Drive Cycle Analysis, Measurement of Emissions and Fuel Consumption of a PHEV School Bus

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Drive Cycle Analysis, Measurement of Emissions and Fuel Consumption of a PHEV School Bus

Robb Barnitt and Jeff Gonder
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ABSTRACT

Plug-in hybrid electric vehicle (PHEV) technology may reduce fuel consumption and tailpipe emissions in many medium- and heavy-duty vehicle vocations, including school buses. The true magnitude of these reductions is best assessed by comparative testing over relevant drive cycles. The National Renewable Energy Laboratory (NREL) collected and analyzed real-world school bus drive cycle data, and selected similar standard drive cycles for testing on a chassis dynamometer. NREL tested a first-generation PHEV school bus equipped with a 6.4 L engine and an Enova PHEV drive system comprising a 25-kW/80 kW (continuous/peak) motor and a 370-volt lithium ion battery pack. For a baseline comparison, a Bluebird 7.2 L conventional school bus was also tested. Both vehicles were tested over three different drive cycles to capture a range of driving activity. Relative to the baseline school bus, the PHEV fuel savings in charge-depleting (CD) mode ranged from slightly more than 30% on the Urban Dynamometer Driving Schedule for Heavy Duty Vehicles and Rowan University Composite School Bus Cycle drive cycles to a little over 50% on the Orange County Bus cycle. However, the larger fuel savings lasted over a shorter driving distance, as the fully charged PHEV school bus would initially operate in CD mode for some distance, then in a transitional mode and finally in a charge-sustaining (CS) mode for continued driving. The test results indicate that a PHEV school bus can achieve significant fuel savings during CD operation relative to a conventional bus. In CS mode, the tested bus showed small fuel savings and somewhat higher nitrogen oxides (NOx) emissions than the baseline comparison bus. Further refinements to realize hybridization fuel savings in CS mode and calibrations focused on reducing NOx could lead to both higher fuel economy and lower NOx emissions in the next generation PHEV bus design.

INTRODUCTION

School buses encompass a range of sizes and applications. Class 6 and 7 versions (Figure 1) are those most commonly identified as school buses, with a typical capacity of 71 to 84 passengers. These so-called large school buses are the focus of this study, although there are smaller versions that are applied to different routes by school districts. In general, school buses are an attractive platform for application of plug-in hybrid electric (PHEV) technology due to several compelling attributes:

1. Many transient-intensive drive cycles conducive to PHEV application;
2. Fleet-based vehicles that return to a home base, facilitating overnight and possibly midday charging;
3. Potential for significant fuel savings per vehicle; and
4. Attractive value proposition, given the potential for reduced maintenance costs, a longer period of vehicle ownership, and reduced exposure of children to combustion emissions.

Figure 1: Class 6/7 School Bus

The National Renewable Energy Laboratory (NREL) completed a two-phase project to assess the performance of a first-generation PHEV school bus. The first project component involved collection and analysis of school bus vocational drive cycle data. Next, chassis dynamometer testing of a PHEV and a conventional diesel baseline school bus was conducted at NREL's Renewable Fuels and Lubricants (ReFUEL) research laboratory, where fuel consumption and emissions were measured over three vocationally relevant drive cycles.

APPROACH

DRIVE CYCLE DATA COLLECTION AND ANALYSIS

Knowledge of vocational drive cycles is important for comparative testing and vehicle design purposes. First, comparing an advanced technology to a baseline in a controlled test will only yield relevant results if the drive cycles tested match or at least bound the in-use drive cycles of the vehicle type. Testing a school bus on the very aggressive Manhattan Bus drive cycle, for example, may over-predict the fuel consumption and emissions reduction advantages of a PHEV school bus typically driven on less intensive routes. Second, designing a PHEV school bus with adequate power and onboard energy to cover 100 miles of intense driving may not be necessary if, for example, the actual route is 35 miles and less intense.

