

Chassis Dynamometer Testing of a Class 5 Battery Electric Commercial Truck

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ABSTRACT

With funding from the California Energy Commission, the California Hybrid, Efficient and Advanced Truck Research Center, contracted with the University of California, Riverside's College of Engineering to evaluate the performance of a Class 5 battery electric urban delivery vehicle over two standardized driving cycles and a steady state range test on a chassis dynamometer. The test vehicle, a Smith Electric Newton Step Van, was equipped with a proprietary data acquisition system which was set to record a wide variety of vehicle parameters at a 1 Hz sampling period. In addition, the chassis dynamometer was set to measure and record additional parameters. Lastly, a portable J1772 EVSE recorded both grid energy and power at 15-minute intervals.

This project provides a controlled test evaluation of the Smith Electric Newton Step Van. It recognizes the vehicle's potential for a successful delivery vehicle and identifies several important findings and areas that will need further research. The Newton Step Van is an efficient and clean alternative to equivalent diesel vehicles. The Newton Step Van showed an equivalent fuel economy between 38.4 and 46.4 MPGe on the three cycles used for this project. While Smith Electric Vehicles advertises a total driving range of up to 80 miles for the Newton Step Van, the chassis dynamometer testing estimated total driving range superior to 100 miles on both the HTUF4 and OCBC cycles.

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INTRODUCTION

The California Hybrid, Efficient and Advanced Truck (CalHEAT) Research Center is a California-based resource center for research, development, demonstration and commercialization of advanced, efficient truck technologies and systems. The center works as a partnership of diverse stakeholder groups developing and implementing an overall research and a market transformation plan to inform manufacturers and suppliers on clean truck technology status, gaps, and needs for commercialization as well as guide state investment and funding for hybrid, efficient and advanced truck technologies.

Medium and heavy duty vehicles are critical to the economy, yet remain a real and growing challenge for fuel use, greenhouse gases, and criteria emissions. Medium and heavy duty on-road truck traffic serving urban and goods movement needs, combined with heavy duty off-road vehicle use at distribution centers and ports, contribute significantly to fuel use, poor regional air quality, and are a sizable source of greenhouse gas emissions. Urban delivery trucks are an important category of trucks contributing to the challenge.

The goal of this project was to evaluate the performance and energy use of a Class 5 battery electric urban delivery vehicle over two standardized driving cycles and a steady state range test on a chassis dynamometer. In particular, the test identifies:

- The energy usage in kWh from the battery output (DC energy, kWh),
- The energy usage in kWh from the point where electricity is introduced from the electrical outlet (AC energy, kWh),
- The total time to recharge the vehicle battery, and
- The usable battery capacity.

The testing was performed by the Center for Environmental Research and Technology (CE-CERT) of the University of California, Riverside's College of Engineering and was carried out on the University of California, Riverside Heavy Duty Chassis Dynamometer (HDCD). The dynamometer is designed to handle a range of vehicles and vehicle loads at on-road driving conditions. It includes a 48" Electric AC Chassis Dynamometer with dual, direct connected 300 horsepower motors attached to each roll set. The dynamometer applies appropriate loads to a vehicle to simulate factors such as the friction of the roadway and wind resistance that is

would experience under typical driving. A driver accelerates and decelerates following a driving trace while the vehicle is chained to the dynamometer.

TEST VEHICLE

The vehicle tested was a Smith Electric Newton Step Van (Figure 1), provided by a parcel delivery fleet, partner for this project.



Figure 1. The Smith Electric Newton Step Van

The Newton Step Van has a Gross Vehicle Weight Rating (GVWR) of 16,500 lbs. and a payload of 5,570 lbs. The vehicle is equipped with a SAE J1772 compliant charge port and an on-board charger fitted for 192 - 276 VAC single-phase and up to 64A. Additional information about the vehicle is shown in Table 1.

