breakdown by distance %

Table 5 presents other duty-cycle statistics gathered from the GPS data logging.

- The hybrids' average driving speed of 21.9 mph was 4% lower than the diesels' 22.7 mph (zero speed time not included).
- The hybrids averaged roughly the same number of stops per day as the diesels (191 vs. 182 for the diesels).
- The hybrids had 2.64 stops per mile, 7% more than the diesels' 2.47.
- The hybrids had 17.4 acceleration events per mile, 21% more than the diesels' 14.4.
- The hybrids had 16.3 deceleration events per mile, 17% more than the diesels' 13.9.

These statistics indicate that the hybrids were operating on very similar routes as the diesels. Major differences include significantly longer idle times and stop durations.

Table 5. Drive Cycle Statistics from Vans with GPS Loggers from Each Study Group

Cycle Statistics	Diesel Average	Hybrid Average	Difference (Diesel – Hybrid)	% Difference
Distance traveled (miles)	75.0	69.8	5.2	-7%
Average speed over cycle (mph)	20.8	18.7	2.1	-10%
Average driving speed (mph)	22.7	21.9	.9	-4%
Maximum speed (mph)	70.9	68.0	2.9	-4%
Time at idle (s)	1,078	2,000	-922	86%
Maximum acceleration (ft/s^2)	12.7	12.7	0	0%
Maximum deceleration (ft/s^2)	-12.6	-14.7	2	16%
Acceleration (% of total cycle)	43.0	39.8	3.2	-7%
Deceleration (% of total cycle)	40.4	35.5	5.0	-12%
Average acceleration (ft/s^2)	2.07	1.96	-0.1	-5%
Average deceleration (ft/s^2)	-2.2	-2.2	0	0%
Number of acceleration events	1,081	1,215	-133	12.0%
Number of acceleration events per mile	14.4	17.4	-3	21%
Number of deceleration events	1,045	1,133	-88	8%
Number of deceleration events per mile	13.9	16.3	-2.3	17%
Number of stops	191	182	9	-5%
Average duration of stop (s)	97	134	-38	39%
Number of stops per mile	2.47	2.64	-0.17	7%

Fuel Economy

UPS fuels its hybrids and diesels with standard ultra-low-sulfur diesel, which has a sulfur content of less than 30 parts per million. Due to inconsistencies in fueling records that resulted in some unattainable monthly fuel economy results a statistical method known as Chauvenet's Criterion (Taylor, 1997) was used to identify van monthly mile-per-gallon (mpg) results that were statistical outliers. Chauvenet's Criterion is an iterative statistical method that either accepts or rejects statistical outliers found in experimental data based on the data set size, mean, and standard deviation. As part of employing Chauvenet's Criterion, the probability of the largest outlier in the data set is determined using the data set mean and standard deviation. If the probability of the observed outlier multiplied by the size of the data set results in a value less than 0.5, it is concluded that the statistical outlier observed as part of the data set can be rejected based on the limited probability of this outlier occurring as part of the data set. If the outlier is rejected, the data set mean and standard deviation are recalculated without the rejected data point, and the probability for the largest remaining outlier is determined. This process is repeated until no further outliers are rejected. From the 192 months of recorded fuel economy data on each vehicle group, this method removed 18 vehicle months from the diesel van group and 8 vehicle months from the hybrid van group that were statistically not possible to occur for that particular vehicle based on the complete 32-month data set. In addition to employing Chauvenet's Criterion to remove statistically impossible data points, a 95% confidence interval analysis was performed on the remaining outliers to remove an additional six vehicle months from the diesel group and nine vehicle months from the hybrid group. The 95% confidence interval was chosen in an effort to ensure the removal of data that had a very low likelihood of occurring during normal operation. Performing a visual inspection of the data upon the conclusion of this process revealed that most of the data points removed by this approach were obvious data artifacts that were impossible for the vehicles to attain. However, using a consistent statistical approach assures the grey areas for each vehicle were treated in the same manner.

The 24 diesel-group vehicle months of fuel economy data and 17 hybrid-group vehicle months of fuel economy data have been removed from the total of 192 vehicle months of fuel economy results presented in this report. This is in addition to four months at the beginning of 2009 for which no fuel economy data is available for any of the vehicles. As such, miles used for the calculation of fuel economy are different from those reported in other sections of the report.

Table 6 shows the fuel consumption and economy data for each van in each study group. The hybrid vans consumed 19,148 gallons of fuel over 249,449 miles for the 32-month period, resulting in an average fuel economy for the hybrid vans of 13.0 mpg, which was 23.1% greater than that of the diesel van group's 10.6 mpg (P value = 0.0009).