NREL instrumented school buses in three geographic regions (Colorado, Texas and New York) to collect global positioning system-based spatial and velocity data. GeoStats Geologger and Isaac Instruments DRU908 and DRU900 data acquisition devices were used to collect global positioning system data with at least 1 Hz frequency. With assistance from the Adams County School District in Colorado and its telematics vendor Zonar Systems, additional data were collected. The overall dataset included 861 individual vehicle operational shifts, 109 unique vehicles, and a mix of large, medium and small school buses. The results presented here focus on the larger class 6/7 school buses with a capacity of over 71 passengers. The data for these larger school buses included 614 operational shifts and 73 unique vehicles. These data were analyzed using the NREL Vehicle Drive Cycle Tool [1], and each drive cycle was characterized according to 172 key metrics, including speed bins, stops per mile, daily (and shift) distance driven, and kinetic intensity [2]. Kinetic intensity, a metric that is derived from the vehicle road load equation, is linked to the magnitude and frequency of accelerations, and as such offers insight into the cycle-specific benefits of electric drive. Select results are presented in Table 1.

Table 1: Large school bus drive cycle data

Drive Cycle Metric	Mean	Standard Deviation
Shift Distance Traveled (miles)	35.38	15.89
Average Driving Speed (mph)	25.14	4.69
Time at zero speed (%)	45.95	13.78
# of stops per mile	1.66	0.59
Maximum Driving Speed (mph)	58.36	9.35
Kinetic Intensity (1/mile)	1.28	0.74
Standard Deviation of Speed (mph)	15.92	2.95

Additional characteristics of the large school bus data set are presented in Figures 2 through 4. Understanding true vehicle usage is critical not only in design, but also in deployment. Onboard vehicle power and energy should be functions of real vocational driving requirements. Until more electric drive options are available, it is important for fleets to match routes to technology to maximize benefits (reduced fuel consumption) while accelerating their return on investment.

