Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

BATTERY ELECTRIC PARCEL DELIVERY TRUCK TESTING AND DEMONSTRATION

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Prepared by: California Hybrid, Efficient and Advanced Truck Research Center

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Transportation

Battery Electric Parcel Delivery Truck Testing and Demonstration is the final report for the CalHEAT Project Task 5, (contract number 500-09-019) conducted by CALSTART. The information from this project contributes to PIER's Transportation Program. This final report includes the following CalHEAT deliverables:

- Battery performance and state of health report,
- Final report on plug-in parcel delivery truck testing and demonstration.

The California Hybrid, Efficient and Advanced Truck (CalHEAT) Research Center was established by the California Energy Commission in 2010 as a project operated by CALSTART to research, plan, support commercialization and demonstrate truck technologies that will help California meet environmental policies mandated through 2050.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

Battery-electric vehicles hold significant promise for reducing emissions and fuel consumption in package delivery applications. To assess the performance of battery-electric vehicles, the California Hybrid, Efficient and Advanced Truck (CalHEAT) Research Center carried out a comprehensive performance evaluation of three E-Truck models using information and data from in-use data collection, on-road testing and chassis dynamometer testing. The results presented in this report provide a comprehensive overview of the performance of commercial E-Trucks in parcel delivery applications.

The findings of this report confirm the good fit of E-Trucks for parcel delivery applications previously identified by the CalHEAT Roadmap. This report also informs fleets and E-Truck manufacturers on the overall performance of E-Trucks, provides insights on how the technology can be improved on the one hand and better used on the other hand and gives information to the CalHEAT Roadmap to outline actionable steps on the electrification pathway identified by the Roadmap. The key findings and recommendations of this report fall into five major categories:

- Performance,
- Maintenance,
- Fleet deployment,
- Charging,
- Business case.

E-Truck technology is relatively new to the market, as commercial vehicles have been introduced only in the past few years. By providing unbiased, third-party assessment of this technology, we believe this report will offer relevant, timely and valuable information to the industry.

Keywords: CalHEAT, parcel delivery, walk-in van, step-van, E-Truck, battery electric vehicle, Navistar eStar, FCCC MT E-Cell, Smith Electric Newton Step Van, in-use data collection, on-road testing, chassis dynamometer testing, charging infrastructure.

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EXECUTIVE SUMMARY

This final report presents results, findings and recommendations of the testing and demonstration of battery electric parcel delivery trucks operated by a large parcel delivery fleet in Los Angeles, CA. This report presents the results of a comprehensive performance evaluation of three battery electric truck models (see Figure ES-1) using information and data from in-use data collection, on road testing and chassis dynamometer testing.

Figure ES-1: A Navistar eStar, a FCCC MT E-Cell and a Smith Electric Newton Step Van

a. E-Truck Performance Evaluation

Seven trucks were selected for the in-use data collection activity. Five of the trucks were battery electric trucks or E-Trucks (4 Navistar eStars and 1 Freightliner Custom Chassis MT E-Cell). From March 26 to December 18, 2012, the four Navistar eStars drove a combined total of 9,082 miles and consumed 9,496 kWh for an average AC energy consumption of 1.05 AC kWh per mile, equivalent to 35.8 MPG. From June 26 to December 18, 2012, the FCCC MT E-Cell covered 1,306 miles and consumed 1,986 kWh for an average AC energy consumption of 1.52 AC kWh per mile, equivalent to 24.7 MPG. The vehicles covered between 220 and 330 miles per month and consumed between 230 and 360 AC kWh per month. Most of the days, the eStars drove less than 30 miles per day and used less than 20% of the battery capacity.

Two conventional diesel trucks (Isuzu Reach Vans) were used to collect baseline data for comparison. For a period of three weeks, the two Isuzu Reach Vans drove a combined total of 844 miles. Their lifetime fuel economy was between 10.9 and 11.5 MPG.

Data showed that E-Trucks are more efficient than conventional diesel vehicles, with E-Truck efficiency being up to 4 times better than the fuel efficiency of similar diesel vehicles. E-Trucks are also cheaper to operate since they are more efficient and are generally fueled with cheap electricity. E-Truck yearly fuel cost is up to 80% lower than diesel fuel cost. With no tailpipe emissions, E-Trucks are cleaner to operate than vehicles fueled with fossil fuels. On a well-to-wheel basis, E-Trucks emit up to 70% less greenhouse gases when recharged with California electricity. Using domestically produced electricity, E-Trucks use almost no crude oil.

One prototype FCCC MT E-Cell was tested by the Electric Vehicles Technical Center of Southern California Edison over two routes designed on local street roads. The main goal of this task was to evaluate the maximum vehicle range, energy consumption from the grid in kWh in mile and total charging time following a controlled testing process.

Table ES-1: Summary of MT E-Cell on-road testing data

	Urban Range Test Min. Payload	Urban Range Test Max. Payload	Delivery Route Min. Payload
Duration of Drive	2h 52min	2h 15min	3h 28min
Total Distance Travelled	67.6 miles	56.2 miles	56.5 miles
Low Indicator Range	53.6 miles	44.9 miles	45.6 miles
Power Limiting Range	66.1 miles	55.8 miles	54.5 miles
Charge Duration (bulk of the charge)	13h 15min	13h 45min	13h 20min
Total Charge Energy	66.8 AC kWh	67.5 AC kWh	67.4 AC kWh
AC Energy Consumption	0.99 AC kWh/mile	1.20 AC kWh/mile	1.19 AC kWh/mile

The total vehicle range was measured between 56 and 68 miles depending on the payload and duty cycle. Vehicle efficiency was calculated between 1.0 and 1.2 AC kWh/mile, equivalent to 31.3 and 37.6 MPG.

Charging duration was measured as about 13 hours and 30 minutes to reach the bulk of the charge and can take up to 17 hours and 30 minutes to reach a full charge. A continuous power draw of 260 to 300 W was recorded after the charge was completed and until the vehicle was unplugged.

A Smith Electric Newton Step Van was tested on a chassis dynamometer at the Center for Environmental Research and Technology of the University of California, Riverside over two standardized drive cycles (the Hybrid Truck Users Forum Parcel Delivery Class 4 – HTUF4 and the Orange County Bus Cycle – OCBC) as well as a steady state range test. The main goal of this task was to evaluate maximum vehicle range, energy consumption from the grid in kWh per mile and total charging time.

Table ES-2: Summary of the chassis dynamometer main results

Test Cycle	Overall AC Energy Consumption	Equivalent MPG	Total Driving Range
HTUF4	0.81 AC kWh/mile	46.4 MPGe	110.7 miles (estimated)
OCBC	0.88 AC kWh/mile	42.7 MPGe	101.9 miles (estimated)
Steady State	0.98 AC kWh/mile	38.4 MPGe	91.6 miles (measured)

The Newton Step Van reached the best equivalent fuel economy and the lowest energy consumption on the HTUF4 drive cycle. Total driving range was estimated as 110.7 miles. The OCBC drive cycle, with more accelerations and decelerations, is a more intensive drive cycle and thus, equivalent fuel economy was lower and energy consumption higher than for the HTUF4 cycle. Total driving range was estimated as 101.9 miles. As expected, the Newton Step Van had the lowest equivalent fuel economy and the highest energy consumption on the steady state range test. Total driving range was measured as 91.6 miles.

The bulk charge duration (battery SOC goes from 0 to 100%) took about 13 hours and total charge duration took about 14 hours and 20 minutes (battery SOC goes from 0 to 100% and battery current drops to 0). A continuous power draw of 65 to 140W was measured after the charge was completed and until the vehicle was unplugged.

b. E-Truck User Acceptance

In order to assess the user acceptance of the E-Trucks, we conducted surveys and interviewed several fleet staff. Comparisons were made between electric and conventional trucks to determine the advantages and disadvantages during normal everyday use. Driver surveys assessed the performance of the E-Trucks and the mechanics surveys assessed their serviceability and maintainability.

The user acceptance surveys and interviews revealed several E-Truck specific issues on the Navistar eStar. Particularly, drivers noted the long time needed to start the vehicle. However, complaints also originated from vehicle design issues, unrelated to E-Truck specific characteristics. The eStar had design characteristics that were not fully adapted to parcel delivery operation and as a result, driver operations were considerably slowed down compared to a conventional vehicle. The user acceptance surveys and interviews also revealed a gap in driver training. With the eStar in particular, there were more than a few new operating steps that drivers needed to assimilate.

c. Service and Maintenance

The E-Trucks encountered several issues that made them generally less available than conventional diesel trucks. Since these vehicles were early production vehicles and had limited in-service experience, maintenance issues were anticipated to arise during the project performance period. Fleet mechanics had limited experience with E-Truck maintenance procedures and thus, all major repairs were handled by the E-Truck manufacturers. In addition, E-Truck manufacturers carried a limited inventory of spare parts.

From general maintenance costs and maintenance intervals data, we estimate that for an E-Truck operating from the downtown Los Angeles facility, maintenance savings would be around $250 per year, or 2-3¢ / mile for a vehicle that drives about 10,000 miles per year without including brakes and tires savings. For a vehicle that drives about 15,000 miles per year and including some brake and tire savings, we estimate that maintenance savings would be around $1,300 per year, or equivalent to 8-10¢ / mile.

d. E-Truck Charging

Based on the in-use data collection, on-road testing, and chassis dynamometer testing, a comprehensive analysis of E-Truck charging was developed to evaluate E-Truck charging patterns in parcel delivery operation and assess the impacts of E-Trucks charging on the building where they are recharging as well as on the local and state grid.

Typical charge duration for the FCCC MT E-Cell was measured between 12 and 14 hours to achieve the bulk of the charge and over 17 hours to achieve a full charge. Maximum charging current was recorded at 23.2 A (AC) and maximum grid charging power at 5.6 AC kW. A continuous power draw of 260 to 300 W was recorded after the charge was completed and until the vehicle was unplugged.

Total charge duration for the Navistar eStar was estimated between 12 and 13 hours. Maximum charging current was recorded at 24.3 A (DC) and maximum grid charging power was estimated at 8.8 AC kW.

At a continuous charging current of 32A, typical charge duration for the Smith Electric Newton Step Van was measured at about 13 hours to achieve the bulk of the charge and 14 hours and 20 minutes to achieve a full charge. Maximum charging current was recorded at 17 A (DC) and maximum grid charging power at 6.7 kW. A continuous power draw of 65 to 140W was measured after the charge was completed and until the vehicle was unplugged.

e. Findings and Recommendations

The findings of this report confirm the good fit of E-Trucks for parcel delivery applications previously identified by the CalHEAT Roadmap. This report also informs fleets and E-Truck manufacturers on the overall performance of E-Trucks, provides insights on how the technology can be improved on the one hand and better used on the other hand and gives information to the CalHEAT Roadmap to outline actionable steps on the electrification pathway identified by the Roadmap. The key findings and recommendations of this report fall into five major categories:

- **Performance:**

Table ES-3: Summary of E-Truck performance key findings

E-Truck Performance Key Findings	Report Section(s)
Operating conditions impact E-Truck performance	3.2 – 3.3
AC energy consumption is a better measure of overall vehicle efficiency	3.1 – 3.3
E-Trucks are more efficient and cheaper to operate	3.3 – 3.4
E-Trucks are cleaner to operate on a well-to-wheels basis	3.3 – 3.4
Different data collection methods exist to evaluate E-Truck performances	3.1 – 3.2 – 3.3

Recommendations:

1. Further testing should be carried out to better understand the impact of operating conditions on E-Truck performance.
2. AC kWh/mile should be used to compare the efficiency of E-Trucks with other vehicles.
3. Appropriate data collection techniques should be used to provide better performance data on E-Truck deployment projects.

- **Maintenance:**

Table ES-4: Summary of E-Truck maintenance key findings

E-Truck Maintenance Key Findings	Report Section(s)
E-Trucks need strong maintenance repair networks	5.1
E-Trucks have lower maintenance costs	5.2

Recommendations:

1. Local and regional maintenance repair networks as well as spare parts inventories need to be developed in correlation with E-Truck sales. In addition, fleet mechanics need to be trained to diagnose and service E-Truck maintenance issues.
2. A more complete analysis is needed to further investigate and understand the potential maintenance savings of E-Trucks.

❖ Fleet deployment:

Table ES-5: Summary of E-Truck fleet deployment key findings

E-Truck Fleet Deployment Key Findings	Report Section(s)
Train E-Truck drivers	3.5 – 4.2
Assign "early-adopter" drivers	4.2

Recommendations:

1. Drivers operating E-Trucks should be trained and coached to adapt their driving techniques to E-Trucks to take advantage of regenerative braking for instance.
2. "Early adopters" drivers should be selected first for E-Truck deployment project in order to build a positive experience.

❖ Charging:

Table ES-6: Summary of E-Truck charging key findings

E-Truck Charging Key Findings	Report Section(s)
Charging infrastructure is an important component of any E-Truck deployment project	6.1
Charging time depends on charging infrastructure	6.2
E-Truck "stand-by" power can negatively impact overall energy consumption	3.2 – 3.3 – 6.2
Impacts of E-Truck charging will be focused on building and local grid infrastructure	6.3

Recommendations:

1. Fleet managers should carefully plan E-Truck deployments to minimize charging infrastructure costs.
2. The charging current should be specified to guarantee vehicle availability.
3. Further testing should be carried out to better understand the origin of the stand-by current draw of E-Trucks when plugged in but not charging and explore ways to reduce its impact on overall E-Truck efficiency.
4. Demand response strategies should be implemented to take advantage of low energy prices such as Time-Of-Use pricing and avoid penalties such as demand charges.
5. Electric utilities and companies deploying E-Trucks need to work together to share the costs of local infrastructure upgrades in a way that is fair for ratepayers and acceptable for utility cost recovery structures but does not deter companies from deploying E-Trucks.