Table 1. Specifications of the test vehicle

Model / Model Year	Newton Step Van / 2013
Manufacturer	Smith Electric Vehicles
Motor	180 bhp (134 kW) Peak 480 lb-ft (650 Nm) Peak Smith Drive Brushless Permanent Magnet
Controller	Smith Drive Vector controlled AC system with regenerative braking
Battery	Smith Power Lithium-ion (iron phosphate) – 80 kWh
Rated Maximum Battery Capacity	240 Ah (at 100% SOC)
Battery Voltage	Nominal 343V / Maximum 354V
Charger	On-board, fully automatic SAE J1772
Charging Time (From 0 to 100% SOC)	At 75A: 6 to 8 hours ¹ At 30A: 14 to 17 hours ²
Braking	2 stage regenerative braking puts energy back into battery during coasting & braking
GVWR	16,500 lbs.
Vehicle Curb Weight	10,930 lbs.
Payload (including driver weight)	5,570 lbs.
Cargo Space	684 cubic feet
Overall Dimensions (Length / Height / Width)	268 in. / 94 in. / 87 in.
Wheelbase	154 in.
Chassis Configuration	4 x 2 (Rear Wheel Drive)
Range	Up to 80 miles
Top Speed	~63 MPH

¹ Charging current recommended by Smith Electric Vehicles.

² Due to the testing site infrastructure limitations, this is the charging current used for this testing.

DRIVE CYCLES USED FOR TESTING

Testing was conducted on the vehicle using two drive cycles: the Hybrid Truck Users Forum Parcel Delivery Class 4 (HTUF4) driving schedule and the Orange County Bus Cycle (OCBC). These drive cycles were used in a previous study conducted in partnership with the National Renewable Energy Laboratory (NREL) to evaluate gasoline/electric hybrid parcel delivery trucks [1].

HTUF4

The HTUF4 has three phases, Phase 1 from 0 to 419 seconds, Phase 2 from 420 to 1877 seconds, and Phase 3 from 1878 to 3336 seconds. Phase 3 is an exact duplicate of Phase 2. CE-CERT chose to run only Phase 1 and 2. The drive cycle, which includes five periods of engine off time, is shown in Figure 2.

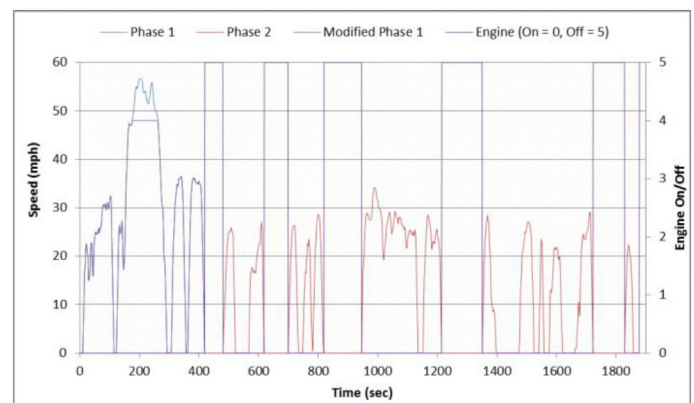


Figure 2. HTUF Class 4 Driving Schedule

OCBC

The OCBC is a continuous cycle from 0 to 1909 seconds with accelerations and decelerations from 0 to speeds between ~8 and ~40 MPH as seen in Figure 3.

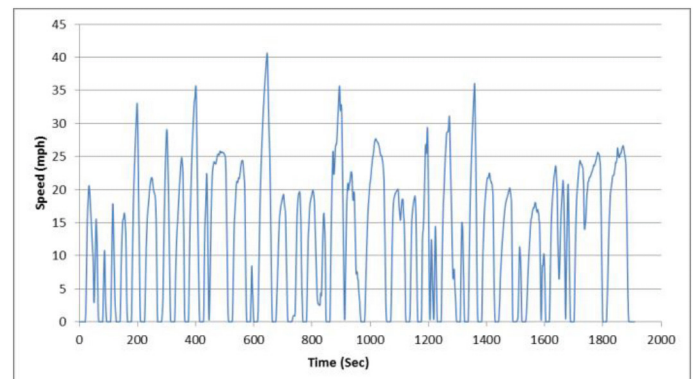


Figure 3. Orange County Bus Cycle

Steady State Range Test

The California Air Resources Board procedure to test zero-emission and hybrid electric vehicles specifies that the vehicle needs to be tested on a chassis dynamometer until "[it] is no longer able to

maintain the speed and time requirements specified” [2]. Given the drive cycles selected for this test and the vehicle range, this would prove impractical. For instance, if the vehicle has a total range of 100 miles, it will need to run sixteen OCBC drive cycles consecutively to fully deplete the battery. Including fifteen 10-minute soaks between tests, it would take a total of 10 hours and 59 minutes to complete this test.