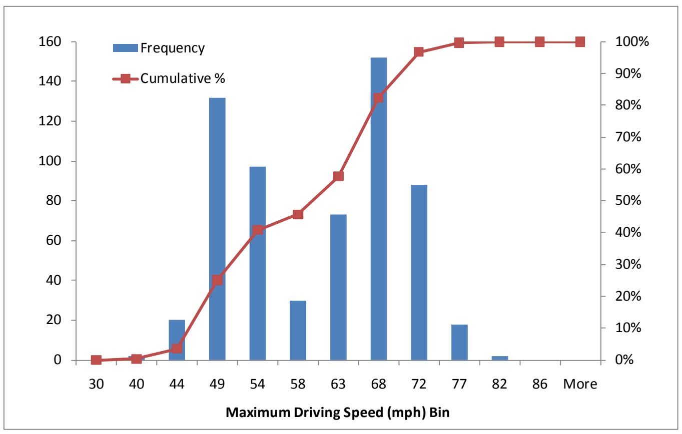

Figure 2: Maximum driving speed 3-sigma distribution

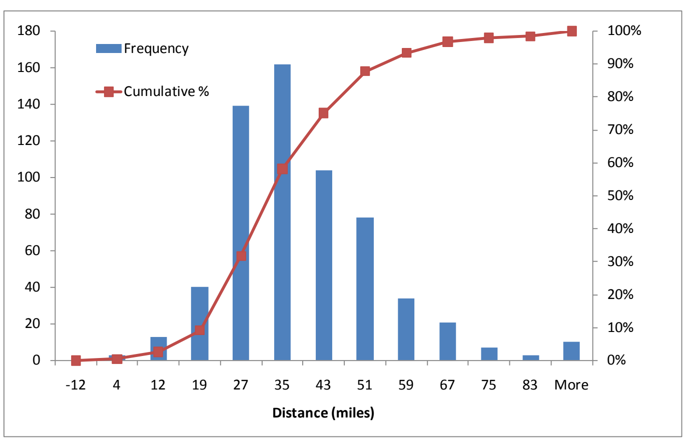

Figure 3: Route length 3-sigma distribution

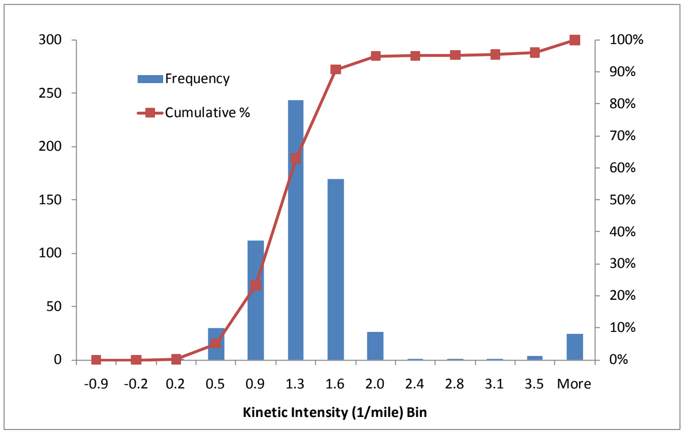

Figure 4: Kinetic intensity 3-sigma distribution

TEST CYCLE SELECTION

Drive cycles were compared primarily on the basis of kinetic intensity and, based upon this characterization and evaluation, three standard test cycles were identified as vocationally relevant to observed school bus usage inasmuch as they closely matched the average, lower and upper bounds of calculated kinetic intensity (Table 2).

Table 2: Drive cycle analysis results

Drive Cycle Characteristic	Data Avg. (stdev)	UDDSHDV	RUCSBC [3]	OCC
Average Driving Speed (mph)	25.14 (4.69)	28.23	26.59	15.67
Max. Driving Speed (mph)	58.36 (9.35)	58	49.7	40.63
Stops per Mile	1.66 (0.59)	2.52	1.44	4.74
Kinetic Intensity (1/mile)	1.28 (0.74)	0.61	1.68	3.59
Std Deviation of Speed (mph)	15.92 (2.95)	19.83	16.05	10.30

LABORATORY VEHICLE EMISSIONS AND FUEL ECONOMY MEASUREMENT

The ReFUEL laboratory utilizes a heavy-duty vehicle (chassis) test cell with emissions and fuel consumption measurement capability. One PHEV and one comparable conventional diesel school bus owned and operated by the Adams County School District were transported to and tested at the ReFUEL laboratory. The goal of the ReFUEL laboratory testing was to compare the fuel consumption and emissions of these two vehicles. At the time of testing, the ReFUEL laboratory's chassis dynamometer was capable of testing class 3 – 8 vehicles weighing between 8,000 and 80,000 lbs. The test cell utilized a combination of mechanical (flywheels) and electrical (direct current [DC] motor) inertia, connected to twin 40-in. rolls with an adjustable wheelbase. The lab's precision emissions testing equipment can measure criteria pollutants at levels consistent with the 2007 Code of Federal Regulations for 2010 heavy-duty on-road emissions technology. For the fuel consumption results, the lab utilizes a high-accuracy (±0.5%) fuel metering system to measure the net fuel flow into the engine. Although the ReFUEL laboratory does have the ability to modify the engine's air intake to match different ambient test conditions, including sea-level elevation testing, the tests on the two school buses were conducted at Denver's local altitude (5,280 feet above sea level). The Not-To-Exceed standard promulgated by the U.S. Environmental Protection Agency ensures that heavy-duty engine emissions are controlled over the full range of speed and load combinations commonly experienced in use. One element of meeting the Not-To-Exceed standard is vehicle altitude, which must be less than or equal to 5,500 feet [4]. Thus, ReFUEL emissions test results are applicable to altitudes less than or equal to 5,500 feet.

Table 3 summarizes the characteristics of the two school buses tested. The test mass for each bus reflects the curb mass, a full tank of fuel, plus 37 occupants at 150 lbs each (assuming one driver plus 50% of the maximum passenger capacity). Both buses had a 72-

passenger seating capacity, and both contained a diesel particulate filter (DPF) and engines certified to 2010 emissions levels. Note, however, that the on-road duty cycles for a particular application (e.g., a school bus) can apply different loads on the engine relative to those applied by standard certification testing on an engine dynamometer. Chassis-level testing becomes even more important for medium- and heavy-duty hybrids and PHEVs due to their added disconnect between load demands at the engine and at the wheels of the vehicle.