❖ **Business case:**

Table ES-7: Summary of E-Truck business case key findings

E-Truck Business Case Key Findings	Report Section(s)
Use E-Trucks on higher mileage routes	3.1 - 7.1
Incentives for purchase play a crucial role for the early E-Truck market	7.1
Right-sizing E-Truck battery is a viable cost reduction pathway	7.1
Future battery prices will make E-Trucks more cost competitive	7.1
Vehicle-To-Grid could improve the business case for E-Trucks	7.2

Recommendations:

1. E-Trucks should be deployed on routes with daily mileage greater than 50 miles.
2. Incentive funding needs to be available at this early stage of the E-Truck market.
3. Fleets, battery and E-Truck manufacturers should work together to develop, test and demonstrate E-Trucks with scalable battery packs.
4. Fleets, battery and E-Truck manufacturers should work together to reduce battery costs.
5. Fleets, battery and E-Truck manufacturers should work together to develop, test and demonstrate V2G options for E-Trucks in delivery applications.

Chapter 1 : Introduction

The California Hybrid, Efficient and Advanced Truck (CalHEAT) Research Center was established in 2010 by the Energy Commission to perform research in planning, commercializing and demonstrating truck technologies for efficient medium and heavy-duty vehicles. This project was part of a larger research and demonstration effort within the CalHEAT Research Center and focused on evaluating the performance of plug-in electric parcel delivery trucks in Southern California. Battery electric trucks or E-Trucks are expected to play an important role in the future of medium and heavy-duty transportation in California and will help our state achieve its long term goals of reducing petroleum use and greenhouse gas (GHG) emissions and improving air quality.

1.1 Purpose of the Report

This report presents the testing and demonstration results of E-Trucks in parcel delivery application. The goal of the report is twofold. First, the testing and demonstration of E-Trucks provide information to the CalHEAT Roadmap to outline actionable steps on the electrification pathway identified by the Roadmap (see section 1.2).

The second goal is to inform fleets and E-Truck manufacturers on the overall performance of E-Trucks and provide insights on how the technology can be improved on the one hand and better used on the other hand. E-Truck technology is relatively new to the market, as commercial E-Trucks have been introduced only in the past few years. By providing unbiased, third-party assessment of this technology, we believe this report will offer relevant, timely and valuable information to the industry.

This project evaluated the performance of several E-Truck models that are presented in Chapter 2. A comprehensive performance evaluation is covered in Chapter 3 which includes review of information from in-use data collection, on-road testing and chassis dynamometer testing. User acceptance is detailed in Chapter 4 followed by a preliminary reliability and maintenance evaluation of E-Trucks in Chapter 5. E-Truck charging is covered in detail in Chapter 6. Finally, a business case analysis for E-Trucks is detailed and main findings and recommendations are presented in Chapter 7.

1.2 CalHEAT Roadmap and Electrification of Transportation

The CalHEAT Research Center was established to support commercialization and demonstration of truck technologies that will help California meet or exceed its 2020 goals in petroleum reduction, carbon reduction, and air quality standards, and identify longer term goals through 2050. The CalHEAT Roadmap focuses on medium and heavy-duty vehicle technology strategies and identifies action items to help mitigate emissions and improve efficiency of trucks [1]. Overall, the action items focus on 13 technology strategies which are grouped broadly into 1) electrification strategies, 2) engine or driveline efficiency strategies, and 3) chassis, body and roadway systems. Electrification technology strategies are particularly important as they are seen as the principal way to reduce petroleum dependence and decrease emissions. The electrification technology strategies include the following:

- Hybrid Electric
- Electrified Auxiliaries
- E-Trucks
- Electrified Power Take-off
- Plug-in Hybrid Electric
- Electrified Corridor
- Alternative Fuel Hybrids

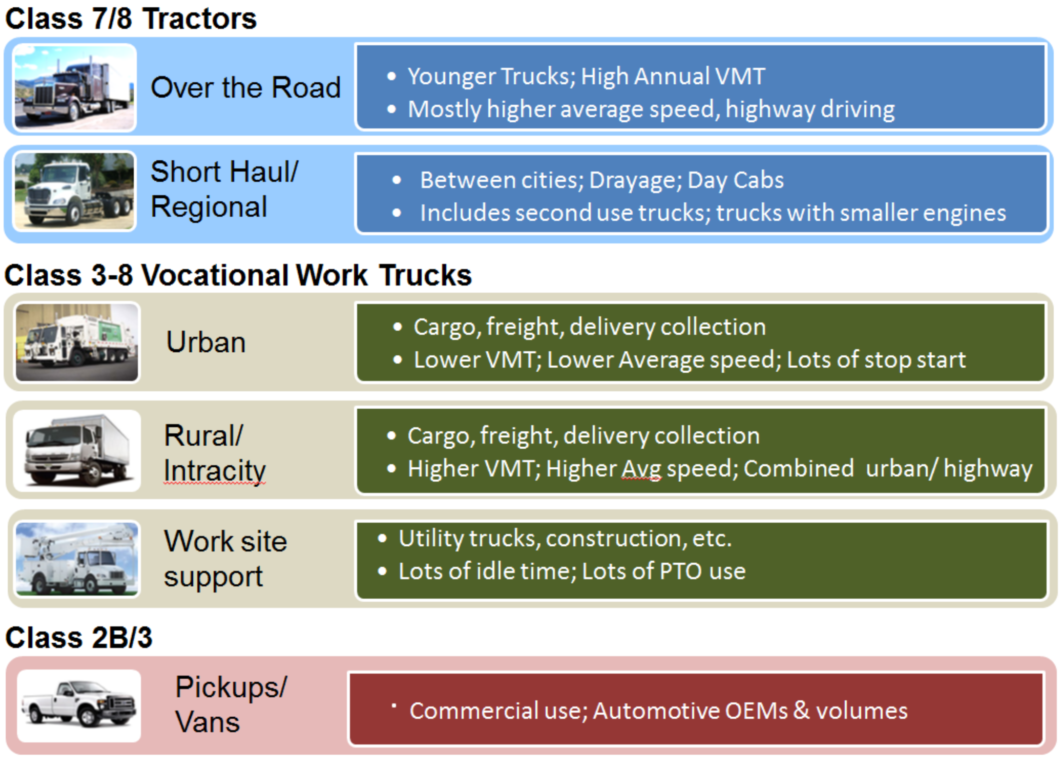
The findings and recommendations of this report support the E-Truck technology strategy of the CalHEAT Roadmap. Although E-Trucks remain significantly more expensive than conventional vehicles, have limited driving range and require a dedicated charging infrastructure, they provide transportation with no tailpipe emissions and well-to-wheel emissions defined by the source of the electricity used to recharge the batteries.

The Roadmap identified three technology stages for E-Trucks. Stage 1 is the current stage, Stage 2 would follow in the 2013-2017 timeframe, and Stage 3 from 2017-2020. The main goals of Stage 2 and 3 are to reduce the payback period to 5-8 years and finally to 3-5 years. This would be accomplished with the achievement of the following technical capabilities:

- improved integration of the electric driveline,
- optimization of system design,
- development of standards for battery packs in multiple sizes,
- fast charging,
- controlled V2G and smart charging,
- energy storage compatible with rapid charging,
- option for cost effective use of smaller batteries,
- secondary market for energy storage.

To better understand the impact of different technology strategies, the Roadmap identified six truck categories to classify the various types of medium and heavy-duty vehicles used in California. The truck categories were defined by vehicle weight, vocation and duty cycle characteristics. The 6 different CalHEAT trucks categories are described in Figure 1-1.

Figure 1-1: CalHEAT truck classifications, by weight and application [1]



The Roadmap identified that E-Trucks will play a noticeable role in the Class 3-8 Vocational Work Trucks - Urban category. This truck category includes delivery applications such as cargo, freight and package delivery and is characterized by lower vehicle miles travelled, lower average speed and high number of stops. Therefore parcel delivery vehicles are good candidates for testing and demonstrating the benefits of E-Trucks.

1.3 Battery Electric Trucks for Parcel Delivery

According to the truck inventory of California vehicles carried out by the CalHEAT Research Center, there were about 253,000 Class 3-8 Work-Urban trucks in California in 2010. They represented 17% of the total truck population in California and were responsible for 11% of the yearly total truck greenhouse gas (GHG) emissions [1]. This report focused on Class 3-4 Vocational Work Trucks - Urban and we estimated that there were about 70,000 of them in the state. If 10% of these Class 3-4 Vocational Work Trucks - Urban were E-Trucks, we estimate that it would represent 224,000 barrels of oil saved and a reduction of 56,700 metric tons of GHG emitted in the atmosphere every year.[1]

As of June, 2013, 382 vouchers had been funded for electric vehicles through the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), including 329 for medium and heavy-duty electric trucks [2]. Although this number may not be representative of the number of E-Trucks currently on the road, it is a good estimate of the state of the E-Truck market in California. In addition, since its first year in 2010, the California HVIP has been responsible for about 75% of E-Trucks sales in the U.S. [3].

A number of E-Truck models dedicated to parcel delivery are currently commercially available. The list below provides a brief description of the characteristics for each model.

Boulder Electric DV500

Address:
1460 Overlook Drive
Lafayette, CO 80026

Website:
http://www.boulderev.com/

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Up to 100 miles	LiFePO4 72 kWh	11,500 lbs. Class 3	4,000 lbs.	534 ft^3 15.1 m^3	75 mph	Yes

[1] We assumed E-Trucks would replace diesel trucks driving 15,000 miles per year with a 12 MPG fuel economy. We also assumed that producing and burning 1 gallon of diesel emits 12.9 kg of CO_2 equivalent on a well-to-wheel basis, while the carbon intensity of California electricity is 0.45 kg of CO_2 equivalent per kWh. We also assumed that 1,000 gallons of diesel required 25.7 barrels of oil to be produced and transported, while 1,000 kWh of California electricity requires 0.0125 barrels of crude oil to be produced [4].

EVI Walk-In Van

Address:
1627 Army Court, Suite 1
Stockton, CA 95206

Website:
http://www.evi-usa.com/

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Up to 90 miles	LiFeMgPO4 99 kWh	16,001 & 23,000 Class 5 & 6	-	662 & 970 ft^3 18.7 & 27.5 m^3	65 mph	Yes

FCCC MT E-Cell Plug-In EV Truck

Address:
552 Hyatt St.
Gaffney, SC 29341

Website:
http://freightlinerchassis.com/

Driven By You

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
65-90 miles	LiFeMgPO4 78-99 kWh	14,001 & 26,000 Class 4 to 6	-	-	65 mph	No

Smith Electric Newton Step Van

Address:
12200 N. W. Ambassador Drive,
Kansas City, MO 64163

Website:
http://www.smithelectric.com/

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Up to 80 miles	LiFePO4 80 kWh	16,500 Class 5	5,570 lbs.	684 ft^3 19.4 m^3	~63 mph	Yes

The CalHEAT Roadmap identified the delivery application as a good fit for E-Trucks [1]. The following characteristics make E-Trucks and parcel delivery a good match:

- Vehicles operate in dense urban areas characterized by low speeds and stop-and-go operation,
- Vehicles operate on a fixed route covering less than 100 miles per day,
- Vehicles return to the same depot every day where they can be recharged,
- Vehicles can be recharged overnight,
- Electric motors are able to produce maximum torque at low speeds, giving E-Trucks strong driving characteristics, particularly in stop-and-go or urban driving situation,
- Electric motors also offer the ability to operate with very low noise, an advantage in certain delivery applications.

To the best of our knowledge, this report is the most comprehensive testing and demonstration study of E-Trucks in parcel delivery application to date. While other evaluation efforts have involved a large number of vehicles across a wider region, they did not analyze E-Truck performance with the same level of detail. For instance, the U.S. Department of Energy supported two E-Truck performance evaluation projects both managed by the National Renewable Energy Laboratory (NREL):

1) $32M for Smith Electric Vehicles to develop and deploy approximately 500 electric medium-duty trucks with a 100 mile range, and
2) $39.2M for Navistar, Inc. to develop, validate, and deploy 950 advanced battery electric delivery trucks with a 100 mile range.

As of December 31st, 2012, about 200 Smith Electric Newtons were reporting data in 14 states across the nation. Table 1-1 below summarizes some keys parameters of the Smith Newton Vehicle Performance Evaluation. Vehicles were deployed among different truck vocations including delivery [5].

Table 1-1: Summary of the NREL Smith Newton Vehicle Performance Evaluation [5]

Reporting Period	Number of Vehicles	Vehicle days driven	Charge Energy	Total Miles	Avg. Miles Per Day	Overall AC Energy	Overall DC Energy
10/1/2011 - 4/30/2012	187	7996 days	546,408 AC kWh	249,670 miles	31.2 miles/day	2.19 AC kWh/mile	1.72 DC kWh/mile

As of March 31st, 2013, over 100 Navistar eStars were reporting data across the nation. Table 1-2 below summarizes the keys parameters of the Navistar eStar Vehicle Performance Evaluation. Vehicles were deployed among several delivery fleets, including parcel delivery [6].

Table 1-2: Summary of the NREL Navistar eStar Vehicle Performance Evaluation [6]

Reporting Period	Number of Vehicles	Vehicle days driven	Charge Energy	Total Miles	Avg. Miles Per Day	Overall AC Energy	Overall DC Energy
7/1/2012 - 3/31/2013	104	6480 days	89,003 AC kWh	96,434 miles	14.9 miles/day	1,01 AC kWh/mile	0.92 DC kWh/mile

Chapter 2 : Test Vehicles and Fleet Operations

2.1 Description of Test Vehicles

Three different E-Truck models were used for this project: 2 MT E-Cell All-Electric Delivery Vans from Freightliner Custom Chassis Corporation, 4 eStars from Navistar and 1 Newton Step Van from Smith Electric Vehicles. The sections that follow provide descriptions for each vehicle model and their technical characteristics.