Table 6. Hybrid and Diesel Van Fuel Use and Economy

Hybrid Vehicles			
Van	**Fuel Economy Miles**	**Fuel Economy Gallons**	**Miles per Gallon**
666131	34,290	2,751	12.5
666132	43,949	3,153	13.9
666133	49,337	3,683	13.4
666139	43,086	3,419	12.6
666142	39,924	3,204	12.5
666145	38,863	2,938	13.2
Hybrid Total	249,449	19,148	13.0
Diesel Vehicles			
Van	**Fuel Economy Miles**	**Fuel Economy Gallons**	**Miles per Gallon**
663982	42,606	3,898	10.9
665020	54,128	4,722	11.5
665044	34,935	2,982	11.7
665086	52,376	5,924	8.8
665087	58,477	5,658	10.3
665150	47,467	4,229	11.2
Diesel Total	289,989	27,413	10.6

Figure 11 shows the monthly miles per gallon for each van group and cumulative miles per gallon for each van group. In this figure, the group is considered as a whole, and monthly miles per gallon are calculated by considering the sum of the miles and sum of the gallons for the group each month. This figure weights all vehicle miles equally and relates directly to the fleet's actual fuel consumption.

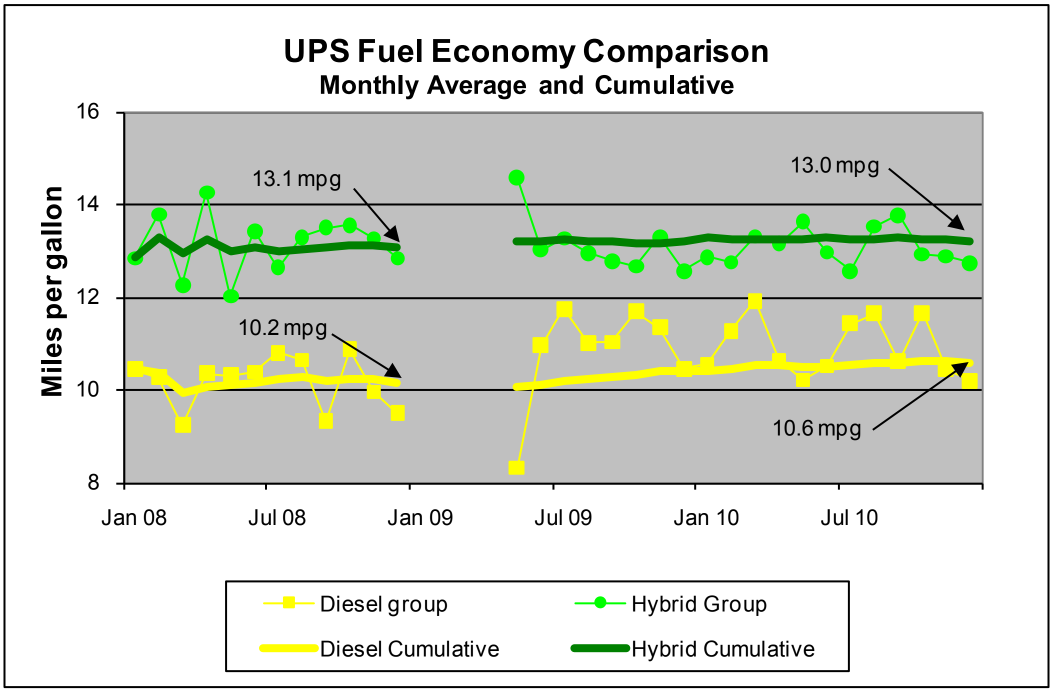

Figure 11. Average monthly and cumulative fuel economy

Figure 12 shows the average monthly miles per gallon for each group of vans with ±95% confidence interval lines. This figure considers each group as six individual vehicles and averages their monthly miles per gallon results. This figure weights each vehicle equally and better takes into account the effect of different duty cycles and miles per day on fuel economy. With a small sample size, one outlier can offset the average significantly. The width of the 95% confidence interval gives some idea about how uncertain we are about the average. By considering each vehicle as an individual and calculating a 95% confidence interval, it is possible to understand the consistency of the population's fuel economy and gain a better understanding of how a larger population of vehicles would behave. In May of 2009, four of the six diesels were removed (for that monthly only) as statistical outliers and, as a result, the remaining two data points have a very large 95% confidence interval.

For laboratory fuel economy and emissions results on similar vans, please see the original 12-month report on this study at http://www.nrel.gov/docs/fy10osti/44134.pdf