Table 3: Test vehicle characteristics

	PHEV School Bus	Conventional Diesel School Bus
Chassis / Integrator	2007 IC Corp / Enova	2008 Bluebird
Engine	6.4L MAXXFORCE 149 kW (200 hp)	7.2L Caterpillar 261 kW (350 hp)
Electric Motor	25/80 kW (cont./peak)	NA
Traction Battery	Valence U24-12XP 370 V, 100 Ah, 35.8 kWh	NA
Test mass (lbs)	27,850	24,550
Passenger Capacity	72	72
DPF Equipped	Yes	Yes

As discussed in the previous section, NREL tested each bus over three distinct duty cycles. In order to confirm repeatability of the emissions and fuel use measurements, the test matrix included three "hot-start" replicates of each test cycle (meaning test runs that had been preceded by a warm-up cycle). For the baseline conventional bus (and a few test runs of the PHEV bus with the hybrid system turned off), this involved performing multiple back-to-back repetitions of the Urban Driving Dynamometer Schedule for Heavy Duty Vehicles (UDDSHDV), Rowan University Composite School Bus Cycle (RUCSBC) and Orange County Bus Cycle (OCC) test cycles. Although data were recorded on the first test cycle of the day, which started "cold," the corresponding emissions and fuel consumption measurements were not included in the average and standard deviation calculations of the hot-start repetitions. Similarly, cycles that included an active DPF regeneration event were left out of the average values presented in the next section to exclude the variable impacts of regeneration on the results summary over repeatable test conditions.

A similar procedure was used to obtain replicate results from the PHEV bus testing, although two factors adding complexity included: 1) the fact that PHEVs employ different operating modes based on the traction battery's state of charge, and 2) the lengthy time required to fully test the PHEV on each cycle over the full range of battery charge. Figure 5 illustrates the PHEV behavior over a full test, including both charge-depleting (CD) and charge-sustaining (CS) modes of operation.

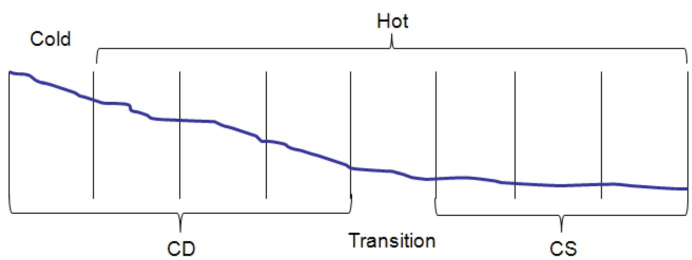

Figure 5. Typical PHEV behavior over multiple operating modes

The downward sloping line in Figure 5 represents the qualitative decline in the charge of the PHEV traction battery over multiple repetitions of a given drive cycle (where the space between adjacent pairs of vertical lines represents one cycle repetition). The test begins at the far left after the PHEV battery has been fully charged overnight with the vehicle soaked at the ambient test condition. The first cycle is then run with a cold start and begins depleting the battery. The tested bus's engine also runs during CD mode as it employs a blended PHEV design [5] (as opposed to a design that operates all-electrically in CD mode). The subsequent cycle repetitions are all hot starts: these steadily deplete the battery at first; battery depletion then tapers and finally levels off as the vehicle enters CS mode. After completing the last cycle repetition, the vehicle was plugged in for 12 hours (overnight) to bring the battery back to full charge. Fully repeating this sequence three times for all three of the test cycles examined would have required more days of testing than the project budget allowed. Instead, the presented average replicate results summarize the fairly repeatable PHEV behavior during the hot-start CD and CS operating modes (which only required running extra CS cycles once the battery depleted).

NREL monitored alternating current (AC) from the wall plug during charge and DC from the vehicle battery during cycle testing using a Fluke clamp meter. The currents were converted/integrated to obtain power and energy by using the AC plug voltage (directly measured) and the DC battery voltage (recorded from the Enova monitoring system between cycle repetitions), respectively. Applying these methods revealed roughly 34 kWh depleted during each of the full test cycle repetitions (the DC-measured total over all the CD and transition cycles for a given drive profile test) and roughly 44 kWh (AC-measured) required to fully recharge the PHEV battery over 12 hours. The next section presents only per-mile electricity consumption results using AC energy as that is what the bus operator would pay for. The DC energy measurements are only used to allocate the appropriate fraction of the total AC recharge energy to each individual cycle (e.g., to obtain the replicate values for each hot-start CD cycle).