2.1.1 FCCC MT E-Cell All-Electric Delivery Van

Model Year	2010
Chassis Manufacturer	FCCC
Powertrain Manufacturer	Enova
Battery Manufacturer	Tesla Motors

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
80 to 100 miles	Li-ion 55.5 kWh	14,200 Class 4	4,200 lbs.	550 ft³ 15.5 m³	55-60 mph	No

Introduced in 2010, the MT E-Cell All-Electric Delivery Van was the result of a joint initiative to develop an all-electric commercial chassis between Enova Systems (EV controls, traction motor, gear box and battery management system), Tesla Motors (battery technology) and FCCC (chassis) [7]. In 2012, the alliance was ended and FCCC now commercializes the MT E-Cell with different partners (see section 1.3). Only 4 units were built and 2 commercialized in this now defunct configuration. Table 2-1 lists the specifications for the MT E-Cell.

Table 2-1: FCCC MT E-Cell vehicle characteristics [8]

Traction Motor	
Peak power	160 HP (120 kW)
Peak torque	479 lb-ft (648 Nm)
Dimensions	
Tires	225/70 R19.5
Wheelbase	138 in.
Overall Length	257 in.
Overall Width	88 in.
Overall Height	118 in.
Cargo Area Length	144 in.
Cargo Area Width	86 in.
Cargo Area Height	83 in.
Rear Loading Floor Height	32 in.

Rear Door Opening Height	60 in.
Rear Door Opening Width	72 in.
Charging	
Connector	NEMA l6-30 charging connector
Charger type	On-board charger for traction battery 220V single phase
Advertised charging time	6 to 8 hours for a full charge

For this project, one E-Cell was in service at the selected facility (named Unit E). In addition, one prototype E-Cell (named Prototype Unit) was made available by FCCC for the road testing done by Southern California Edison (see section 3.2).

2.1.2 Navistar eStar

Model Year	2010
Chassis Manufacturer	Navistar
Powertrain Manufacturer	Modec
Battery Manufacturer	A123

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Up to 100 miles	Li-ion 80 kWh	12,100 Class 3	4,000 lbs.	417 ft^3 11.8 m^3	50 mph	Yes

The Navistar eStar, a joint venture between Navistar and Modec (a now defunct UK electric vehicle manufacturer), was an all-electric delivery van first introduced in fleet operation in the United States in May 2010. The Navistar eStar project was part of a U.S. Department of Energy program to manufacture and distribute a zero tailpipe emission light-duty commercial electric vehicle in the United States. With more than 300 units in service delivered by Modec in Europe and over 100 units delivered by Navistar in the U.S., the Navistar eStar is a widely adopted E-Truck [6] [9]. In March 2013, Navistar disclosed that it had discontinued its eStar electric van [10]. Table 2-2 lists the specifications for the eStar.

Table 2-2: Navistar eStar vehicle characteristics [8]

Traction Motor	
Peak power	102 HP (76 kW)
Peak torque	221 lb-ft (300 Nm)
Dimensions	
Tires	215/75 R17.5
Wheelbase	142 in.
Overall Length	250 in.
Overall Width	77 in.
Overall Height	106 in.

Cargo Area Length	168 in.
Cargo Area Width	74 in.
Cargo Area Height	77 in.
Rear Loading Floor Height	26 in.
Rear Door Opening Height	70 in.
Rear Door Opening Width	61 in.
Charging	
Connector	SAE J1772 charging standard
Charger type	On-board charger for traction battery 220V single phase
Advertised charging time	Approximately 8 hours for a full charge

For this project, 4 Navistar eStars (named Unit A, B, C & D) were in service at the selected facility.

2.1.3 Smith Electric Newton Step Van

Model Year	2012
Chassis Manufacturer	Smith Electric
Powertrain Manufacturer	Smith Electric
Battery Manufacturer	A123 Systems

Advertised Range	Battery	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Up to 80 miles	LiFePO4 80 kWh	16,500 Class 5	5,570 lbs.	684 ft^3 19.4 m^3	~63 mph	Yes

The Smith Electric Newton Step Van is the latest addition to the Smith Electric product line-up and is one of the latest all-electric trucks to be introduced to the U.S. market. At the end of 2012 nearly 200 Smith Electric Newton vehicles in several configurations (box, refrigerated box, utility boom and stake bed) had been deployed all across the United States [5]. Almost 100 were deployed in California alone [2]. Table 2-3 lists the specifications for the Newton Step Van.

Table 2-3: Smith Electric Newton Step Van vehicle characteristics [8]

Traction Motor	
Peak power	180 HP (134 kW)
Peak torque	480 lb-ft (650 Nm)
Dimensions	
Tires	225/70 R19.5
Wheelbase	153.5 in.
Overall Length	274 in.
Overall Width	96 in.
Overall Height	119 in.

Cargo Area Length	156 in.
Cargo Area Width	94 in.
Cargo Area Height	81 in.
Rear Loading Floor Height	36 in.
Rear Door Opening Height	75 in.
Rear Door Opening Width	62 in.
Charging	
Connector	SAE J1772 charging standard
Charger type	On-board charger for traction battery 240V single phase
Advertised charging time	6 to 8 hours for a full charge

For this project, 1 Smith Electric Newton Step Van was made available by the partner fleet for chassis dynamometer testing done at the Center for Environmental Research and Technology of the University of California, Riverside.

Not all vehicles were used in the same way during this project testing and demonstration. Table 2-4 below summarizes the vehicles used for this project and their roles in the different components of the project.

Table 2-4: Vehicle assignment for the performance evaluation and testing

Vehicles	Performance Evaluation & Testing
FCCC MT E-Cell	
Unit E	In service
Prototype Unit	On-road testing
Navistar eStar	
Unit A / B / C / D	In service
Smith Electric Newton Step Van	Chassis dynamometer testing

The FCCC MT E-Cell is a class 4 truck. While it has the smallest battery of the 3 vehicles we tested (55.5 kWh), its performance is comparable to or better than similar conventional diesel trucks with high peak power (160 HP) and peak torque (479 lb.-ft.). Lastly, it does not meet the SAE J1772 recommendations for vehicle charging.

The Navistar eStar is a class 3 truck and has the smallest payload and cargo volume of the 3 vehicles tested. It is also less powerful with low peak power (102 HP) and peak torque (221 lb.-ft.). With a top speed of 50 MPH, it is only suited for city roads and cannot operate at highway speeds. The eStar is SAE J1772 compliant.

The Smith Electric Newton Step Van is a class 5 truck and has the largest payload and cargo volume of the 3 vehicles tested. With the highest peak power (180 HP) and peak torque (480 lb.-ft.) in this study, its performance is comparable to or better than diesel vehicles used in similar conventional trucks. It is also SAE J1772 compliant.

2.2 Description of Conventional Parcel Delivery Vehicles

A wide variety of conventional vehicles are available for parcel delivery operations. These vehicles are generally separated in 3 categories [11]:

- **Walk-in vans**

Also known as step vans, walk-in vans are particularly well suited for parcel delivery in dense urban areas, with their quick and easy access to cargo. They generally are driven below 15,000 miles per year (or 60 miles per day) [11]. Because of this duty cycle, this vehicle type is well suited for alternative fuels and advanced technologies such as hybrid electric, hydraulic hybrid, CNG and battery electric. Examples of walk-in vans include the MT-45 and MT-55 chassis from FCCC and the Isuzu Reach Van.

Figure 2-1: The MT-45 walk-in van from FCCC

- **Large vans**

Large vans typically drive between 15,000 and 45,000 miles per year (or between 60 and 180 miles per day) [11]. They generally drive at higher average speeds and make fewer deliveries per day than walk-in vans. Examples of large vans include the Sprinter Cargo Van from Mercedes-Benz and the 2014 Ford Transit.

Figure 2-2: The Sprinter Cargo Van from Mercedes-Benz[2]

[2] Photo from http://www.mbsprinterusa.com/sprinter/cargo-van

- **Panel vans**

Panel vans typically drive over 45,000 miles per year (or over 180 miles per day) [11]. They generally drive at higher average speeds and make fewer deliveries per day than walk-in vans and large vans. Examples of panels vans include the Chevrolet Express Cargo Van or GMC Savana and the Ford E Series Cargo Van.

Figure 2-3: The Chevrolet Express Cargo Van[3]

[3] Photo from http://trialx.com/curetalk/wp-content/blogs.dir/7/files/2011/06/cars/2004_Chevrolet_Express_2500_Cargo-1.jpg

2.3 Description of General Fleet Operation

The 5 vehicles that were evaluated in parcel delivery service (1 MT E-Cell and 4 eStars) were based in a facility located in downtown Los Angeles, CA. Figure 2-4 shows an aerial picture of the downtown Los Angeles area where the parcel delivery facility where the E-Trucks were based was located. Situated about 3 miles southwest of the Los Angeles financial district and close to the University of Southern California campus, vehicles from this facility serve a large number of business customers within a 20 mile radius of the depot. In the dense urban area that is downtown Los Angeles, vehicles operating from this facility generally drive less miles per day than comparable facilities located in depots serving less dense suburban areas.

General operating hours for this facility are from 8 am to 8 pm, with deliveries occurring mostly in the morning and pick-ups in the afternoon.

Figure 2-4: Aerial photo of the downtown Los Angeles area[4]

With over 100 vehicles involved in pick-up and delivery, the downtown Los Angeles depot is an average-size depot for the partner fleet. Vehicles used at this facility are fairly representative of typical parcel delivery operations, with walk-in vans (FCCC MT-45 and MT-55 and Isuzu Reach Van), large vans (Mercedes Sprinter) and panel vans (Ford E Series). However, this facility has been used by the partner fleet as a test bed for alternative technologies such as hybrid electric and is one of the first to have received E-Trucks.

[4] Photo from http://www.photopilot.com

Chapter 3 : E-Truck Performance Evaluation

This chapter discusses the performance of E-Trucks based on in-use data collection (manual and using data loggers), on-road testing, and chassis dynamometer testing. The Navistar eStar and FCCC MT E-Cell vehicles were monitored during the in-use data collection. A prototype MT E-Cell underwent on-road testing, and a Smith Electric Newton Step Van was used for the chassis dynamometer testing. The results provide a comprehensive overview of the performance of commercial E-Trucks in parcel delivery applications in comparison to each other and in comparison to conventional vehicles normally used in this application.

3.1 In-Use Data Collection

3.1.1 Methodology

Manual Data Collection

We recorded mileage and grid electricity consumption from each E-Truck in operation at the downtown Los Angeles facility: 4 Navistar eStars (Unit A, Unit B, Unit C and Unit D) and 1 FCCC E-Cell (Unit E). Both mileage and electricity consumption were read regularly from the end of March to mid-December 2012.

Each vehicle was assigned a specific parking space within the facility and each parking space had a corresponding submeter measuring AC kWh consumed. Mileage was read from the vehicles odometer and grid electricity consumption was read from the assigned submeter (Figure 3-1).

Figure 3-1: eStar dashboard (left) and meters measuring kWh consumption (center & right)

Data Acquisition System

Each E-Truck was equipped with data loggers installed by the vehicle manufacturers to continuously record vehicle, powertrain and battery data during daily vehicle operations. Two conventional diesel trucks were equipped with data acquisition systems provided and installed by CALSTART staff to collect vehicle and route information.

On-Road Testing

One prototype MT E-Cell was made available by FCCC for the on-road testing done by Southern California Edison. Information about the on-road testing and the methodology used can be found in Appendix A.

Chassis Dynamometer Testing

For this project, 1 Smith Electric Newton Step Van was made available by the partner fleet for chassis dynamometer testing done at the University of California, Riverside. More information about the chassis dynamometer testing can be found in Appendix B.

3.1.2 Results & Discussions

Manual Data Collection

Table 3-1 below presents the summary of the data that was collected for a period of about 10 months.

Table 3-1: Summary of eStar and E-Cell manual data collection

	eStar				MT E-Cell
	Unit A	Unit B	Unit C	Unit D	Unit E
Start	3/26/2012	3/26/2012	3/26/2012	3/26/2012	6/26/2012
Finish	12/18/2012	12/18/2012	12/18/2012	12/18/2012	12/18/2012
Miles	1883	2035	2818	2346	1306
AC kWh	3962		3005	2529	1986
AC kWh/mile	**1.01**		**1.07**	**1.08**	**1.52**

During the data collection period, it was noticed that 2 eStars (Unit A & B) were exchanging their assigned parking spots, making it difficult to allocate the energy measured to the truck that consumed it. It was decided that the energy measured for these 2 vehicles would be merged.

We also realized that the submeter used to measure energy for the MT E-Cell was not wired correctly, giving incoherent energy measurements. The issue was reported to fleet management, who had a contractor rewire the submeter. Therefore, all the MT E-Cell data before June 26, 2012 was not usable.

From March 26 to December 18, 2012, the 4 Navistar eStars drove a combined total of 9,082 miles and consumed 9,496 kWh for an average AC energy consumption of 1.05 AC kWh per mile. From June 26 to December 18, 2012, the FCCC MT E-Cell covered 1,306 miles and consumed 1,986 kWh for an average AC energy consumption of 1.52 AC kWh per mile. Vehicles covered between 220 and 330 miles per month and consumed between 230 and 360 AC kWh per month.

Data Acquisition System

❖ **FCCC MT E-Cell**

Despite several attempts, we were not able to extract the data from the proprietary data acquisition system installed on this vehicle. Therefore no data was available to analyze.

❖ **Navistar eStar**

Data collected between March 16 and December 7, 2012 from each eStar was available for analysis. For unit A, 9 months of data was available, whereas unit B had only 7 months of data was available and unit C & D only 6 months. Table 3-2 below presents the summary of data that was collected on the 4 eStars.

