

In-Use and Vehicle Dynamometer Evaluation and Comparison of Class 7 Hybrid Electric and Conventional Diesel Delivery Trucks

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ABSTRACT

This study compared fuel economy and emissions between heavy-duty hybrid electric vehicles (HEVs) and equivalent conventional diesel vehicles. In-use field data were collected from daily fleet operations carried out at a FedEx facility in California on six HEV and six conventional 2010 Freightliner M2-106 straight box trucks. Field data collection primarily focused on route assessment and vehicle fuel consumption over a six-month period. Chassis dynamometer testing was also carried out on one conventional vehicle and one HEV to determine differences in fuel consumption and emissions. Route data from the field study was analyzed to determine the selection of dynamometer test cycles. From this analysis, the New York Composite (NYComp), Hybrid Truck Users Forum Class 6 (HTUF 6), and California Air Resource Board (CARB) Heavy Heavy-Duty Diesel Truck (HHDDT) drive cycles were chosen. The HEV showed 31% better fuel economy on the NYComp cycle, 25% better on the HTUF 6 cycle and 4% worse on the CARB HHDDT cycle when compared to the conventional vehicle. The in-use field data indicates that the HEVs had around 16% better fuel economy than the conventional vehicles. Dynamometer testing also showed that the HEV generally emitted higher levels of nitric oxides than the conventional vehicle over the drive cycles, up to 77% higher on the NYComp cycle (though this may at least in part be attributed to the different engine certification levels in the vehicles tested). The conventional vehicle was found to accelerate up to freeway speeds over ten seconds faster than the HEV.

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INTRODUCTION

Companies that rely on heavy-duty fleet vehicles are continually investigating ways to improve the performance of their vehicles, whether it is better fuel economy, enhanced durability, or improved air quality by reducing harmful vehicle emissions. Hybrid electric vehicles (HEVs) play an important role in the strategy to reduce fuel consumption in the medium- and heavy-duty trucking industry markets. Because heavy-duty hybrid electric powertrain technology is relatively new, there is still a need for investigations into the overall performance of these systems in vehicles.

Medium- and heavy-duty parallel hybrid electric drivetrains typically consist of electricity storage in batteries and use of electrical motors integrated into traditional powertrain systems. These HEV systems offer fuel economy benefits by recapturing energy via regenerative braking and

then using that energy to assist the powertrain during accelerations. These systems still rely on the traditional powertrain of the vehicle, but complement it with additional power through the electric motor so that the demand on the petroleum-driven power plant is decreased.

The main purpose of this study was to evaluate and compare fuel economy and emissions of HEVs with their conventional diesel truck counterparts of the equivalent capabilities.

BACKGROUND AND METHODS

FedEx Express recently purchased and implemented several new HEV and conventional powertrain straight trucks into their fleets in California. The National Renewable Energy Laboratory (NREL) worked in conjunction with FedEx Express to perform an in-use field and dynamometer

evaluation of many of the vehicles from this new fleet. The field evaluation took place in Ontario, California.

In-Use Field Evaluation Setup

Vehicles with 2010 emissions certification levels were evaluated in the field. These vehicles have diesel aftertreatment technology including diesel oxidation catalysts (DOCs), diesel particulate filters (DPFs), and selective catalytic reduction (SCR) systems in the exhaust. The Ontario, California, FedEx fleet included several 2010 Freightliner M2-106 Class 7 straight trucks that met these criteria. The fleet also included one HEV of the same make and model. Ontario was an ideal location for this evaluation as the fleet there operates over varying types of duty cycles, from city to highway driving.

Isaac Instruments DRU900/908 data loggers were deployed on 12 of the original Ontario vehicles in the fleet, including the one HEV, for three weeks. They recorded J1939 controller area network (CAN) bus communication and global positioning system (GPS) data as the FedEx drivers worked their usual daily routes. This data was then analyzed for drive cycle analysis, as described in the Drive™ Analysis section later.

After the drive cycle analysis was performed, five additional Freightliner M2-106s HEVs were transferred to Ontario from another FedEx Express location, making a total of six HEVs in the fleet. These six HEVs, in addition to six equivalent conventional diesel vehicles of the same make and model, were included in a six-month performance evaluation over routes selected for their representative kinetic intensities (KI) [1]. The drivers of these 12 vehicles were asked to complete fuel logs so that fuel economy comparisons could be made. Other maintenance records of vehicles included in the study were kept as well. Also, during the six-month study period, one conventional vehicle and one HEV recorded operational data with the Isaac loggers.