RESULTS

Because PHEVs consume two different "fuels" (petroleum and electricity), representing the vehicle's fuel consumption and comparing it to a baseline conventional vehicle can be challenging. Figure 6 provides one way to visualize PHEV energy use during each mode of operation using a two-dimensional consumption plot. Each point on the plot represents the fuel and electricity consumption for one repetition of a given drive cycle. The vertical axis in the plot represents petroleum-only fuel consumption. It follows that the results for the baseline conventional bus and for the PHEV bus operating in pure CS mode fall on this line. Data points moving off this line in the horizontal direction reflect conditions where electricity (originally supplied by the charging plug) begins contributing to vehicle operation. The points slope downward as larger electric contributions offset more and more fuel use, reducing fuel consumption. Note that for a given vehicle and test cycle the points form a linear slope with a defined y-intercept. If the points were to continue down and intersect the horizontal axis, the x-intercept point would represent the electricity consumption for 100% electric operation with no fuel use. As mentioned above, the results for the tested PHEV bus revealed no electric-only operation; all CD operation occurs above the horizontal axis in the blended region where driving power derives from a combination of fuel and electricity use.

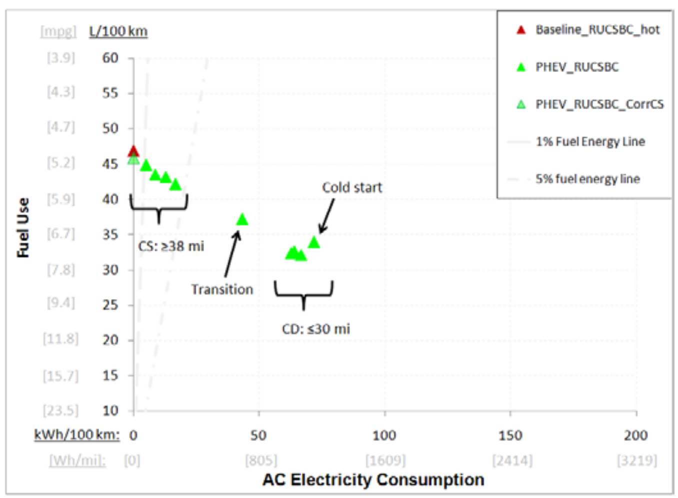

Figure 6. Two-dimensional consumption plot of RUCSBC test results

The labels in Figure 6 illustrate how each of the cycle consumption points corresponds with the cycle repetitions shown in Figure 5. The test begins chronologically at the data point indicated as the cold start. Note that this point falls slightly above the linear trend formed by the other points due to the typical warm-up consumption penalty that accompanies a cold-start cycle. The points nearest the cold-start point represent the next three (hot-start) CD cycles, and the fact that the points fall nearly on top of each other confirms the consistency anticipated with respect to the rate of fuel and electricity consumption for these cycles. The lone transition point begins showing the trend between reducing electricity consumption and increasing fuel consumption, and the trend continues with the cycle consumption results labeled as "CS" in the plot. These points progressively move closer and closer to the vertical axis, indicating that the vehicle is actually still slightly depleting the battery as it asymptotically approaches CS operation. Nevertheless, the electricity use for these cases is small (<5% of the corresponding fuel use on an energy-equivalence basis) and together they form a well-defined slope of fuel vs. electricity consumption that may be used to perform a zero-delta state-of-charge correction (i.e., translate each of the points to a truly CS result that would fall on the vertical axis).

Figure 7 adds the results for the OCC and UDDSHDV tests to those for the RUCSBC shown in Figure 6. The results for all three test cycles show similar trends as the battery depletes over multiple cycle repetitions, albeit with different spreads in fuel consumption between the CD and CS modes. The consumption results for the three cycles show the UDDSHDV to have the lowest relative energy intensity and the OCC to have the highest. All three cycles have cold-start points that fall slightly above the right side of the trend line (the OCC shows two since the vehicle ran through two full depletion tests on that cycle). All the other points falling above the trend lines reflect hot-start cycles with some sort of anomalous behavior, such as an active DPF regeneration event. The OCC seemed to require active regeneration more often than the other two, perhaps due to that cycle's operation at lower speeds with significant stop and go.