Table 3-2: Summary of Navistar eStar data acquisition system data

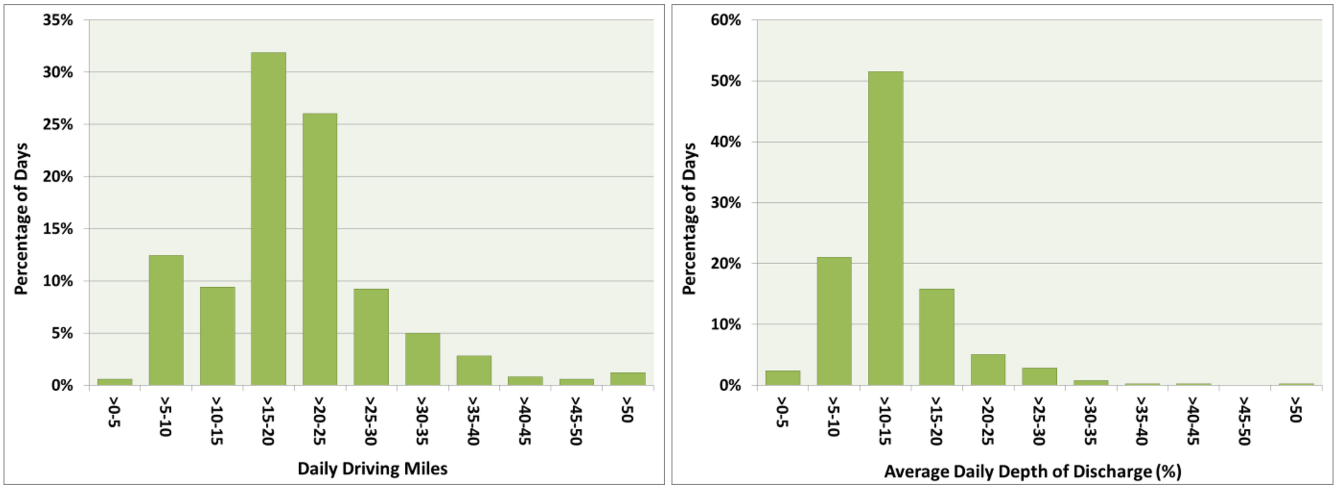
Period of 03/16/12 to 12/07/12	Unit A	Unit B	Unit C	Unit D	Total
Days in operation recorded	148	138	118	95	**499**
Total miles recorded (miles)	2921	2543	2613	2344	**10421**
Total miles driven (miles)	3004	3383	4557	3484	**14428**
Average daily vehicle miles travelled (miles)	20	18	22	25	**21**
Avg. DC energy consumption (DC kWh/mile)	0.45	0.50	0.49	0.52	**0.49**
Average daily depth of discharge	11.9%	11.9%	13.8%	16.7%	**13.6%**
Minimum battery state of charge recorded	28%	67%	46%	51%	**28%**
Average daily regen. braking recapture rate	22%	22%	24%	23%	**23%**
Number of charging events recorded	134	134	81	84	**433**
Average duration of charging event	1h46	1h43	2h43	2h35	**2h12**
Avg. energy recharged per charging event (DC kWh)	9.9	9.4	15.8	14.5	**11.7**

The eStars drove an average of 21 miles per day in operation with the minimum for unit B driving 18 miles/day and the maximum for unit D driving 25 miles/day on average.

The average battery depth of discharge was 13.6% with a maximum of 16.7%, stressing the fact that the eStars were used on low mileage routes, not requiring more than 13.6% of the total battery capacity on average. Minimum battery state of charge was measured as 28%, following several days when one of the vehicles was not recharged after the end of each shift.

In order to understand vehicle usage in greater details, we plotted the distribution of daily driving miles in increments of 5 miles and average daily depth of discharge in increments of 5% (Figure 3-2).

Figure 3-2: Distribution of daily driving miles (left) and average depth of discharge (right) for eStar



For about 90% of the recorded days when the vehicles were in operation, the eStars drove less than 30 miles per day and used less than 20% of the battery capacity.

The average DC energy consumption was calculated as 0.49 DC kWh/mile based on data from the data acquisition system. In comparison, from the manual data collection we calculated the average AC energy consumption as 1.05 AC kWh/mile. This large difference between AC "grid" energy[5] and DC "vehicle" energy[6] may be explained by the charger and battery efficiency and the standby current when the vehicle is plugged in to a charger but not drawing any current. This "stand-by" power is likely caused by the low voltage system batteries and the vehicle accessories (fans, battery cooling system, vehicle display) remaining powered on.

The average daily regenerative braking recapture rate was calculated as 23%, indicating that 23% of the total energy used for operating the vehicle was energy recovered when braking. The eStar regenerative braking feature improved vehicle efficiency and extended available range by 22%.

The number of charging events recorded show that vehicles were not charged every day they were operating. On average the measured charging time was 2 hours and 12 minutes with the minimum for unit B as 1 hour and 43 minutes and the maximum for unit C as 2 hours and 43 minutes on average.

[5] Energy charging the battery from the point where electricity is introduced from the electric outlet to the battery charger.

[6] Energy charging the battery from the point where electricity is introduced from the battery charger to the battery.

3.2 On-Road Testing

3.2.1 Purpose

The CalHEAT Research Center contracted with the Electric Vehicle Technical Center (EVTC) of Southern California Edison to test one E-Truck over 2 routes designed by the EVTC on local street roads, and at the safe speed of traffic in order to simulate real-world operation. The test vehicle, a MT E-Cell (see vehicle characteristics in section 2.1.1), was a prototype vehicle used by FCCC for testing and demonstration, similar to the one used by the partner fleet at the downtown Los Angeles facility. The main goal of this task was to evaluate the maximum vehicle range, energy consumption from the grid in kWh per mile and total charging time following a controlled testing process.

Figure 3-3: The MT E-Cell walk-in van used for the on-road testing

Actual electric range and overall energy consumption 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.

3.2.2 Results

We present below the main results and findings of the road testing. For further information, please see Appendix A.

a. Performance Testing

The performance tests revealed that vehicle acceleration time increases as the battery State-Of-Charge (SOC) decreases. For instance, the average acceleration time from 0 to 55 MPH was 38 seconds at 80% SOC and 51 seconds at 40% SOC.

b. Range Testing (from 100% to 0% SOC)

In order to evaluate the total driving range, the vehicle was driven by an experienced driver on 2 different routes without using auxiliary loads (such as air conditioning and cabin fan) until the vehicle could no longer operate. Then the vehicle was brought back to the EVTC where it was fully charged. Table 3-3 below presents the summary of the on-road testing data.

Table 3-3: Summary of MT E-Cell on-road testing data

	Urban Range Test Min. Payload[7]	Urban Range Test Max. Payload[8]	Delivery Route Min. Payload
Duration of Drive	2h 52min	2h 15min	3h 28min
Total Distance Travelled	67.6 miles	56.2 miles	56.5 miles
Low Indicator Range	53.6 miles	44.9 miles	45.6 miles
Power Limiting Range	66.1 miles	55.8 miles	54.5 miles
Charge Duration (bulk of the charge)	13h 15min	13h 45min	13h 20min
Total Charge Energy	66.8 AC kWh	67.5 AC kWh	67.4 AC kWh
AC Energy Consumption	0.99 AC kWh/mile	1.20 AC kWh/mile	1.19 AC kWh/mile

The total vehicle range was measured between 56 and 68 miles depending on payload and duty cycles. The total vehicle range for the urban range test was 17% lower for the maximum payload test than for the minimum payload test. The total vehicle range was 16% lower for the delivery route than for the urban range test at minimum payload. The delivery route was designed to simulate a more intensive duty cycle, with more stops per mile than the urban range test.

Once the low indicator range is active, the vehicle has about 12 miles of range available before the vehicle goes in limp-home mode where the power is limited. In normal operation, one would most likely not want to operate after the low indicator range is active. This reduces the useful vehicle range available for normal operation to between 45 and 54 miles depending on payload and duty cycles.

Vehicle efficiency was calculated between 1.0 and 1.2 AC kWh/mile, equivalent to 31.3 and 37.6 MPG[9].

c. Charger Performance Test

Charging duration was measured as about 13 hours and 30 minutes to reach the bulk of the charge and can take up to 17 hours and 30 minutes to reach a full charge[10]. Total charge energy was measured as about 67 AC kWh. Given the total vehicle range determined by the road

[7] Minimum payload = driver and test equipment only.

[8] Maximum payload = payload close to 4,520 lbs.

[9] 1 gallon of diesel = 37.6 kWh [5]

[10] Bulk charging is defined as battery State-Of-Charge goes from 0 to 100% and total charging as battery SOC goes from 0 to 100% and battery current drops to 0.

testing (between 56.2 and 67.6 miles), we estimate that 1 hour of charging represents 4.0 to 4.8 miles of range.

A continuous power draw of 260 to 300 W was recorded after the charge was completed and until the vehicle was unplugged.

3.2.3 Conclusions

The vehicle performance characterization performed by the Electric Vehicle Technical Center provided controlled test evaluation of a FCCC MT E-Cell all-electric delivery van. The evaluation recognized the vehicle's potential for a successful delivery vehicle and identified several issues to be addressed:

a. *Vehicle total range was significantly lower than advertised*

The lower than advertised range could limit the versatility of the vehicle and decrease its ability to drive enough miles to offset diesel fuel and thus payback the higher electric vehicle upfront cost in a satisfactory period of time.

b. *Vehicle useful range is dependent on payload and duty cycle*

When implementing a battery electric truck project, route characteristics (payload, daily miles, average speed, number of stops per mile, etc…) should be considered to select a route that will closely match the useful range of the vehicle and include a buffer to be able to comfortably cover the route and return to the depot.

c. *Charging time is much longer than advertised*

The higher than advertised charging time could limit the ability of the vehicle to be recharged overnight and be available for service the next business day.

d. *Calculated vehicle efficiency is lower than what we measured in the in-use data collection*

While this test calculated vehicle efficiency between 1.0 and 1.2 AC kWh/mile, in-use data collection recorded an efficiency of about 1.5 AC kWh/mile (see section 3.1.2). This evaluation did not pinpoint the reasons for this difference but identified payload, duty cycle and continuous power draw after the charge was completed as factors affecting vehicle total range and vehicle efficiency.

e. *Vehicle charging should meet existing safety requirements and adhere to the widely adopted SAE J1772 standard*

3.3 Chassis Dynamometer Testing

3.3.1 Purpose

The CalHEAT Research Center contracted with the Center for Environmental Research and Technology (CE-CERT) of the University of California, Riverside's College of Engineering to evaluate the performance and energy use of a Class 5 (Gross Vehicle Weight Rating = 16,500 lbs.) battery electric urban delivery vehicle. The test vehicle, a Smith Electric Newton Step Van, was tested over 2 standardized drive cycles (the Hybrid Truck Users Forum Parcel Delivery Class 4 – HTUF4 and the Orange County Bus Cycle - OCBC) as well as a steady state range test. Testing was carried out on the University of California, Riverside Heavy-Duty Chassis Dynamometer. The main goal of this task was to evaluate maximum vehicle range, energy consumption from the grid in kWh per mile and total charging time.

Figure 3-4: The Newton Step Van on the UC Riverside Heavy-Duty Chassis Dynamometer

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.

3.3.2 Results

We present below the main results and findings of the chassis dynamometer testing. For further information, please see Appendix B.

Please note that due to testing site infrastructure limitations, we were not able to use the charging current recommended by Smith Electric Vehicles to recharge the Newton Step Van (220V/63A or 208V/75A). The charging current used for this testing was 32A. 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 calculated in this report may be larger than if the vehicle had been charged at the recommended charging rate.

a. Energy consumption, regenerative braking and equivalent fuel economy

Table 3-4 below summarizes the overall DC and AC energy consumption, the regenerative braking recapture rate and the equivalent fuel economy for the 2 drive cycles (HTUF4 and OCBC) and the steady state range test the Newton Step Van was tested on.

Table 3-4: Summary of the chassis dynamometer main results

Test Cycle	Overall DC Energy Consumption	Overall AC Energy Consumption	Regenerative Braking Recapture Rate	Equivalent MPG
HTUF4	0.67 DC kWh/mile	0.81 AC kWh/mile	32%	46.4 MPGe
OCBC	0.72 DC kWh/mile	0.88 AC kWh/mile	37%	42.7 MPGe
Steady State	0.80 DC kWh/mile	0.98 AC kWh/mile	1%	38.4 MPGe

The Newton Step Van reached the best equivalent fuel economy and the lowest energy consumption on the HTUF4 drive cycle. The OCBC drive cycle, with more accelerations and decelerations, is a more intensive drive cycle and thus, equivalent fuel economy was lower and energy consumption higher than for the HTUF4 cycle. However, the increased number of decelerations compared to the HTUF4 cycle allowed the vehicle to recapture 5% more energy during braking.

While the Newton Step Van was tested on the steady state range test to primarily measure the total battery capacity, we report energy consumption, regenerative braking recapture rate and equivalent fuel economy for information and comparison purposes. As expected, the Newton Step Van had the lowest equivalent fuel economy and the highest energy consumption on the steady state range test. Regenerative braking recaptured very little energy, which was expected since the drive cycle had only 1 acceleration event and 1 deceleration event.

b. Total battery capacity

From the steady state range test, the total battery capacity was measured at 89.64 AC kWh.

c. Total driving range

Using the overall AC energy consumption for the HTUF4 and OCBC drive cycles and the total battery capacity, the total driving range for each drive cycle was estimated using the equation below:

$$Total\ Driving\ Range\ (mile) = \frac{Total\ Battery\ Capacity\ (AC\ kWh)}{Overall\ AC\ Energy\ Consumption\ (AC\ kWh/mile)}$$

Table 3-5 below shows the estimated total driving range for the HTUF4 and OCBC drive cycles and the measured total driving range for the steady state range test.

Table 3-5: Newton Step Van total driving range on selected drive cycles

Test Cycle	Total Driving Range
HTUF4	110.7 miles (estimated)
OCBC	101.9 miles (estimated)
Steady State	91.6 miles (measured)

d. Battery charging

Table 3-6 below shows the charge duration at bulk charging (battery SOC goes from 0 to 100%) and total charging (battery SOC goes from 0 to 100% and battery current drops to 0):

Table 3-6: Newton Step Van charging times at 32A charging current

At 32A Charging Current	Time (hh:mm:ss)
Bulk Charging	12:58:49
Total Charging	14:20:45

The bulk charge duration took about 13 hours and total charge duration took about 14 hours and 20 minutes.

e. Charging efficiency

Dividing the overall DC energy consumption by the overall AC energy consumption, the charging efficiency from AC to DC was calculated. Table 3-7 below shows the charging efficiency from the point where electricity is introduced from the electric outlet to the battery (AC to DC):

Table 3-7: Newton Step Van AC/DC charging efficiency at 32A charging current

At 32A Charging Current	AC/DC Charging Efficiency
HTUF4	82.7%
OCBC	81.8%
Steady State	81.6%
Average	**82.0%**

The average charging efficiency from AC to DC was calculated at 82%, meaning that for 1 AC kWh sent to the vehicle, the battery receives 0.82 DC kWh.

f. Stand-by energy consumption

A continuous power draw of 65 to 140W was measured after the charge was completed and until the vehicle was unplugged.