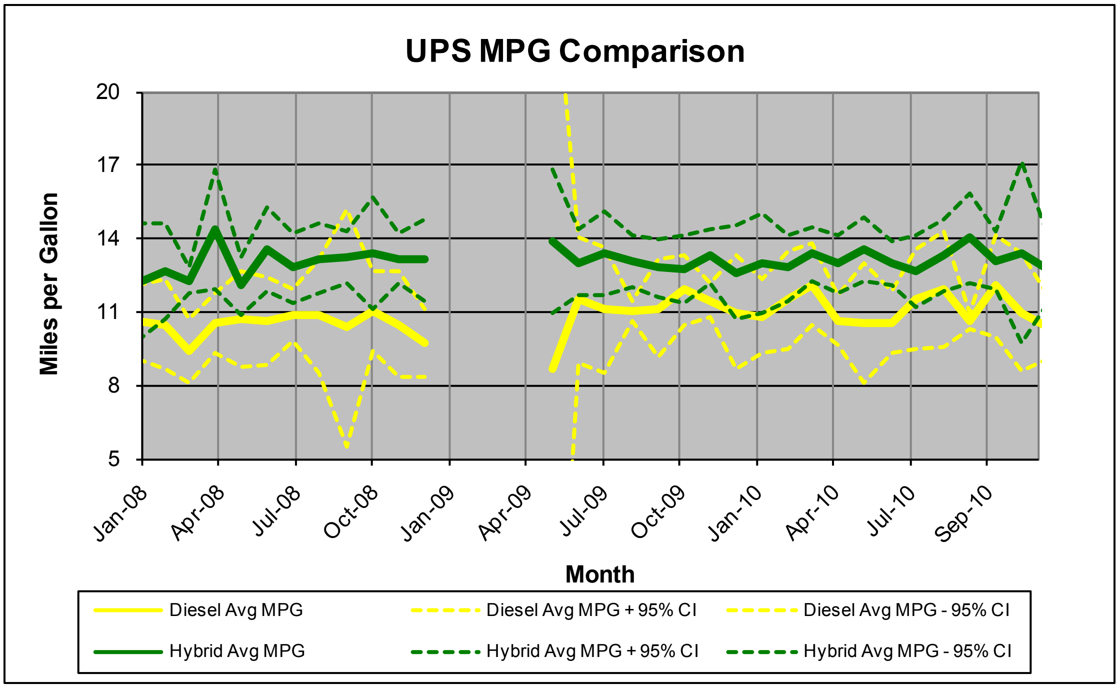

Figure 12. Average monthly fuel economy with 95% confidence interval

Maintenance Cost Analysis

This evaluation focuses on van operations spanning 36 of the first 42 months of operation for the hybrid vans. This snapshot does not yield enough operating cost data to provide a complete understanding of the full life-cycle cost of the hybrid vans, however. Understanding costs requires an examination of the purchase cost of the vans plus warranty and operation costs. Longer term maintenance activities, such as engine rebuilds or replacements and battery replacements, also must be considered. Finally, it is critical that areas in which cost savings can be achieved (e.g., in brake repair) be examined. The intent of this evaluation, however, is to capture accurate, known operations costs associated with the hybrid and diesel vehicles for the selected period. This analysis is not predictive of maintenance costs assumed by UPS beyond the warranty period. The exact components and warranty periods as negotiated by UPS, Eaton, and Freightliner are contractual and confidential.

The hybrid and diesel vans all are still new enough that much of the maintenance is completed under warranty. All maintenance for the Eaton hybrid drive was done by Eaton mechanics. These maintenance costs are not included in the maintenance-cost analysis in this section. Not accounting for warranty repairs in the evaluation of total maintenance cost does offer an incomplete picture of total maintenance cost. Even without warranty costs, however, this analysis reflects the actual cost to UPS during the period selected.

Maintenance costs were collected in the same manner for each study group. All work orders and parts information available were collected for the study vans. The maintenance practices are the same for both diesel and hybrid study groups. The maintenance analysis discussions include only the maintenance data that were gathered during the evaluation period on the study group vans.

Maintenance Costs

This cost category includes the costs for parts and for labor at $50 per hour; it does not include warranty costs. All costs related to an accident on a hybrid vehicle have been removed from this section as they do not represent the vehicle and powertrain comparison of interest. Cost per mile is calculated as follows.

Cost per mile = ((labor hours * 50) + parts cost)/mileage.

The labor rate has been set artificially at a constant rate of $50 per hour; other analysts can change this rate to one more similar to their own situations. This rate does not directly reflect UPS's current hourly mechanic rate.

Table 7 shows total and propulsion-related maintenance costs for the two study groups. The propulsion-related vehicle systems include the engine; transmission; electric propulsion; exhaust; fuel; and nonlighting electrical, which includes general electrical, charging, cranking, and ignition. The propulsion-related maintenance cost per mile of $0.037 for the hybrid vans was 25% more than the $0.029 for the diesel vans. The total maintenance cost per mile of $0.141 for the hybrid vans was 9% more than the $0.130 for the diesel vans. Compared to the original 12-month analysis the hybrids have maintained a fairly constant cost per mile while the diesels have become cheaper.