DRIVE™ Analysis

NREL's Drive-cycle Rapid Investigation, Visualization, and Evaluation (DRIVE™) analysis tool [2, 3] was used to filter and analyze the field data collected as part of the study. Employing NREL's DRIVE analysis tool, researchers were able to visualize collected drive cycle data to produce route maps using Google Earth software, which when coupled with daily vehicle mileage data, helped ensure high levels of data quality. In addition to data quality validation via route mapping and mileage distributions, NREL researchers employed DRIVE to analyze daily vehicle operation, producing a list of approximately 150 unique drive cycle metrics that were then used to characterize vehicle operating behavior and select representative chassis dynamometer test cycles. Drive cycle metrics calculated as part of the analysis ranged from vehicle energy level metrics such as kinetic power density consumed (watts per kilogram) and KI to high-level route descriptors such as average driving speed (mph) and stops per mile. All of the analytical metrics were

calculated using different variations of the fundamental road load equation. Due to a lack of reliable road grade and vehicle mass information, the effects of changes in road grade and vehicle mass were not included in calculations.

Chassis Dynamometer Testing Methods

Chassis dynamometer test cycle selection

An un-weighted multivariate least squares method was applied to analyzed drive cycle data in order to select industry standard chassis test cycles for chassis dynamometer testing purposes. Examining drive cycle metrics such as average driving speed, stops per mile, and others, a highly representative set of chassis dynamometer test cycles was chosen to highlight shortcomings and advantages of the HEV under varying in-use duty cycles. The cycles selected using this least squares method corresponding in order of greatest to least advantage were the New York Composite (NYComp) cycle (Figure 1), the Hybrid Truck Users Forum Class 6 (HTUF 6) cycle (Figure 2), and the California Air Resources Board Heavy Heavy-Duty Diesel Truck (CARB HHDDT) cycle (Figure 3). See Table 1 for individual cycle statistics and information.

Table 1. Drive cycles selected for chassis dynamometer testing.

	CARB HHDDT	HTUF 6	NYComp
Duration (sec)	3604	3906	1029
Distance (miles)	26.0	10.9	2.5
Ave. Speed (mph)	26.0	10.0	8.8
Max Speed (mph)	59.3	56.6	36
Kinetic Intensity (1/mile)	0.17	1.55	4.30
Total # of Stops	13	28	20

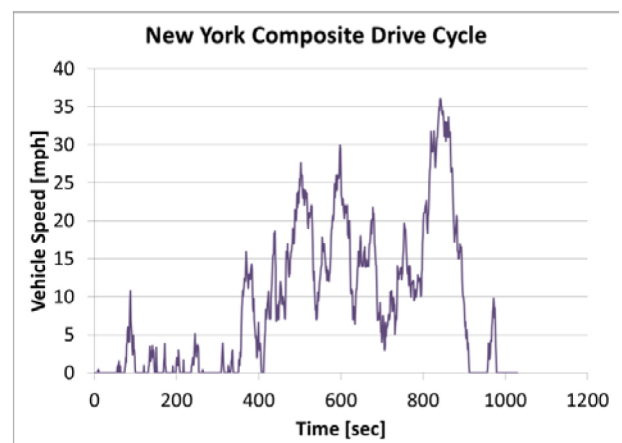


Figure 1. New York Composite drive cycle.

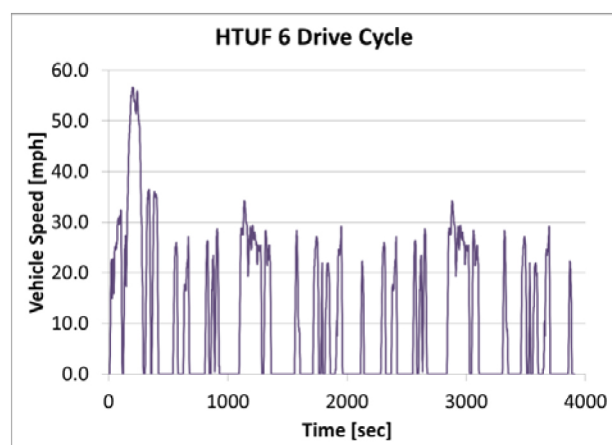


Figure 2. Hybrid Truck Users Forum Class 6 drive cycle.