3.3.3 Conclusions

The chassis dynamometer testing performed by the Center for Environmental Research and Technology of the University of California, Riverside provided a controlled test evaluation of the Smith Electric Newton Step Van. The testing recognized the vehicle's potential for a successful delivery vehicle and identified several important findings and areas that will need further research.

a. The Newton Step Van is more efficient and cleaner than equivalent diesel vehicles

Table 3-8 below compares the fuel economy and well-to-wheel greenhouse gas emissions of the Smith Electric Newton Step Van and a 2006 FCCC MT-45 tested on chassis dynamometer by NREL in 2010 [12].

Table 3-8: Fuel economy & GHG emissions comparison between MT-45 and Newton Step Van

Drive Cycles	2006 FCCC MT-45		2012 Smith Electric Newton Step Van	
	Fuel Economy	GHG Emissions[11]	Fuel Economy	GHG Emissions[12]
NYCC	6.1 MPG	2108 gCO2e/mile	N/A	N/A
OCBC	9.5 MPG	1354 gCO2e/mile	42.7 MPGe	160 - 471 gCO2e/mile
HTUF4	11.7 MPG	1099 gCO2e/mile	46.4 MPGe	147 - 434 gCO2e/mile

We find that the Smith Electric Newton Step Van is over 3 times more efficient than a 2006 FCCC MT-45. Equivalent fuel economy on the Newton Step Van was less dependent on drive cycle than the MT-45. For instance, the Newton Step Van equivalent fuel economy was 8% lower on the OCBC cycle compared to the HTUF4 cycle, while the MT-45 fuel economy was 19% lower on the OCBC cycle compared to the HTUF4 cycle.

The Newton Step Van emits much less greenhouse gases than a diesel MT-45 but E-Trucks greenhouse gas emissions depend on the power content of the electricity used to recharge the vehicle. For instance, on the OCBC cycle, greenhouse gas emissions varied between 160 gCO_{2e} / mile if the vehicle is recharged in PG&E territory and 471 gCO_{2e} / mile depending if the vehicle is recharged in LADWP territory.

[11] We assumed that producing and burning 1 gallon of diesel emits 12.9 kg of CO_2 equivalent on a well-to-wheel basis [4].

[12] Estimated GHG emissions factors in 2011 for the 5 largest utilities in California varied from 400 to 1180 lbs. CO_2 / MWh [13].

b. Total driving range was higher than advertised

While Smith Electric Vehicles advertises a total driving range of up to 80 miles for the Newton Step Van, the chassis dynamometer testing estimated a total driving range superior to 100 miles on the HTUF4 and OCBC cycles.

c. Vehicle useful range is dependent on operating conditions

Total driving range was 8% lower on the OCBC cycle than on the HTUF4 cycle. As expected, actual electric range and overall energy consumption will vary widely with driving conditions such as drive cycle and vehicle accessories utilization.

We recommend that further testing be carried on to analyze all factors influencing actual electric range and overall energy consumption. In particular, temperature effects on battery performance and air conditioning usage should be investigated to characterize their impact on total driving range.

d. Regenerative braking extends total driving range

Regenerative braking recapture rate was calculated as 32% for the HTUF4 cycle and 37% for the OCBC cycle. The Newton Step Van regenerative braking feature extended available range by 34 miles for the HTUF4 cycle and by 38 miles for the OCBC cycle.

e. Battery charging was comparable with other E-Trucks

Despite charging at a lower current than what was recommended, the Newton Step Van can be fully recharged in about 14 hours and 20 minutes, which is similar or better than the total charging times of the Navistar eStar and the FCCC MT E-Cell. Charging at the recommended current will markedly decrease the charging time to about 6 to 8 hours.

f. Grid energy consumption better represents E-Truck energy consumption

While E-Trucks use DC energy from the vehicle batteries, they are generally recharged using AC energy from the grid. A small amount of energy is lost in the conversion from AC to DC. While DC kWh/mile is sometimes used to characterize the efficiency of the electric powertrain, AC kWh/mile is a better metric to represent the overall efficiency of E-Trucks and should be used when comparing efficiencies with other propulsion technologies such as diesel vehicles.

g. Stand-by current draw decreases overall vehicle efficiency

The Newton Step Van stand-by current draw was lower than for the FCCC MT E-Cell but was still significant enough to impact overall vehicle efficiency.

We recommend that further testing be carried out to better understand the origin of the stand-by current draw of E-Trucks when plugged in but not charging and explore ways to reduce its impact on overall E-Truck efficiency.

3.4 Comparison with Conventional Vehicles

3.4.1 Freightliner Custom Chassis Corporation (FCCC) MT-45

Model Year	2006
Chassis Manufacturer	FCCC
Engine Manufacturer	Cummins

Engine	Fuel	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Cummins 5.9L ISB 200	Diesel	16,000 Class 4	6,300 lbs.	700 ft^3	>65 mph	No

The MT-45 is a class 4 truck available in different configurations. It has traditionally been one of the walk-in van platforms of choice for parcel delivery fleets. Table 3-9 below lists the engine characteristics of the MT-45.

Table 3-9: FCCC MT-45 engine characteristics

Engine	
Peak power	200 HP (150 kW)
Peak torque	520 lb-ft (702 Nm)

In 2010, the National Renewable Energy Laboratory and CALSTART evaluated the performance of parcel delivery trucks. Odometer and retail fueling records data were collected on 3 FCCC MT-45 parcel delivery trucks operating in and around Los Angeles, CA. Over a 1-year period, the 3 vehicles drove 35,567 miles with an average fuel economy of 7.9 MPG. Table 3-10 below summarizes the data collected on these 3 vehicles [12].

Table 3-10: Summary of in-use results from previous study [12]

	Unit 1	Unit 2	Unit 2
Miles Collected	13,099 miles	11,344 miles	11,124 miles
Miles per Day	21.4 – 49.3 miles (Average 39.4 miles)		
Average Speed (>0)	16.3 – 20.9 MPH		
Lifetime Fuel Economy	7.2 MPG	8.6 MPG	8.2 MPG

In addition, a vehicle was tested on a chassis dynamometer over 3 different drive cycles. Table 3-11 below summarizes the fuel economy measured during the test.

Table 3-11: Summary of chassis dynamometer results from previous study [12]

Drive Cycles	Fuel Economy (mpg)
NYCC	6.1
OCBC	9.5
HTUF4	11.7

3.4.2 Isuzu Utilimaster Reach Van

Model Year	2011
Chassis Manufacturer	Isuzu
Powertrain Manufacturer	Isuzu

Engine	Fuel	GVWR (lbs.)	Payload	Cargo Volume	Top Speed	HVIP Eligible Vehicle
Isuzu 4JJI-TC 3.0L turbo	Diesel	12,000 Class 3	3,408 (12') 3,267 (14')	540 ft^3 (12') 630 ft^3 (14')	>65 mph	No

The Reach Van is a class 3 truck available in two different configurations: with a 12-foot and a 14-foot body. It represents a smaller option than the FCCC MT-45, with a smaller payload and cargo space and a smaller engine. Table 3-12 below lists the engine performance of the Reach Van.

Table 3-12: Isuzu Reach Van Vehicle Characteristics [14]

Traction Motor	
Peak power	150 HP (112.5 kW)
Peak torque	282 lb-ft (381 Nm)
Dimensions	
Tires	215/52 R16E
Wheelbase	151 in.
Overall Length	260.9 in. (12') / 281.0 in. (14')
Overall Width	88 in.
Overall Height	113 in.
Cargo Area Length	150.9 in. (12') / 171.0 in. (14')
Cargo Area Width	73 ¼ in.
Cargo Area Height	82 in.
Rear Loading Floor Height	31 in.
Rear Door Opening Height	74 in.
Rear Door Opening Width	67 in.

We collected data from 2 Reach Vans operating from the Los Angeles facility. These 2 vehicles were operating on routes similar to the routes the E-Trucks were operating on. Table 3-13 below summarizes the data collected on these 2 vehicles.

Table 3-13: Summary of in-use data for 2 Isuzu Reach Van

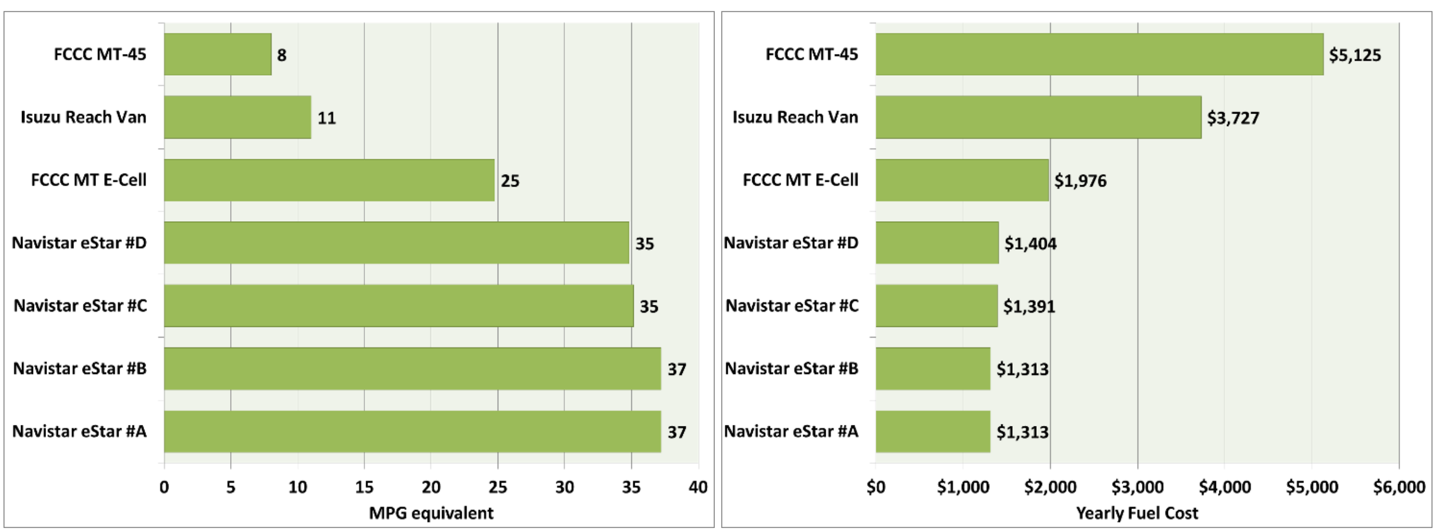
	Unit 1	Unit 2
Miles Collected	249 miles	595 miles
Miles per Day	8.0 – 45.1 miles Average 17.0 miles	9.4 – 65.1 miles Average 40.0 miles
Average Speed	16.9 MPH	19.5 MPH
Lifetime Fuel Economy	10.9 MPG	11.5 MPG
Lifetime Fuel Consumption	1.4 gallons/hr	1.4 gallons/hr

3.4.3 Fuel efficiency and fuel cost comparison

We assumed each vehicle was driven 10,000 miles per year and that diesel sold for $4.1 per gallon and electricity for 13¢ per kWh [15]. Fuel economy for the FCCC MT-45 was taken from the in-use data collection done by NREL in 2010 [12]. Fuel economy for the Isuzu Reach Van, FCCC MT E-Cell and Navistar eStar was taken from the in-use data collection done for this project, assuming that 1 gallon of diesel contains 37.6 kWh [5].

Figure 3-5 below compares the miles per gallon equivalent and the yearly fuel cost for 2 diesel vehicles: FCCC MT-45 and Isuzu Reach Van and 5 E-Trucks: 1 FCCC MT E-Cell and 4 Navistar eStar.

Figure 3-5: In-use fuel efficiency and yearly fuel cost comparison between project E-Trucks and selected diesel vehicles.

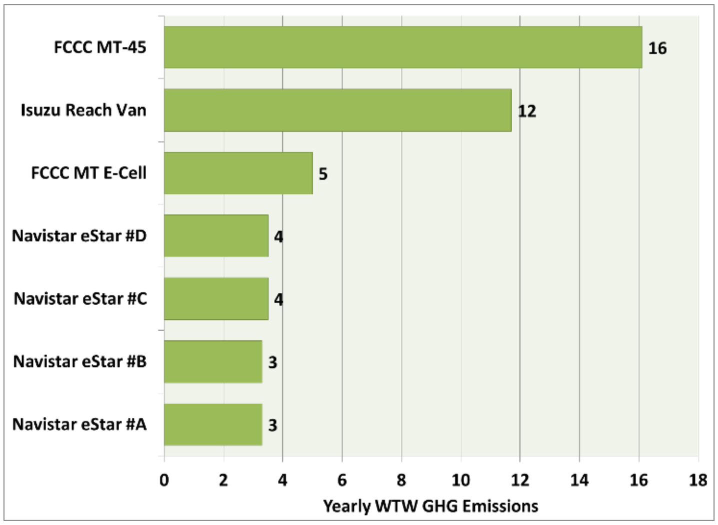


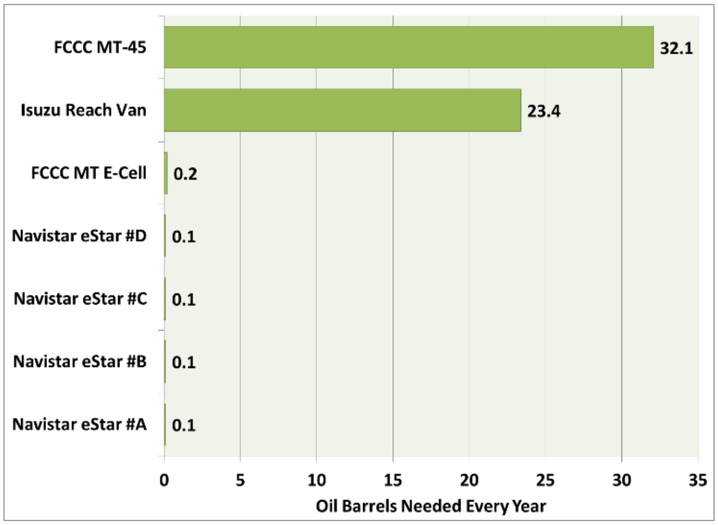
We see that E-Trucks are more efficient than conventional diesel vehicles, with E-Truck efficiency being up to 4 times better than the fuel efficiency of similar diesel vehicles. E-Trucks are also cheaper to operate since they are more efficient and are generally fueled with cheap electricity. E-Truck yearly fuel cost is up to 80% lower than diesel fuel cost.