Table 7. Hybrid and Diesel Van Total and Propulsion Maintenance Costs

Study Group	Miles	Parts Cost	Labor Hours	Maintenance Cost	Cost per Mile ($/mile)
Hybrid total	307,731	$13,934	587.9	$43,326	$0.141
Hybrid propulsion-related	307,731	$878	207.7	$11,264	$0.037
Diesel total	380,280	$16,556	655.1	$49,311	$0.130
Diesel propulsion-related	380,280	$2,835	166.7	$11,172	$0.029

Included in the "total" maintenance cost data are tire replacements, which are a large part of the vehicle operating costs and are responsible for spikes in monthly total maintenance costs. Cumulative tire expenses are almost on the same level as cumulative propulsion-related costs for either drive train ($0.024/mile to $0.026/mile). Figure 13 shows total monthly and cumulative maintenance costs for the two study groups. Tire costs are responsible for most of the spike in March 2008 ($0.08/mile) for the hybrid group. A group of tire changes during the month of September 2008 ($0.16/mile) is responsible for the spike during that month. Despite that spike; both study groups have similar tire replacement costs over the course of the three years ($8,142 for hybrids vs. $9,156 for diesels). The large hybrid group spike in November 2009 was caused by three vans having the brake "hydroboost" component replaced, one van receiving new tires, and one van having the clutch pack and vehicle battery replaced. The large diesel group spike in July 2010 was caused by four vans having tires replaced, and three of those vans replacing either the accelerator pedal, transmission harness or power steering pump and brake work. The October 2010 hybrid group spike is due to one vehicle receiving new tires and having ongoing transmission calibration/communication issues requiring troubleshooting. Many of these repairs cause vehicle downtime, which reduces mileage and makes the cost per mile impact seem larger than it would in straight cost. Also, many of the above component failures also explain the corresponding spikes in propulsion-related cost per mile (Figure 14).

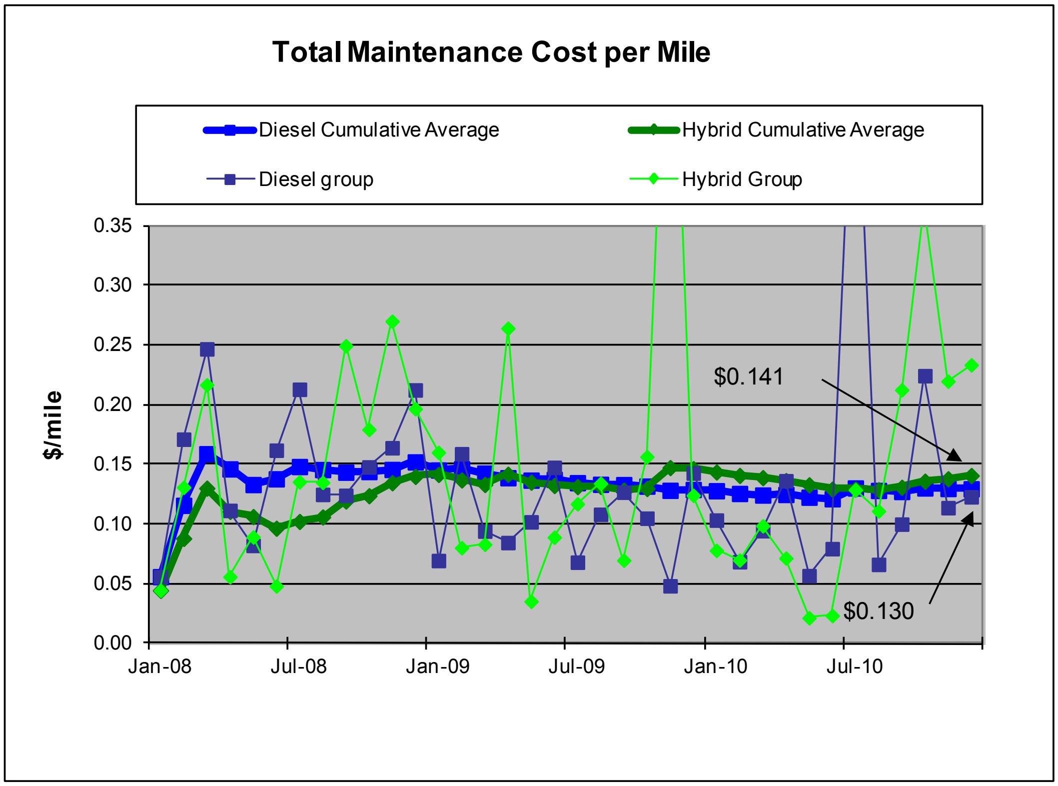

Figure 13. Total maintenance cost per mile

Figure 14 shows monthly and cumulative propulsion-related maintenance costs for the two study groups. The hybrid spike during October and November 2008 is due to Eaton recalibration activities and is responsible for raising the hybrid cumulative propulsion-related maintenance cost per mile to parity with that of the diesel group. Three of the hybrid units were experiencing faults related to the calibration of a prototype parking pawl in use on these vans. While Eaton covered the costs for materials, UPS technicians spent time troubleshooting and working with Eaton, and these hours generated the spike in propulsion maintenance cost per mile. The two groups maintained parity for the next two years of this study, which explains the lack of a statistically significant difference between the groups. The large hybrid group spike in November 2009 was caused by one van having the clutch pack and vehicle battery replaced as well as the associated downtime, which lowered the miles driven. The large conventional group spike in July 2010 was caused primarily by one van having its transmission harness replaced and the missed miles from that and other vans repaired for non-propulsion items mentioned above also missing miles. The October 2010 hybrid group spike is due to one vehicle having ongoing transmission calibration/communication issues requiring troubleshooting and missing miles during this time.