The PHEV showed slightly less fuel consumption in CS mode on all three cycles relative to the baseline bus. However, the savings seem to result from the smaller engine rather than hybridization since fuel consumption tests on the UDDSHDV and the OCC with the hybrid system switched off showed no significant difference from the CS mode results (when both were run at the PHEV test mass). The limited electric motor assist to the 149-kW engine resulted in occasional trace miss in CS mode and in roughly 5% less cycle energy as measured at the dynamometer rolls in CS relative to CD mode. Comparing the CD mode to the baseline bus results reveals significant fuel savings while the PHEV depletes the electric charge stored in its battery—on the order of 30%–50% depending on the cycle.

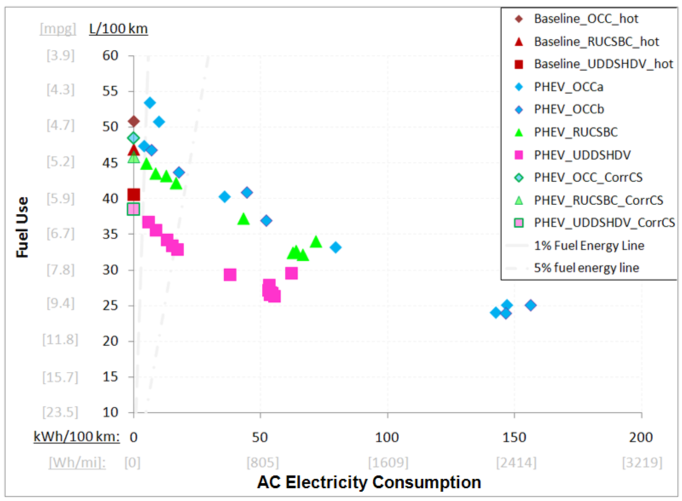

Figure 7. Two-Dimensional consumption plot of multiple test cycle results

One limitation of the two-dimensional consumption plot is that it does not readily convey the distance over which the PHEV operates in CD vs. CS mode. Figure 6 includes annotations indicating that CD mode occurs over roughly 30 miles (four RUCSBC cycle repetitions) before the vehicle begins transitioning to CS mode. The depletion distance can vary for other cycles, such as the OCC, which has a much higher rate of CD electricity consumption that depletes the battery charge over a shorter distance. Figures 8 and 9 illustrate how the PHEV's *cumulative* consumption relative to the baseline vehicle varies with respect to the distance it drives between battery charges.