3.4.4 GHG emissions and oil comparison

Figure 3-6 below compares the yearly well-to-wheels (WTW) greenhouse gases (GHG) emissions and crude oil consumption on the same vehicles presented above using the same assumptions. In addition, we assumed that producing and burning 1 gallon of diesel emits 12.9 kg of CO_2 equivalent on a WTW basis, while the carbon intensity of California electricity is 0.45 kg of CO_2 equivalent per kWh. We also assumed that 1,000 gallons of diesel required 25.7 barrels of oil to be produced and transported, while 1,000 kWh of California electricity requires 0.0125 barrels of crude oil to be produced [4].

Figure 3-6: Yearly greenhouse gases emissions and oil consumption comparison between E-Trucks and selected diesel vehicles.





With no tailpipe emissions, E-Trucks are cleaner to operate than vehicles fueled with fossil fuels. On a WTW basis, E-Trucks emit up to 70% less greenhouse gases when recharged with California electricity. Using domestically produced electricity, E-Trucks use almost no crude oil.

3.5 E-Truck Performance Conclusions

The performance evaluation carried out for this project evaluated 7 E-Trucks from 3 different vehicle models. While the in-use data collection provided valuable insights on how E-Trucks were being used in parcel delivery operation, the on-road testing and the chassis dynamometer testing provided a better understanding of E-Truck technology and evaluated in a controlled environment the performance of 2 different models. Among the many findings and recommendations derived from the performance evaluation, the following eight are of particular importance:

- ***Use E-Trucks on higher mileage routes***

The 5 E-Trucks deployed at the downtown Los Angeles facility were used on low mileage routes. During the performance evaluation period, the 4 eStars drove an average of 21 miles per day while the MT E-Cell drove an average of 27 miles per day. Such short driving range will not offset sufficient fuel to pay for the higher upfront costs of E-Trucks. We recommend that E-Trucks be deployed on longer routes. While the on-road testing of the MT E-Cell revealed a usable driving range limited to 40-60 miles, the data collected on the 4 Navistar eStars shows that the eStar could be driven on longer routes while still keeping enough battery capacity as a safety margin. For instance, data shows that driving an average of 1.55 miles would use 1% of battery SOC. The Navistar eStar could drive on similar drive cycles close to 100 miles per charge and still have about 40% of battery capacity left.

To minimize range anxiety, E-Trucks should be deployed first on short routes to increase a fleet's positive experience with electric vehicle technology. Then E-Trucks should be gradually moved to longer routes, aiming to use the maximum battery capacity possible while keeping a certain percentage of battery capacity as a safety margin.

- ***Train E-Truck drivers***

Data collected on the eStars as well as on the chassis dynamometer testing showed that regenerative braking recovers a significant amount of energy while braking. Drivers should make the best use of regenerative braking features to extend total driving range. We recommend that drivers be trained and coached to learn how to adapt their driving techniques to E-Trucks.

- ***Operating conditions impact E-Truck performance***

The on-road and chassis dynamometer testing showed that payload and drive cycle influenced vehicle energy consumption and ultimately total driving range. While we were not able to test the impact of vehicle accessories utilization such as air conditioning and cabin fan, vehicle accessories usage will use energy from the batteries and impact total driving range. Lastly, Lithium-ion batteries used on E-Trucks generally perform differently depending on ambient temperature. Weather conditions will also impact E-Truck performance.

We recommend that further testing be carried out to better understand the impact of operating conditions on E-Truck performance.

- ***"Stand-by" energy consumption impacts overall E-Truck efficiency***

A current draw was measured on both the MT E-Cell and Newton Step Van after the charge was completed and until the vehicle was unplugged. In addition, data from the eStar indicates that a similar current draw may exist on this vehicle as well.

While we were not able to precisely determine the origin of this "stand-by" current draw, it is likely caused by the low voltage system batteries and the vehicle accessories (fans, battery cooling system, vehicle display…) remaining powered on. We recommend that further testing be carried out to better understand the origin of the stand-by current draw of E-Trucks when plugged in but not charging and explore ways to reduce its impact on overall E-Truck efficiency.

- ***AC energy consumption is a better measure of overall vehicle efficiency***

AC energy represents the energy charging the battery from the point where electricity is introduced from the electric outlet to the battery charger. DC energy represents the energy charging the battery from the point where electricity is introduced from the battery charger to the battery. The conversion from AC to DC is not perfect and a certain amount of energy is lost in the process so that the AC energy consumption is always greater than the DC energy consumption.

While DC energy consumption (DC kWh/mile) is a good indicator of the efficiency of the drivetrain, AC energy consumption (AC kWh/mile) is a better indicator of the overall efficiency of the vehicle and should be used to compare the efficiency of E-Trucks with other vehicles.

- ***E-Trucks are more efficient and cheaper to operate***

E-Trucks are more efficient than conventional diesel vehicles, with E-Truck efficiency being up to 4 times better than the fuel efficiency of similar diesel vehicles. E-Trucks are also cheaper to operate since they are more efficient and are generally fueled with cheap electricity. An E-Truck yearly fuel cost is up to 80% lower than diesel fuel cost.

- ***E-Trucks are cleaner to operate on a well-to-wheels basis***

With no tailpipe emissions, E-Trucks are cleaner to operate than vehicles fueled with fossil fuels. On a well-to-wheel basis, E-Trucks emit up to 70% less greenhouse gases when recharged with California electricity. Using domestically produced electricity, E-Trucks use almost no crude oil.

- ***Different data collection methods exist to evaluate E-Truck performance***

The performance evaluation carried out for this project used a wide range of data collection techniques, from manual readings of vehicle odometers and electric meters to chassis dynamometer testing. Each data collection technique presented different benefits and drawbacks:

- Manual data collection was fairly cheap to implement, requiring only revenue-grade meters to record vehicle electric consumption. Many commercial fleets currently track vehicle mileage and fuel consumed, so data collection and processing is easy to implement. However, information remains limited.

- Using data acquisition system is more expensive to implement but costs remain reasonable. The information will provide a lot of details about vehicle operation and E-Truck performance. However, data can be expensive to process and analyze, especially if a lot of vehicle parameters are being collected at a high sampling rate.
- Road testing proved to be a very cost effective option, providing a lot of information about the performance of one particular E-Truck model. Testing was used to replicate closely in-use operation and did not require expensive equipment.
- Chassis dynamometer testing is the most expensive options as it requires one to contract with one of the few facilities in North America able to test medium and heavy-duty vehicles. Results may differ somewhat from in-use operation if one does not select a representative drive cycle but testing will provide the most thorough information about the performance of one particular E-Truck model.

Chapter 4 : E-Truck User Acceptance

In order to assess the user acceptance of the E-Trucks, we conducted surveys and interviewed several fleet staff. Comparisons were made between electric and conventional trucks to determine the advantages and disadvantages during normal everyday use. Driver surveys assessed the performance of the E-Trucks and the mechanics surveys assessed their serviceability and maintainability.

Drivers were asked to complete a survey rating the E-Trucks in key vehicle performance areas compared to typical baseline trucks. Due to the subjective nature of driver impressions performance was rated on a scale from "Much worse" to "Much better" than a similar conventional truck. The driver survey covered the following areas:

- Maneuverability at low speeds
- Acceleration / Deceleration
- In-cab controls
- Braking
- Interior / Exterior noise level
- Overall vehicle rating
- Additional driver comments

A sample driver survey is provided in Appendix C.

In order to evaluate the serviceability and maintainability of the E-Trucks, mechanics were asked to provide subjective feedback on various service and maintenance aspects of electric and conventional vehicles. A sample mechanic survey is provided in Appendix D.

Lastly, the fleet manager was asked to rate the E-Trucks from a parcel delivery fleet management perspective compared to conventional vehicles. A sample fleet manager survey is provided in Appendix E.

4.1 Summary of User Acceptance Surveys

Four drivers completed the survey for the Navistar eStar (1 full time and 3 part time). In addition, 2 fleet maintenance mechanics and 1 fleet manager also completed the survey. While this is a small sample size, the information captured by the surveys provides valuable input from actual E-Truck users to evaluate the performance of the Navistar eStar and identify areas of improvement. The tables below provide the summary of the survey results that were obtained from the 4 drivers, 2 mechanics and the fleet manager. All surveys were also accompanied by extended interviews.

Table 4-1: Summary results of performance surveys

Property of the Navistar eStar compared to a similar conventional truck	Much worse	Somewhat worse	Same	Better	Much better
Initial launch from stand still	☐	☒	☐	☐	☐
Maneuverability at slow speeds	☐	☐	☐	☒	☐
Acceleration	☐	☐	☐	☒	☐
Shift quality of the transmission	☐	☐	☒	☐	☐
Pulling power with load	☐	☐	☒	☐	☐
Coasting / Deceleration	☐	☐	☐	☒	☐
Overall braking behavior	☐	☐	☐	☒	☐
Productivity (able to cover routes quicker)	☐	☒	☐	☐	☐

Table 4-2: Summary results of operation surveys

Property of the Navistar eStar compared to a similar conventional truck	Much worse	Somewhat worse	Same	Better	Much better
Cold Start	Not applicable				
Reliability	☐	☐	☒	☐	☐
Inside noise level	☐	☐	☐	☐	☒
Outside noise level	☐	☐	☐	☐	☒
Issues with pedestrian traffic	No particular problem noted				
In-cab ergonomics (control, switches, access doors…)	☐	☒	☐	☐	☐

- **Did you have any issues with electric range (ran out of battery, battery running low at the end of the shift…)?**

No issues.

- **Did you have any issues with charging (vehicle not charging when plugged in, vehicle discharged in the morning, vehicle not fully charged in the morning…).**

Before the problem was solved by Navistar, drivers had to wait for the vehicle to be completely shut off (dashboard turned off and electrical system powered down) to be able to put the vehicle in charge.

- **Please provide an overall rating of the Navistar eStar.**

Very poor	Poor	Good	Very good	Excellent
☐	☐	☒	☐	☐

The above summary results indicate that the overall ratings of the eStar were found to be good. In terms of performance, most of the ratings were better than a similar conventional truck or equally good. Initial launch and productivity of the truck in parcel delivery operations were judged “somewhat worse” than for a conventional truck. Drivers rated interior and exterior noise levels as “much better” than for a conventional diesel-powered trucks, while they rated in-cab ergonomics as “somewhat worse”.

With only one vehicle in service, less feedback was collected on the MT E-Cell. No particular complaints or issues were reported. The vehicle does not have the same issues as the eStar regarding initial launch from stand still, productivity and in-cab ergonomics. With same or better initial launch from stand still and better acceleration than the eStar, the MT E-Cell was considered a better option for “pick-up and go” operations, characteristic of parcel delivery. In addition, the higher maximum speed makes the vehicle more versatile.

4.2 Summary of Interviews

Following the surveys, drivers and mechanics were interviewed in an informal group discussion to gather feedback on some of the Navistar eStar features, investigate on low rating identified in the surveys and discuss ways the vehicle could be improved. In this section, we discuss findings on the Navistar eStar derived from the interviews.

- **Driver assignment**

Out of the 4 drivers that we interviewed, only one driver was a full time employee, assigned to a specific route and with a designated vehicle (unit C). During the interview process, it was discovered that some full-time drivers had experienced issues with the vehicle early in the project and did not regard the eStar as the best option when one is on a very tight delivery schedule. Since driver performance is evaluated on the ability to cover routes on time, drivers have not assimilated easily and it has led to poor driver acceptance, especially with the full time drivers. As a result, some of the Navistar eStars were used as back up vehicles or assigned to part time drivers who have less choice as to the vehicle they can drive and generally work on shorter routes.

It is interesting to note that unit C, which was assigned to only one full-time driver, did not report any maintenance issues throughout the evaluation period, whereas unit D for instance, which was assigned to several part-time drivers, reported several issues. During the interviews, drivers agreed that the E-Trucks should be designated to 1 driver who would take ownership of his vehicle and take better care of it.

- **Driver training**

During the discussion with drivers, we learned that not all had undergone specific E-Truck driver training. In addition, some drivers were still hesitant about specific E-Truck operations such as putting the vehicle in charge at the end of each shift.