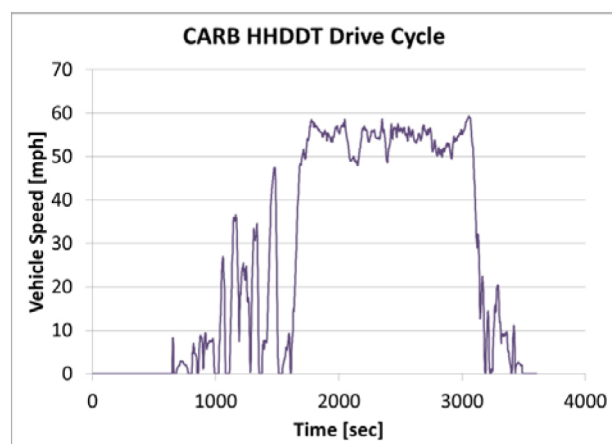


Figure 3. California Air Resources Board Heavy Heavy-Duty Diesel Truck drive cycle.

Heavy-duty chassis dynamometer testing

One HEV and one conventional vehicle were tested on the heavy-duty chassis dynamometer at NREL's Renewable Fuels and Lubricants (ReFUEL) facility [4]. Specifications of both vehicles can be found in Table 2.

The dynamometer used for this testing is capable of simulating transient loads on heavy-duty vehicles of up to 80,000 lbs. gross vehicle weight at speeds up to 60 mph. The dynamometer is an in-ground installation with 40-in.-diameter tandem rolls protruding above the surface to interface with the vehicle wheels. The base inertia of the dynamometer rotating components is 31,000 lbs. A direct-current (DC) motor (380 horsepower absorption/360 horsepower motoring capacity) is supplemented to simulate the vehicle inertia in the range of 8,000 to 80,000 lbs., as well as to simulate aerodynamic drag, rolling resistance, and grade loading.

Table 2. Vehicles used in the in-use field study and chassis dynamometer testing at NREL.

	Conventional Truck	Hybrid Electric Truck
Truck Manuf.	Freightliner	Freightliner
Truck Model	M2-106	M2-106
Truck Model Year	2010	2010
Engine Manuf.	Cummins	Cummins
Engine Model	ISB 6.7 220	ISB 6.7 200
Engine Power (HP)	220 @ 2300 rpm	250*
Engine Date of Manuf.	2010	2009
NO _x EPA FEL (g/bhphr)	0.33	0.40*
Emissions Aftertreatment	DOC, DPF, SCR	DOC, DPF, SCR
Transmission	Allison automatic	Eaton auto-shift hybrid
Gross Vehicle Weight (lbs.)	32,000	32,000
Curb Vehicle Weight (lbs.) (empty)	18,220	18,900
Max Payload (lbs.)	13,780	13,100

*The original calibration of the HEVs engines were 200 HP @2300 rpm but were changed to 250 HP after delivery of vehicles to FedEx. It is unknown what the FEL of the updated calibration is so the original 0.40 level could be incorrect. The HEV transmission calibrations were also switched to "performance" mode at this same time to help improve overall acceleration of the vehicles by adjusting shift timing. EPA= U.S. Environmental Protection Agency
FEL = family emissions limit
g/bhphr = grams per brake horsepower hour

To assure the accuracy and consistency of road load simulations, the dynamometer is subjected to various procedures and checks. With the vehicle lifted off the rolls, an automated dynamometer warm-up procedure is performed prior to testing until the parasitic losses in the dynamometer are stabilized. An unloaded coast-down procedure is also conducted to confirm that inertia and road load are being simulated by the dynamometer control system accurately. Additionally, after each test run a loaded coast-down procedure is performed to further ensure stability of vehicle and dynamometer parasitic losses and accurate road load simulation during testing. The vehicle is operated by a driver who follows a prescribed speed trace on the test aid monitor. A large fan is used to force cooling air onto the vehicle radiator to roughly simulate the ram cooling effect of vehicle in motion.