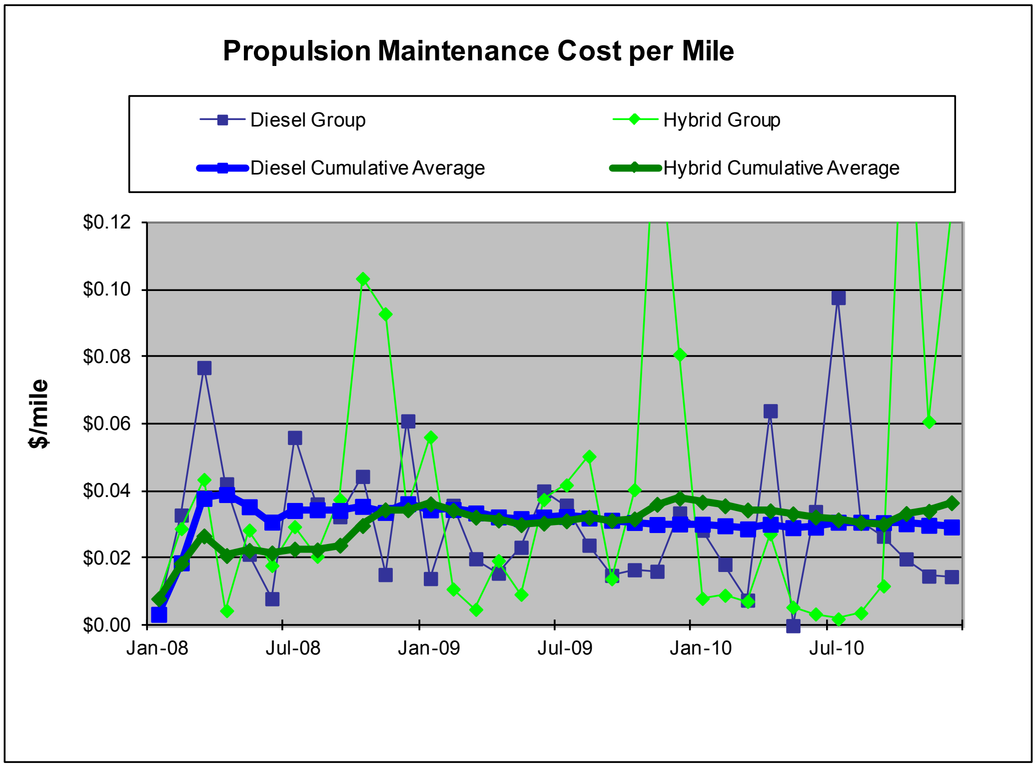

Figure 14. Propulsion maintenance cost per mile

Figures 15 and 16 show a breakdown of total and propulsion-related maintenance costs per mile for the diesel and hybrid study groups, respectively. Note the similar percentage breakdowns for each category, which indicates that the hybrid drivetrain is not driving maintenance costs more than the conventional drivetrain. Also note that for both study groups, the complete propulsion system costs an amount similar to the tire-related costs for the group. Propulsion system and tire-related costs were 22% and 19%, respectively, for the diesel group and were 25% and 19%, respectively, for the hybrid group.

Table 8 shows a breakdown by individual van of the total cost per mile. The total maintenance cost per mile difference between the diesel and hybrid groups had no statistical significance (P value = 0.46), which means the vehicle to vehicle variation was so large that we cannot distinguish between the two study group even if there is a difference in the averages. Propulsion maintenance cost per mile also showed no statistically significant difference between the diesel and hybrid groups (P value = 0.33). Fuel cost per mile dominated the total cost per mile for both groups, and the fuel cost per mile was 19% less for the hybrid group (P value = 0.0048). Fuel prices dropped after 2008, which explains the lower fuel cost per mile savings and the lower total cost per mile savings after three years. As such, the total cost per mile was 10% less for the hybrid group but this difference was not statistically significant (P value = 0.1927). The 2008–2010 average price for diesel was $3.09/gallon, and this figure was used to calculate fuel cost per mile.