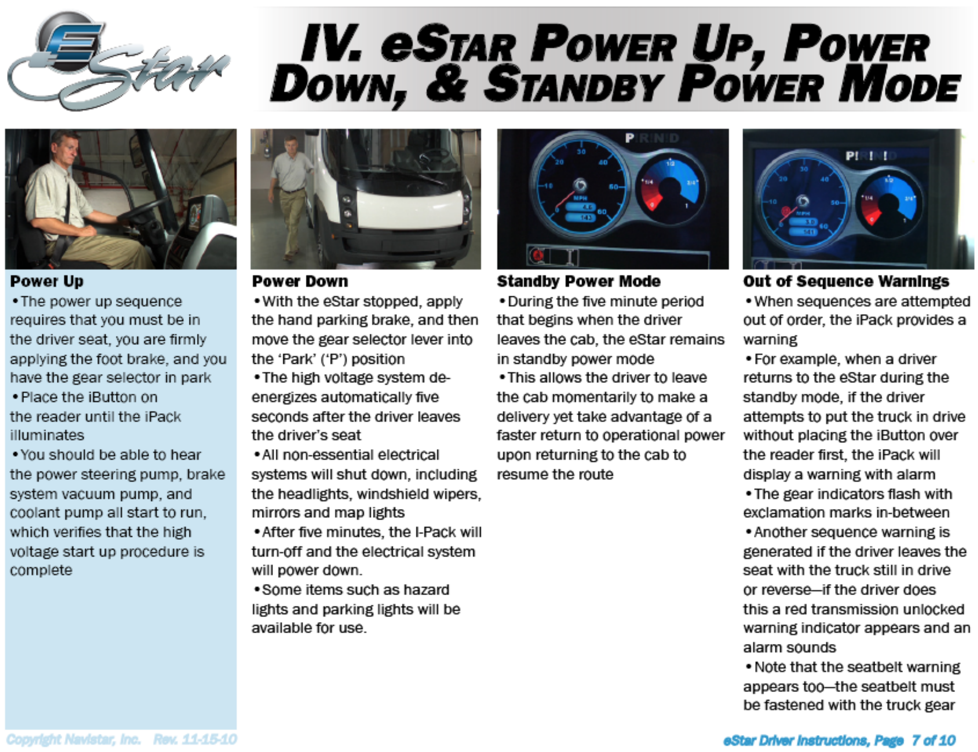
- **Air conditioning**

Two drivers reported having issues with the air conditioning not working.

- **Initial launch from stand still and overall productivity**

The initial launch from stand still and the ability to cover routes quicker were judged somewhat worse or much worse by the drivers and maintenance mechanics. After further discussion, it was determined that the power up sequence as well as the physical configuration of the vehicle was slowing down driver operation.

Figure 4-1: Extract from the eStar Driver Instructions Manual – Page 7 [16]



IV. eStar Power Up, Power Down, & Standby Power Mode

Power Up
- The power up sequence requires that you must be in the driver seat, you are firmly applying the foot brake, and you have the gear selector in park
- Place the iButton on the reader until the iPack illuminates
- You should be able to hear the power steering pump, brake system vacuum pump, and coolant pump all start to run, which verifies that the high voltage start up procedure is complete

Power Down
- With the eStar stopped, apply the hand parking brake, and then move the gear selector lever into the 'Park' ('P') position
- The high voltage system de-energizes automatically five seconds after the driver leaves the driver's seat
- All non-essential electrical systems will shut down, including the headlights, windshield wipers, mirrors and map lights
- After five minutes, the I-Pack will turn-off and the electrical system will power down.
- Some items such as hazard lights and parking lights will be available for use.

Standby Power Mode
- During the five minute period that begins when the driver leaves the cab, the eStar remains in standby power mode
- This allows the driver to leave the cab momentarily to make a delivery yet take advantage of a faster return to operational power upon returning to the cab to resume the route

Out of Sequence Warnings
- When sequences are attempted out of order, the iPack provides a warning
- For example, when a driver returns to the eStar during the standby mode, if the driver attempts to put the truck in drive without placing the iButton over the reader first, the iPack will display a warning with alarm
- The gear indicators flash with exclamation marks in-between
- Another sequence warning is generated if the driver leaves the seat with the truck still in drive or reverse—if the driver does this a red transmission unlocked warning indicator appears and an alarm sounds
- Note that the seatbelt warning appears too—the seatbelt must be fastened with the truck gear

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eStar Driver Instructions, Page 7 of 10

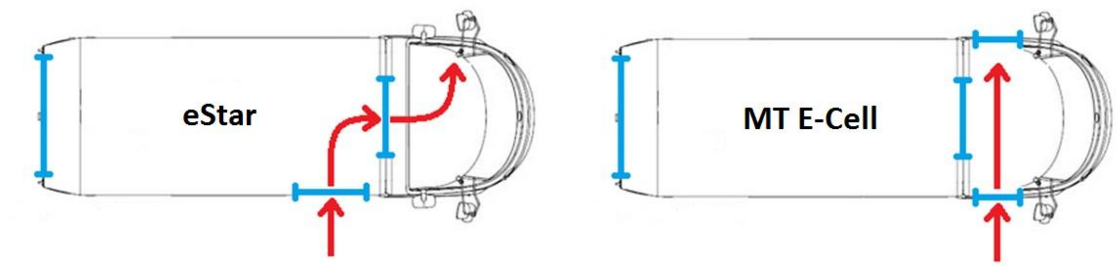
As explained in the eStar Driver Instructions manual (Figure 4-1), starting the vehicle is more complicated than turning a key in conventional walk-in vans or in most personal vehicles. In addition, the power up sequence needs to be followed in the proper order. If the driver ignores the sequence, the system will freeze and will need to be turned off completely before the driver can attempt to restart the vehicle, which can take up to 5 minutes.

Some drivers were confused by the power down and standby power mode. There are no obvious clues to notice the difference between power up and standby power mode (like a diesel engine shutting off). This has left some driver confused as to if the vehicle was still "on" and added to the general feeling that the truck was less productive.

- **Access doors**

Based on an existing walk-in van chassis, the MT E-Cell is equipped with both driver and passenger doors as seen on Figure 4-2 on the right. On the other hand, the eStar was built on a different design not fully adapted to parcel delivery applications. In order to exit or enter the eStar, the driver has to pass through the rear cab door and the side door (see Figure 4-2 on the left). This takes more time to get in and out of the vehicle and also increases the chance of driver hesitation with the keyless entry system.

Figure 4-2: Driver entry path (red line) for the Navistar eStar and FCCC MT E-Cell.



Some drivers noted the "claustrophobic" effect of not having a driver and/or passenger door and stressed that they felt unsafe as a result.

- **Roll back in drive**

Several drivers noticed and/or complained about the vehicle rolling back while in drive. As mentioned in the eStar Driving Instructions manual (Figure 4-3), there is no driveline creep to hold the vehicle from rolling back and the handbrake should be used to hold or launch the vehicle from a stop on an incline.

Figure 4-3: Extract from the eStar Driver Instructions Manual – Page 2 [16]

Roll Back in Drive

- Be aware of potential roll-back while stopping on an incline while in drive
- There is no driveline creep to hold the vehicle from rolling back
- Be prepared to use the handbrake while holding or launching from a stop on an incline
- When applying the hand parking brake, 6 clicks indicates a full application while fewer clicks is only a partial application
- More than 6 hand brake clicks indicates the need for adjustment

- **Lag when starting**

In addition to the long power up sequence described earlier, the eStar has a lag of a few seconds when shifting out of or into park which adds time to the initial launch from stand still (Figure 4-4).

Figure 4-4: Extract from the eStar Driver Instructions Manual – Page 2 [16]

Changing Gears

- The eStar must be stopped to change gears
- The brake pedal must be pressed
- There is no gear engagement sensation with the eStar
- Gear changes are instantaneous except when shifting out of or into park
- When engaging or disengaging park, you need to allow up to 5 seconds for the parking pawl to engage or release

- **Navistar eStar Generation 2**

In early 2012, Navistar launched an updated version of the Navistar eStar, improving heating, air conditioning, motor, charger and battery pack. All 4 vehicles monitored for this project were upgraded with new software and hardware. All the drivers and mechanics noted that the new version was sensibly improved, including better braking behavior, and improved roll back in drive.

- **E-Truck charging**

Several drivers experienced problems with recharging the vehicle. They had to wait for the vehicle dashboard to switch off before putting the vehicle in charge. The issue was fixed with a software upgrade.

- **Additional comments**

Below is a non-exhaustive list of additional driver and mechanic comments regarding the Navistar eStar collected during the interview process:

- ❖ Vehicle needs to start and shut off quicker.
- ❖ Vehicle needs driver and passenger doors for safety and productivity.
- ❖ Vehicle drives smoothly when loaded.
- ❖ Vehicle is very low and not adapted to loading docks.
- ❖ Truck rolls back in drive.
- ❖ Vehicle has weak acceleration.
- ❖ Drivers enjoyed not having to breathe diesel fumes when refueling the vehicle and not breathing exhaust fumes in the cabin.

- ❖ Electric mirrors and reading light are really handy.
- ❖ Vehicle is jerky at low speed.
- ❖ Drivers reported that people “stare” at the vehicle, want to take pictures of it and ask about it and want to know how it works.
- ❖ One vehicle operated on a university campus where delivery vehicles are not allowed to use their horn. The driver reported that the quietness of the vehicle was appreciated by university staff.

4.3 Conclusions

The user acceptance surveys and interviews revealed several E-Truck specific issues on the Navistar eStar. Particularly, drivers complained about the long time needed to start the vehicle caused by the long and laborious power up and down sequences and the delay when shifting out or into park. However, complaints also originated from vehicle design issues, not related to E-Truck specific characteristics. For instance, all drivers complained about the lack of a driver and a passenger door on the eStar, which increased dramatically the time needed to get in and out of the vehicle.

Because of its original design (cabin and electric powertrain), the eStar was not fully adapted to parcel delivery operation and as a result, driver operations were considerably slowed down compared to a conventional vehicle. While electric powertrain design needs to be improved, we also noticed that users will often associate physical design issues, such as driver/passenger doors issues, with E-Truck specific issues. Therefore, it is important to design a new vehicle with the needs of the users in mind to improve the general acceptance of the vehicle.

The user acceptance surveys and interviews also revealed a gap in driver training. We believe driver training is essential to ensure better acceptance of E-Trucks and successful E-Truck deployments overall. With the eStar in particular, there were more than a few new operating steps that drivers needed to assimilate. Drivers are more likely to adopt and accept a vehicle if they are better trained on its operation. Similarly, driver assignment is important to ensure a successful deployment of advanced technology vehicles such as E-Trucks. Some drivers are more willing and able to deal with changes. These “early adopters” drivers should be selected first for advanced technology vehicles deployment.

Chapter 5 : Service and Maintenance

Electric vehicles will typically have lower maintenance costs than conventional fossil-fueled vehicles for the following reasons [17]:

- The battery, motor, and associated electronics require little to no regular maintenance.
- There are fewer fluids to change.
- Brake wear is significantly reduced, due to regenerative braking.
- There are far fewer moving parts, relative to a conventional internal combustion engine.

In order to estimate the service and maintenance benefits of E-Trucks compared to conventional trucks, we interviewed regularly from April to December 2012 the 2 fleet mechanics in charge of vehicle maintenance at the downtown Los Angeles facility. While we only collected general E-Trucks maintenance information and estimates of conventional vehicles maintenance costs, we were able to develop a first look at the service and maintenance benefits of E-Trucks in parcel delivery applications. We believe a more complete and in-depth analysis is needed to further investigate and validate our findings.

5.1 E-Truck Availability Evaluation

Vehicle availability is defined as the percentage of time that a vehicle is potentially available for use, regardless of whether the vehicle is actually used on the particular day. Due to project constraints, vehicle availability was not tracked accurately during the performance testing period but mechanics regularly provided updates on major maintenance issues that occurred during the performance testing period. The following is a list of issues that were recorded for each individual E-Truck in operation at the downtown Los Angeles facility.

Unit A (eStar)

- On May 7th, 2012, the engine light went on and a leak was noticed coming from the driveshaft. The vehicle was sent to the dealership for repairs.
- In early December 2012, it was noticed that the coolant pump needed during driving and charging was working intermittently. The vehicle was sent to the dealership for repairs.

Unit B (eStar)

- In early December 2012, it was noticed that the vehicle dashboard was working in and out and that the vehicle wouldn't shut down. The vehicle was sent to the dealership for repair.

Unit C (eStar)

No issues were reported throughout the testing period.

Unit D (eStar)

- In September 2012, one of the rear-view mirror was damaged. Because of internal billing issues and a long lead time to get the replacement part, the vehicle was out of service for several days. While the vehicle was out of service, the 12V batteries powering the auxiliary loads ran out and had to be recharged. Upon recharge of the 12V batteries, the engine light went on and the truck wouldn't start. The truck was sent to the dealership for repair. In total, the vehicle was out of service for 5 weeks for a minor issue.

Unit E (E-Cell)

- One battery pack had to be replaced in November 2011.
- On September 3rd, 2012, the driver noticed a burning smell and the vehicle would not go over 15 MPH. As of May 2013, the vehicle had not been put back in service.

Navistar and FCCC engineers responded promptly to any reported issues in order to bring the vehicles back to service as soon as possible. They also provided several software upgrades to the vehicles that improved their performance or solved issues identified during the deployment.

The E-Trucks encountered several issues that made them generally less available than conventional diesel trucks. Since these vehicles were early production vehicles and had limited in-service experience (for instance only 4 MT E-Cells have been built and 2 commercialized in this configuration), maintenance issues were anticipated to arise during the project performance period. Fleet mechanics had limited experience with E-Truck maintenance procedures and thus, all major repairs were handled by the E-Truck manufacturers. In addition, E-Truck manufacturers carried a limited inventory of spare parts. These 2 factors added considerable delays when solving any maintenance issue. At this early stage of vehicle development, true vehicle availability comparison between E-Trucks and conventional diesel vehicles would be difficult.

5.2 Maintenance Cost Analysis

We collected general maintenance costs and maintenance intervals data for an average conventional vehicle at the downtown Los Angeles facility. The information reported in Table 5-1 refers to recurring maintenance procedures for conventional diesel vehicles that are not needed for E-Trucks. Any additional maintenance costs would be considered non-recurring.

Please note that maintenance costs and intervals reported in this section will vary widely with driving conditions such as miles driven and number of stops per day. The numbers presented in Table 5-1, and in this section are representative of a specific facility and specific driving conditions. They should not be used to predict E-Truck maintenance savings under different driving conditions.