To circumvent this long testing time, a different approach described by Lohse-Busch [3] was selected. The vehicle was tested on a 1909-second steady-state drive cycle at 55 MPH (Figure 4).

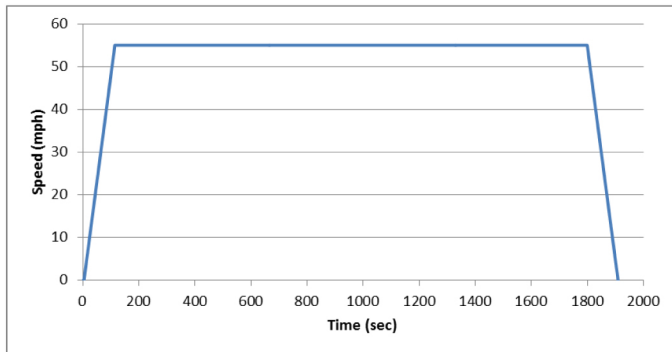


Figure 4. Steady State Range Test

Once the vehicle was no longer able to maintain the test and time requirement specified, it was brought to a stop and plugged in to be fully recharged. To estimate the total battery capacity, the energy required to fully charge the battery after the steady state range test was recorded. Then, using the overall energy consumption (in kWh/mile) for the HTUF4 and OCBC drive cycles and the recorded total battery capacity (in kWh), the total vehicle range for the HTUF4 and OCBC drive cycles was calculated.

Table 2 below presents some metrics of the three drive cycles used:

Table 2. Metrics of the HTUF4, OCBC and Steady-State Cycles

	HTUF4	OCBC	Steady State
Average Speed (MPH)	14.01	12.33	51.74
Standard Deviation of Speed	15.31	10.30	10.51
Maximum Speed (MPH)	56.59	40.63	55.00
Maximum Acceleration (MPH/sec)	5.00	4.06	0.50
Maximum Deceleration (MPH/sec)	-5.00	-5.13	-0.50
Total Time (sec)	1877	1909	1909
Idle Time (sec)	794	406	4
Total Distance (miles)	7.31	6.54	27.42
Number of Idle Periods	17	32	2
Number of Stops	16	31	1
% Idle	42.30	21.27	0.21

Note about Vehicle Accessories and Weather Conditions

It was decided that for all three test cycles, air conditioning and cabin fan would be switched off. In addition it was not possible to assess the influence on vehicle performance of ambient temperature and other weather conditions.

Actual electric range and overall energy consumption will vary widely with driving conditions such as drive cycle and vehicle accessories utilization. The numbers presented in this report are representative of specific drive cycles and driving conditions and were derived from testing done in a controlled environment. They should not be used to predict electric range and overall energy consumption in different driving conditions. For more information about the temperature effects on battery performance and the impact of air conditioning usage on overall energy consumption and total driving range, please see [4], a project conducted by Argonne National Laboratory to assess the performance of two all-electric powered vehicles.

METHODOLOGY

Coast Down Data

Coast down parameters were calculated using the frontal area calculation approach [5]. The frontal area was 56.79 square feet and the vehicle weight chosen for this testing was 13,175 lbs., which is the vehicle curb weight plus one half of the vehicle payload. The calculated coast down data is shown in Table 3.

Table 3. Calculated Coast Down Data

Vehicle Weight (lbs)	Seconds to coast down for MPH range				
	65 - 55	55 - 45	45 - 35	35 - 25	25 - 15
13,175	12.94	17.12	23.26	32.26	44.58

The results of the coast down calculations were used to set the coefficients for the chassis dynamometer testing (Table 4).