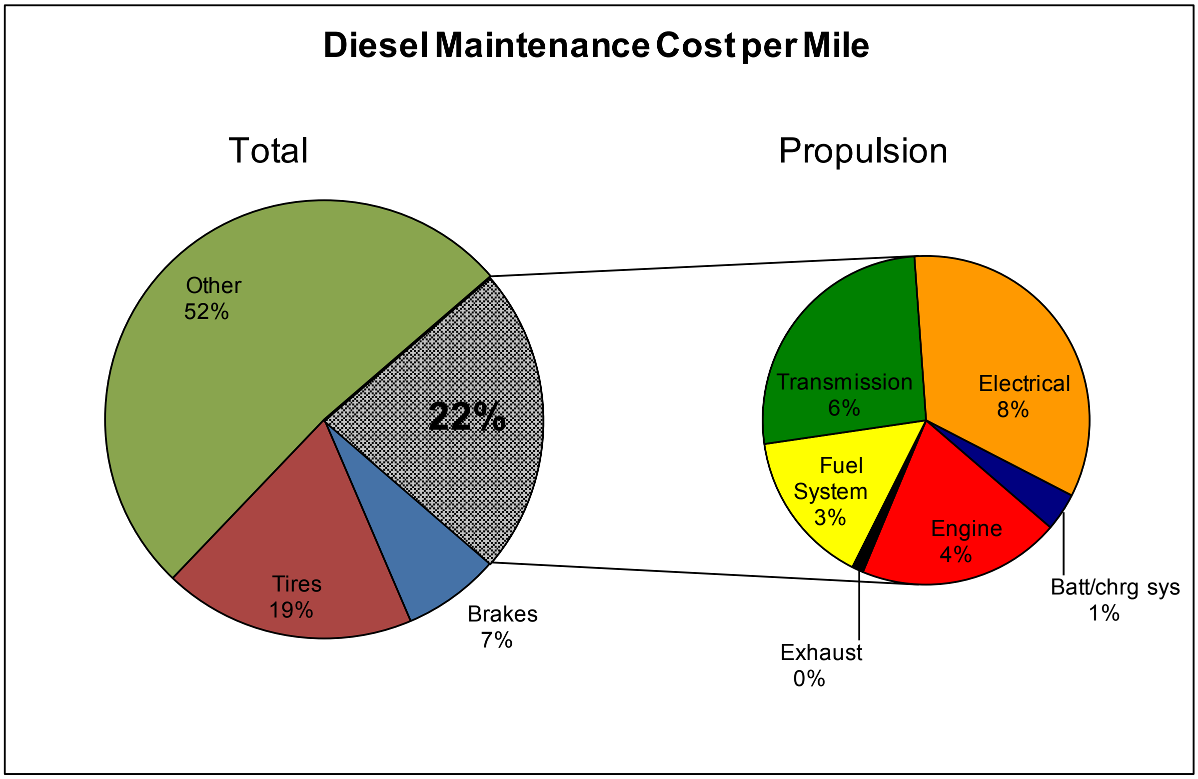

Figure 15. Propulsion maintenance cost per mile (diesels)

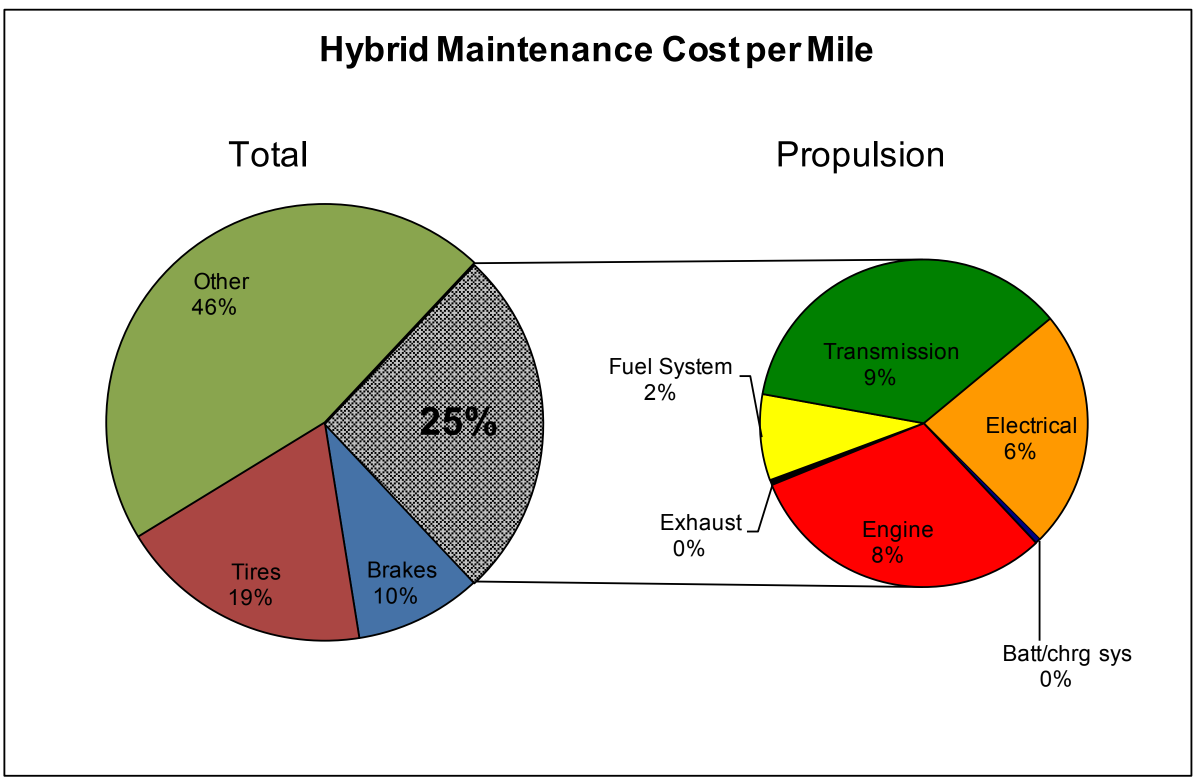

Figure 16. Propulsion maintenance cost per mile (hybrids)