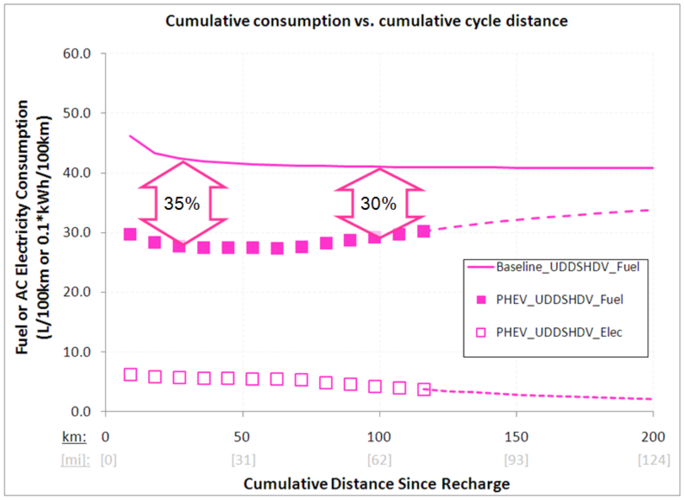

Figure 8. Cumulative consumption rate vs. distance for the UDDSHDV cycle

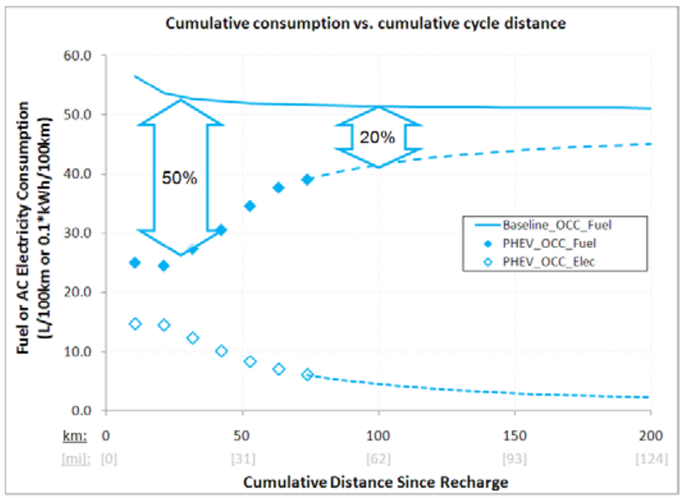

Figure 9. Cumulative consumption rate vs. distance for the OCC

As the figures show, both the driving cycle and the driving distance between charges significantly influence the total fuel savings. For the UDDSHDV, shown in Figure 8, CD fuel savings of roughly 35% persist over the first 40 miles of driving (assuming the battery starts with a full charge). Because of this long depletion distance, the cumulative fuel savings relative to the baseline bus are still 30% after 60 total miles of driving. For the OCC, shown in Figure 9, the large initial electric consumption results in 50% fuel savings relative to the baseline bus over the first 15 miles of driving. However, following the rapid battery depletion, the cumulative savings drop to roughly 20% if the vehicle travels 60 miles on this cycle before recharging (albeit relative to a larger magnitude fuel consumption for the baseline bus on the OCC).

Table 4: Summary results from hot-start replicate cycles

Vehicle, Cycle	Operating Mode	Fuel Consumption L/100 km Avg (mpg Avg)	Fuel Consumption Stdev	% Change vs. Base	Electric Consumption AC kWh/100 km Avg	Electric Consumption Stdev	NOx g/mi Avg	NOx Stdev	% Change vs. Base	Cyc Energy/Dist bhp-h/mi Avg	Cyc Energy/Dist % Chg. vs. Base
Baseline, UDDSHDV	N/A	40.5 (5.8)	0.4	N/A	0	0	4.3	0.05	N/A	1.30	N/A
PHEV, UDDSHDV	CD (<39 mi)	26.8 (8.8)	0.3	-34%	53.9	0.6	5.0	0.15	17%	1.62	25%
PHEV, UDDSHDV	CS (>44 mi)	38.6 (6.1)	0.1	-5%	0.0	0.0	5.7	0.08	32%	1.58	21%
Baseline, RUCSBC	N/A	46.9 (5.0)	0.6	N/A	0.0	0.0	5.0	0.07	N/A	2.03	N/A
PHEV, RUCSBC	CD (<30 mi)	32.4 (7.3)	0.3	-31%	64.5	2.0	4.8	0.01	-4%	2.41	19%
PHEV, RUCSBC	CS (>38 mi)	45.8 (5.1)	0.3	-2%	0.0	0.0	5.6	0.12	12%	2.33	15%
Baseline, OCC	N/A	50.8 (4.6)	0.2	N/A	0.0	0.0	4.2	0.05	N/A	1.67	N/A
PHEV, OCC	CD (<13 mi)	24.0 (9.8)	0.1	-53%	144.6	2.6	5.9	0.02	39%	2.02	21%
PHEV, OCC	CS (>26 mi)	48.6 (4.8)	0.1	-4%	0.0	0.0	9.6	0.17	128%	1.94	16%

Table 4 summarizes the hot-start cycle results for the baseline bus and for the PHEV in CD and CS mode (with cycles containing operational anomalies, such active DPF regeneration, excluded). The second column in the table also indicates the range over which CD vs. CS operation was observed to occur. As mentioned previously, these ranges vary for different driving profiles. The CS mode fuel consumption results shown in the table have been adjusted using the state-of-charge correction procedure described earlier, but no adjustment has been applied to the nitrogen oxides (NOx) emissions measurements. The particulate matter emissions for both buses were 0.01 g/mi or less on each of these cycles (again excluding the cycles containing active regeneration).

As indicated by the small standard deviation values, the results over these test conditions were very repeatable. However, the PHEV bus's actual total CD mode fuel consumption would be slightly worse than the values shown in Table 4 when the cold-start and/or transition cycles are included. Similarly, the actual "CS mode" fuel consumption would be slightly better if including the contribution from diminishing battery depletion as the PHEV asymptotically approaches true charge-neutral operation.