Table 4. Dynamometer Coefficients for the Tests

Load	A	B	C	Hp @ 50
lbs.	lbs./MPH	lbs./MPH	lbs./MPH	
13,175	97.41	-7×10^{-14}	0.1071	48.7

Regenerative Braking

The Smith Electric Newton Step Van is equipped with a two-stage regenerative braking system that puts energy back into the battery pack during coasting and braking. In addition, the vehicle has a switch to activate/deactivate the regenerative braking system. The partner fleet specified that drivers will be required to use the vehicle with the regenerative braking switch in the ON position at all times. Thus, the regenerative braking switch was left in the ON position for the entire testing.

Test Cycle Data

The vehicle was equipped with a proprietary Smith Link data acquisition system which was set to record the following vehicle parameters at a 1 Hz sampling period:

- Date and Time in Greenwich Mean Time (GMT),
- Ambient temperature (°C),
- Electric motor rotation speed (RPM),
- Accelerator pedal position,
- Brake pedal position,
- Battery current (A),
- Battery voltage (V),
- Battery State of Charge (%),
- Battery management system mode (0 = key-off, 1 = charging, 2 = driving)

Note that by convention, negative battery current values indicate energy used from the batteries to move the vehicle and power the accessories and positive battery current values indicate energy added to the batteries through regenerative braking or charging.

The Smith Link logging was continuous throughout the day and transmitted wirelessly to remote servers. After each testing day, an engineer from Smith Electric Vehicles sent all the testing files in .csv format for processing in Microsoft Excel.

In addition, the chassis dynamometer was set to measure and record the following parameters:

- Relative time in seconds from the beginning of the run,
- Speed in MPH,
- Distance in miles,
- Other variables as needed.

At the end of the driving schedule, the chassis dynamometer data was saved and later exported to a .csv file for processing.

Vehicle Charging Data

A portable J1772 EVSE (see [Figure 5](#)) was supplied for this testing. The EVSE came mounted on a cart and equipped with a revenue grade meter which recorded both grid energy (AC kWh) and power (kW) at 15 minute intervals.



Figure 5. Portable EVSE used for recharging the vehicle

Both the facility electrical system and the EVSE used for this testing were limited in the grid current that could be used for charging. Due to these testing site infrastructure limitations, the charging current recommended by Smith Electric Vehicles to recharge the Newton Step Van could not be used.

Therefore, the charging times recorded in this report are longer than what one would expect at a customer site equipped with the recommended charging infrastructure. In addition, using a different charge rate may affect the charger efficiency and thus, the overall energy consumption (in kWh/mile) calculated in this report may be larger than if the vehicle had been charged at the recommended charging rate.

At the end of each test day, the vehicle was put into charge using the portable EVSE until the vehicle dashboard displayed a charge complete window ([Figure 6](#)).



Figure 6. The Newton Step Van dashboard showing a charge complete

At the end of the full testing period, data was downloaded through optical ports on the front of the meter, using a special software tool. Grid energy (in AC kWh) was also manually read from the digital display of the meter attached behind the portable EVSE (see [Figure 5](#) on the right) before plugging and unplugging the portable EVSE.

Definition of Calculated Parameters

Using the test cycle data and the vehicle charging data described above, a wide variety of parameters were calculated to describe the test results.

- **Test Run**
A test run (or a run) represents one run through one of the three test cycles (HTUF4, OCBC or Steady State).
- **Test Day**
A test day represents a complete chassis dynamometer test for one of the three test cycles (HTUF4, OCBC or Steady State). It is composed of several test runs and several 10-minute soak periods between each test run.
- **Vehicle Speed**
Vehicle speed (in MPH) was derived from the Electric Motor Rotation Speed (in RPM) following [equation \(1\)](#) below:

$$\text{Vehicle Speed (MPH)} = A \times \text{Electric Motor Rotation Speed (RPM)} \quad (1)$$

Where A was calculated using vehicle tire diameter and overall drive reduction per Smith Electric Vehicles specifications.