Table 8. Hybrid and Diesel Van Total Cost per Mile

Total Cost per Mile Comparison					
Car	PWRTRN	Non-Prop Mnt ($/mile)	Prop Maint ($/mile)	Fuel Cost ($/mile)	Total Cost ($/mile)
663982	Diesel	$0.108	$ 0.035	$ 0.283	$ 0.426
665020	Diesel	$0.078	$ 0.029	$ 0.270	$ 0.377
665044	Diesel	$0.096	$ 0.025	$ 0.264	$ 0.384
665086	Diesel	$0.112	$ 0.045	$ 0.349	$ 0.506
665087	Diesel	$0.110	$ 0.016	$ 0.299	$ 0.425
665150	Diesel	$0.096	$ 0.025	$ 0.275	$ 0.397
Total	**Diesel**	**$0.100**	**$ 0.029**	**$ 0.292**	**$ 0.422**
666131	Hybrid Diesel	$0.109	$ 0.035	$ 0.248	$ 0.392
666132	Hybrid Diesel	$0.064	$ 0.022	$ 0.222	$ 0.307
666133	Hybrid Diesel	$0.084	$ 0.013	$ 0.231	$ 0.327
666139	Hybrid Diesel	$0.100	$ 0.051	$ 0.245	$ 0.396
666142	Hybrid Diesel	$0.118	$ 0.047	$ 0.248	$ 0.413
666145	Hybrid Diesel	$0.169	$ 0.059	$ 0.234	$ 0.461
Total	**Hybrid Diesel**	**$0.104**	**$ 0.037**	**$ 0.237**	**$ 0.378**

Reliability

UPS records instances in which a vehicle is not available to load in the morning as scheduled. Scheduled maintenance events of any kind do not get recorded in this way. During this 36-month evaluation, there were 759 operational days available for deliveries for a total of 4,554 days for each study group of six vans. Both groups had a comparable number of missed operational days during the first six months of the evaluation. In August 2008, one of the hybrid vehicles was involved in an accident, which caused it to miss 29 operational days during August and September. A combined 55 operational days were missed during October and November while Eaton was troubleshooting faults related to a prototype parking pawl on three of the hybrid units. The diesel study group missed a total of 45 operational days during the 36-month study period, while the hybrid group missed 169 operational days. The reasons mentioned above (excluding the accident) caused the hybrid group's cumulative percent uptime to drop dramatically at the end of the first 12 months, but continued hybrid-related downtime during the following two years has kept the figure in the 96% range. Figure 16 shows the monthly and cumulative uptime for each group as a percentage of the total available delivery days. The 29 days missed because of an accident are not included in Figure 17 or any calculations because that event was outside normal van and powertrain operations.