With respect to NOx emissions, the results indicate the emissions for the PHEV to be higher than for the baseline bus, particularly during CS operation. While the exact reason or reasons for the NOx difference are not known, potential causes include differences in NOx certification between the two engines tested, a sub-optimized NOx engine calibration for integration in this first-generation PHEV configuration, and the downsized nature of the engine in the PHEV. The smaller engine in the PHEV bus operates at or near peak load more often than does the larger engine in the baseline comparison bus. This is particularly true in CS mode where, as discussed earlier, the lack of motor assist forces the PHEV engine to work very hard, and at some points the PHEV bus is unable to keep up with the driving trace. Satisfying higher power demands inevitably moves the engine to a higher torque/speed point on its operating map. While a detailed emissions map was not available for the engines involved in this project, other studies have shown that exhaust gas recirculation can go down at high torque/speed points, which will in turn result in higher NOx emissions [6].

SUMMARY/CONCLUSIONS

This paper summarizes testing performed on a first-generation PHEV school bus in comparison to a baseline conventional diesel bus, and the drive profile analysis that guided cycle selection for the chassis dynamometer testing. The results demonstrate that the PHEV design can save large amounts of fuel—reducing fuel consumption by as much as 30% – 50% during CD operation. The actual fuel savings realized in a specific application, however, will depend on the intensity of the in-use driving profile and the distance the bus travels between recharge events. This has also been shown in light-duty PHEV analyses, but in the case of larger fleet vehicle vocations such as school buses, detailed information on the type and consistency of the driving profile can typically be determined. Knowledge of these usage patterns through duty cycle analysis can aid original equipment manufacturers in targeted design and aid end-users like school districts in deploying PHEVs on the most appropriate routes.

Both tested buses were equipped with DPFs, so their particulate matter emissions were quite low (equal or less than 0.01 g/mi when the DPF was not actively regenerating). The test results did show higher NOx emissions from the PHEV relative to the baseline bus, particularly during CS operation. It is possible that implementation of a lower-NOx engine calibration specifically targeting integration with the electrified driveline could help eliminate that increase. Another opportunity to achieve even further fuel savings in the next generation PHEV design would be to target more efficiency improvements in CS mode using conventional hybrid electric vehicle design techniques. These techniques could include increasing use of the electric motor during CS operation, which could also help lighten the load on the PHEV's engine and reduce NOx emissions at the same time.

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DEFINITIONS/ABBREVIATIONS

AC	alternating current
CD	charge depleting
CS	charge sustaining
DC	direct current
DPF	diesel particulate filter
g	gram
hp	horsepower
Hz	hertz
km	kilometer
kWh	kilowatt-hour
L	liter
lb	pound
mi	mile
NOx	nitrogen oxides
NREL	National Renewable Energy Laboratory
OCC	Orange County bus Cycle
PHEV	plug-in hybrid electric vehicle
ReFUEL	Renewable Fuels and Lubricants
RUCSBC	Rowan University Composite School Bus Cycle
stdev	standard deviation
UDDSHDV	Urban Driving Dynamometer Schedule for Heavy Duty Vehicles

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13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
The National Renewable Energy Laboratory (NREL) collected and analyzed real-world school bus drive cycle data and selected similar standard drive cycles for testing on a chassis dynamometer. NREL tested a first-generation plug-in hybrid electric vehicle (PHEV) school bus equipped with a 6.4L engine and an Enova PHEV drive system comprising a 25-kW/80 kW (continuous/peak) motor and a 370-volt lithium ion battery pack. A Bluebird 7.2L conventional school bus was also tested. Both vehicles were tested over three different drive cycles to capture a range of driving activity. PHEV fuel savings in charge-depleting (CD) mode ranged from slightly more than 30% to a little over 50%. However, the larger fuel savings lasted over a shorter driving distance, as the fully charged PHEV school bus would initially operate in CD mode for some distance, then in a transitional mode, and finally in a charge-sustaining (CS) mode for continued driving. The test results indicate that a PHEV school bus can achieve significant fuel savings during CD operation relative to a conventional bus. In CS mode, the tested bus showed small fuel savings and somewhat higher nitrogen oxide (NOx) emissions than the baseline comparison bus.

15. SUBJECT TERMS
Plug-in Hybrid Electric Vehicle; PHEV; school bus; fuel savings; emissions

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