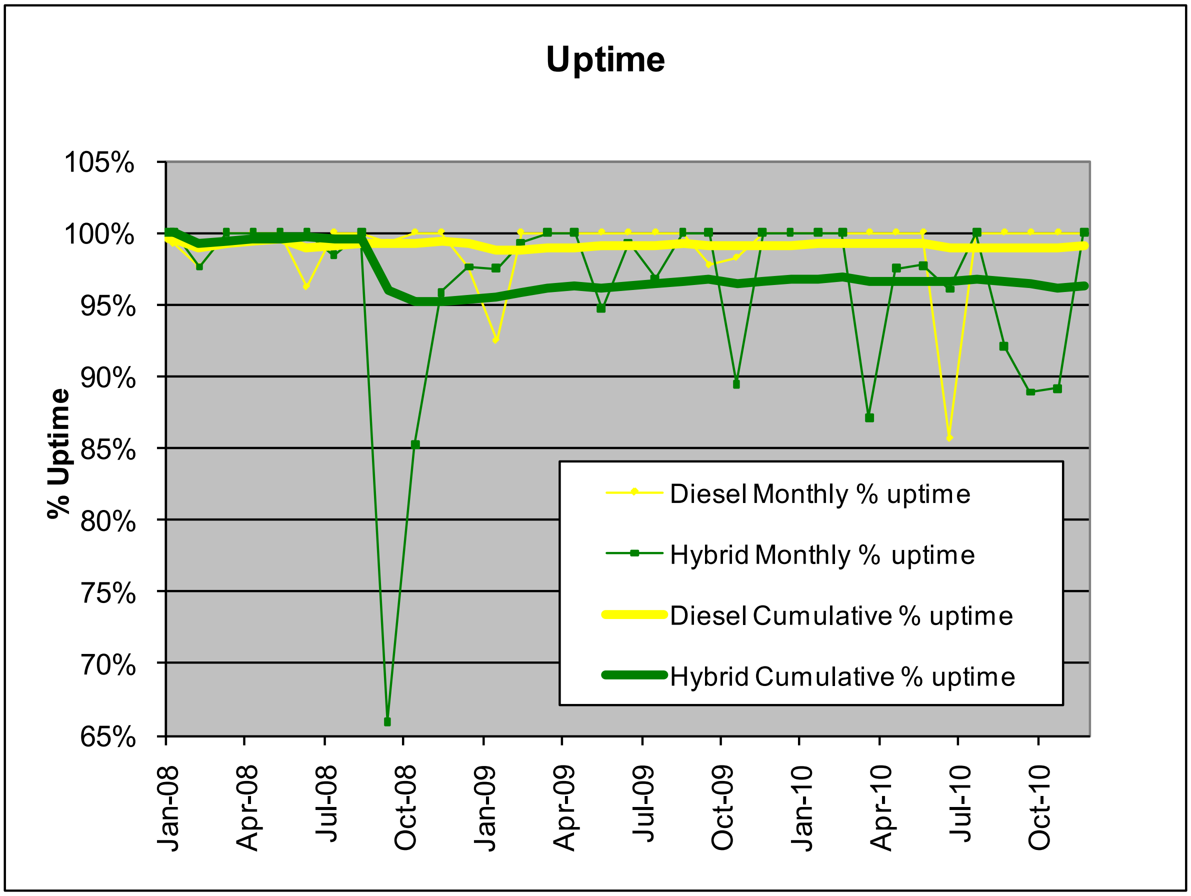

Figure 17. Cumulative uptime

Batteries

The Eaton system uses lithium ion batteries supplied by Hitachi for energy storage. They have a capacity of 1.8 kWh and operate at a nominal voltage of 340 VDC. These batteries were not available to NREL during the evaluation period for detailed evaluation. The batteries are included in the power electronics carrier (PEC) located on the passenger side of the chassis. Eaton's records indicate one PEC was replaced because of water intrusion during an atypical monsoon flood event. UPS records indicate preventive efforts to seal the PEC air filter on the hybrids; these costs are captured as part of the maintenance cost analysis under the "electrical" heading. No battery failure or a cell failure was reported by Eaton or UPS. The service life of the battery is estimated by Eaton at 7 years.

Status of UPS Hybrid Fleet

UPS was satisfied with the performance of the original 50 (prototype) hybrid electric vans over the first years of service. UPS has ordered and taken delivery of an additional 200 hybrids with additional features and updates in 2010 and an additional 135 in 2011. NREL is working on the first year evaluation of eleven of these newer hybrids in operation in Minneapolis, which is due out in mid 2012. An overview of that study can be found at: http://www.nrel.gov/docs/fy12osti/51308.pdf

Conclusions

- Monthly and cumulative miles per van for the hybrids were 18% lower than they were for the diesels. The primary driver (about 16%) for the difference was a more dense/urban delivery route assignment with shorter highway sections with fewer miles per delivery day on average. A secondary driver was downtime due to an accident and Eaton calibration issues causing extended downtime.
- Fuel economy of the hybrid group over these 3 years was 23.1% better than that of the diesel group. This is less than the nearly 29% reported after the first year and 31% to 37% shown during laboratory fuel economy testing. The diesels seemed to slightly improve their fuel economy over time while the hybrids did not. Still, a 23% increase of in-use fuel economy is a substantial benefit for the fleet. It should also be noted that the hybrids were operating on a more urban driving schedule than the conventionals (71 miles/day vs. 84 miles/day) and a larger improvement in mpg could be possible if hybrid and conventional vans were operated on the exact same routes.
- There still was no statistically significant difference between the diesel and hybrid groups for total maintenance cost per mile (P value = 0.46). Vehicle to vehicle variation was great and the difference in the cumulative numbers was small.
- There still was no statistically significant difference between the diesel and hybrid groups for propulsion maintenance cost per mile (P value = 0.33). Vehicle to vehicle variation was great and the difference in the cumulative numbers was small.
- There was a statistically significant 19% hybrid group advantage for fuel cost per mile (assuming $3.09/gal) (P value = 0.0048). Vehicle to vehicle variation was lower than with the maintenance metrics.
- Total operating costs per mile for the hybrids were 10% less than those for the diesels but were not found to be statistically significant. The average fuel costs per mile for each group were 60-70% of total costs per mile but maintenance cost variation was large enough to eliminate the statistical significance that the consistent fuel cost per mile savings the hybrids brought to the equation.
- The hybrid group had a cumulative average of 96.3% uptime over the 36-month study period, less than the diesel group's cumulative average of 99.0% uptime. The hybrids experienced troubleshooting and recalibration issues related to prototype components, which were primarily responsible for the lower uptime figures.

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