Table 5-1: Analysis of diesel maintenance costs and intervals at the downtown Los Angeles facility

Specific to downtown LA facility	Conventional Vehicle Maintenance Interval	Yearly Maintenance Costs[13]	
		Low Estimate	High Estimate
Oil Change / Oil Filter	Older models: ~4 times per year Newer models: based on mileage	$100	$250
Fuel Filter	Depends on mileage & filter conditions 1 – 2 years	$10	$20
Air Filter	Depends on mileage & filter conditions 2 years	$25	$50
Diesel Exhaust Fluid	On 2010 Certified Engines ~2% of fuel consumption[14]	$2.79 per gallon in June 2013 [19]	
Engine Coolant	Depends on mileage & engine conditions Typically 3-4 years	$50	$100
Smog Check	On older vehicles only	$20 for diesel $85-100 for gasoline	
Brakes	Depends on truck usage Typically 1-4 years	$100	$400
Tires	Depends on truck usage Typically 2-3 years	$150	$400
12V Starter Battery	Up to 10 years	Not a significant expense	
Total	Low estimate: 10,000 miles per year High estimate: 15,000 per year	$500	$1300

Maintenance savings for E-Trucks compared to conventional diesel vehicles will vary widely depending on driving conditions, vehicle usage, driver behavior, vehicle model and regenerative braking usage.

We estimate that for an E-Truck operating from the downtown Los Angeles facility, maintenance savings would be around $250 per year, or 2-3¢ / mile for a vehicle that drives about 10,000 miles per year without including brakes and tires savings. For a vehicle that drives about 15,000 miles per year and including some brake and tire savings, we estimate that maintenance savings would be around $1,300 per year, or equivalent to 8-10¢ / mile.

[13] Not including labor costs.

[14] Cummins estimates that DEF consumption will be approximately 2% of fuel consumption, depending on vehicle operation, duty cycle, geography, load ratings, etc… [18]

Chapter 6 : E-Truck Charging

This chapter discusses E-Truck charging based on the in-use data collection, on-road testing, and chassis dynamometer testing described in Chapter 3. The results provide a comprehensive overview of an important aspect of E-Truck deployment by comparing the charging infrastructure needs of different E-Truck models, providing a comprehensive analysis of E-Truck charging patterns in parcel delivery operation and evaluating the impacts of E-Trucks charging on the building where they are recharging as well as on the local and state grid.

6.1 Charging Infrastructure

6.1.1 FCCC MT E-Cell All-Electric Delivery Van

The FCCC MT E-Cell is equipped with a charging port that is not SAE J1772 compliant. In order to charge the vehicle, a simple cord is used with a twist-lock plug on one end of the cord to connect directly to the vehicle charger and a NEMA L6-30 connector on the other end of the cord to connect to a wall plug (Figure 6-1). The charge port is located on the back of the vehicle, between the left rear wheel and the rear bumper.

Figure 6-1: The MT-E Cell recharging (left) and the vehicle side of the charging cable (right)

While this set up has the advantage of working without installing expensive charging equipment, it is not compatible with commercially available electric vehicle charge stations and can present some safety challenges. For instance, the vehicle delivered to the EVTC for the road testing (see Appendix A) did not support Article 625 of the National Electric Code including the following safety requirements:

- *Interlock that de-energizes the electric vehicle connector when disconnected from vehicle.*
- *Automatic de-energization of cable upon over-exposure to strain.*
- *Overcurrent protection.*
- *Personnel protection system against electric shock.*

6.1.2 Navistar eStar

The Navistar eStar is equipped with a charge cord that meets the voluntary SAE J1772 standard, which makes the eStar compatible with commercially available Electric Vehicle Supply Equipments (EVSE) such as the Clipper Creek Model CS-60 that was installed to recharge the eStars at the downtown Los Angeles facility (Figure 6-2 / left). The charge port is located on the back of the vehicle, above the right rear wheel (Figure 6-2 / right).

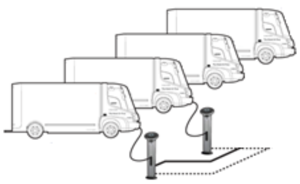
Figure 6-2: A Clipper Creek Model CS-60 (left) and a Navistar eStar recharging (right)

One EVSE was installed for each eStar in operation and each driver was requested to plug-in at the end of each shift. This allowed the vehicles to be fully recharged for the next shift the following day. However, given the low daily mileage that these vehicles covered, we identified that charging infrastructure could be better optimized to fit vehicle use patterns. We present next three different cases that provide an alternative to the option of having one EVSE per E-Truck.

From the in-use data that we collected at the downtown Los Angeles depot (see section 3.1.2), we can make the following assumptions: driving 20 miles will use 15% of the battery SOC and will require 2 hours of charging to get the battery SOC back to 100%, driving 40 miles will use 30% of the battery SOC and will require 4 hours of charging to get the battery SOC back to 100% and driving 60 miles will use 45% of the battery SOC and will require 6 hours of charging to get the battery SOC back to 100%.

Case #1 - While the downtown Los Angeles depot installed 1 charger per vehicle, this case shows that only 2 chargers could be used to recharge all 4 vehicles without any vehicle ever reaching battery SOC levels lower than 70% or a charging duration higher than 4 consecutive hours.

Table 6-1: eStar charging infrastructure analysis – Case #1

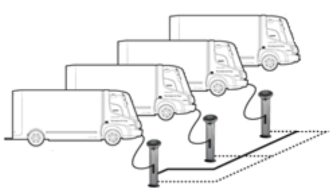


Case #1
Installed 2 charger for 4 vehicles
Each vehicle drives an average of 20 miles/day
Maximum charging duration = 4 consecutive hours
Minimum battery SOC = 70%

Charging Times	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Unit A	2h	No charging	4h	No charging	4h	No charging	No charging
Unit B	2h	No charging	4h	No charging	4h	No charging	No charging
Unit C	No charging	4h	No charging	4h	No charging	4h	No charging
Unit D	No charging	4h	No charging	4h	No charging	4h	No charging

Case #2 - On the other hand, if the vehicles drove an average of 40 miles per day, a third charger would need to be installed to recharge the 4 vehicles without any vehicle ever reaching battery SOC levels lower than 40% or a charging duration higher than 8 consecutive hours.

Table 6-2: eStar charging infrastructure analysis – Case #2

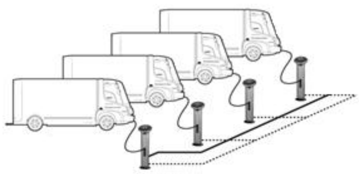


Case #2
Installed 3 charger for 4 vehicles
Each vehicle drives an average of 40 miles/day
Maximum charging duration = 8 consecutive hours
Minimum battery SOC = 40%

Charging Times	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Unit A	No charging	8h	4h	4h	No charging	8h	No charging
Unit B	4h	No charging	8h	4h	4h	No charging	No charging
Unit C	4h	4h	No charging	8h	4h	No charging	No charging
Unit D	4h	4h	4h	No charging	8h	No charging	No charging

Case #3 - If the vehicles drove an average of 60 miles per day, an additional charger (for a total of 4) would need to be installed to recharge the 4 vehicles without any vehicle ever reaching battery SOC levels lower than 50% or a charging duration higher than 6 consecutive hours.

Table 6-3: eStar charging infrastructure analysis – Case #3



Case #3
Installed 4 charger for 4 vehicles
Each vehicle drives an average of 60 miles/day
Maximum charging duration = 6 consecutive hours
Minimum battery SOC = 50%

Charging Times	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Unit A	6h	6h	6h	6h	6h	No charging	No charging
Unit B	6h	6h	6h	6h	6h	No charging	No charging
Unit C	6h	6h	6h	6h	6h	No charging	No charging
Unit D	6h	6h	6h	6h	6h	No charging	No charging

This simple analysis identifies an opportunity where charging infrastructure could be better optimized to fit vehicles use patterns. This could lead to lower charging infrastructure costs, but potential capital cost savings will depend on the particular characteristics of each depot. However, it may be more cost-effective to overbuild the charging infrastructure upfront in anticipation of future E-Truck deployments, if existing vehicles are redeployed on longer routes, or if more E-Trucks are added.

Further analysis is needed to better understand the costs and benefits of optimizing charging infrastructure to fit vehicle use patterns and evaluate potential savings.

6.1.3 Smith Electric Newton Step Van

The Smith Electric Newton Step Van is equipped with a charge cord that meets the voluntary SAE J1772 standard, which makes the Newton Step Van compatible with commercially available EVSEs (Figure 6-3). The vehicle is fitted with an on-board charger compatible with 220V / 63A or 208V / 75A electrical circuits, which will allow for recharge times of 6 to 8 hours. The charge port is located on the back of the vehicle, between the right rear wheel and the rear bumper.

Figure 6-3: The Smith Electric Newton Step Van charge port

6.1.4 E-Truck Charging Infrastructure Costs

In 2012, CALSTART released a report highlighting the key findings and recommendations of the E-Truck Task Force (E-TTF) [20]. The main goal of the E-TTF is to speed and support effective E-Truck production and use. Surveying more than 125 industry leaders, the E-TTF identified infrastructure costs and planning complications as a surprise to fleets and important issues needing resolution. E-Truck charging infrastructure costs include:

- **EVSE options & hardware costs**

Several options exist to charge E-Trucks. The most common options have been defined by the voluntary SAE J1772 standard (Table 6-4).

Table 6-4: Summary of SAE charging configurations [21]

SAE Charging Configurations	AC Level 1[15]	AC Level 2	DC Level 3 "Fast Charging"
Voltage / Current Characteristics	120V 12 - 16A	240V Up to 80A	200-600V DC Up to 400 A
Grid Power	1.4 to 1.9 kW	Up to 19.2 kW	Up to 240 kW
Estimate of Hardware Costs	N/A	$500 to $5,000	~$15,000

- **Installation cost**

Charging infrastructure installation costs vary greatly depending on site conditions (distance to existing electric utility equipment, need to add new circuits and conduits, etc…) and charging current requirement (higher current will allow faster charging but will require more expensive hardware). The E-TTF gave a first estimate of infrastructure installation costs between $100 and $5,000 per EVSE [20].

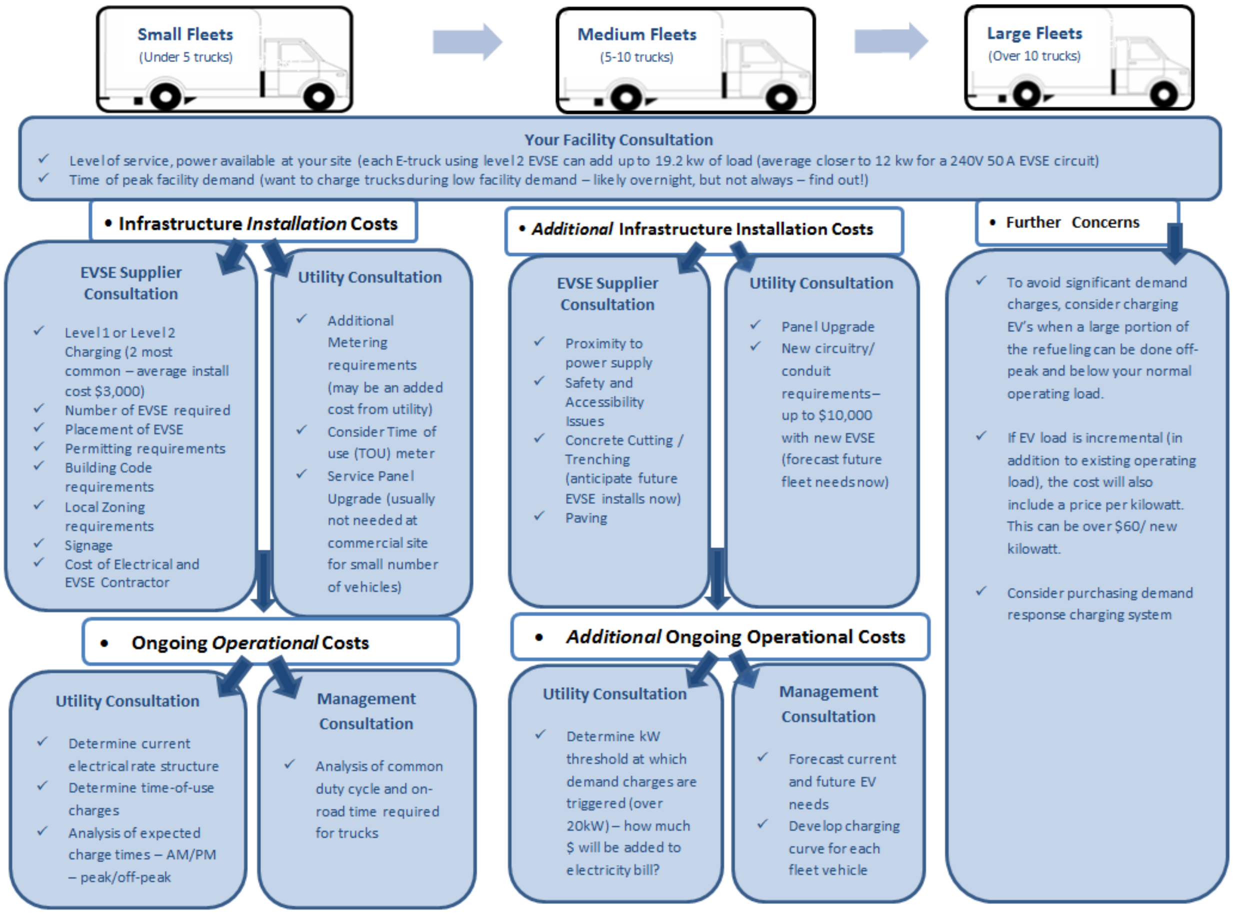
- **Operating Costs**

Operating costs for E-Truck charging infrastructure include electricity costs, distribution or demand charges and potential EVSE network costs.

To achieve a successful E-Truck deployment project, fleet users need to avoid unexpectedly high initial infrastructure costs and electricity demand charges through careful advance deployment planning and through securing strong service and support commitments from manufacturers [20]. The E-TTF provided planning guidelines to help fleets plan E-Trucks infrastructure projects (Figure 6-4).

[15] Not applicable for commercial electric vehicles.

Figure 6-4: E-TTF Infrastructure Planning Guidelines for E-Truck Fleets [20]

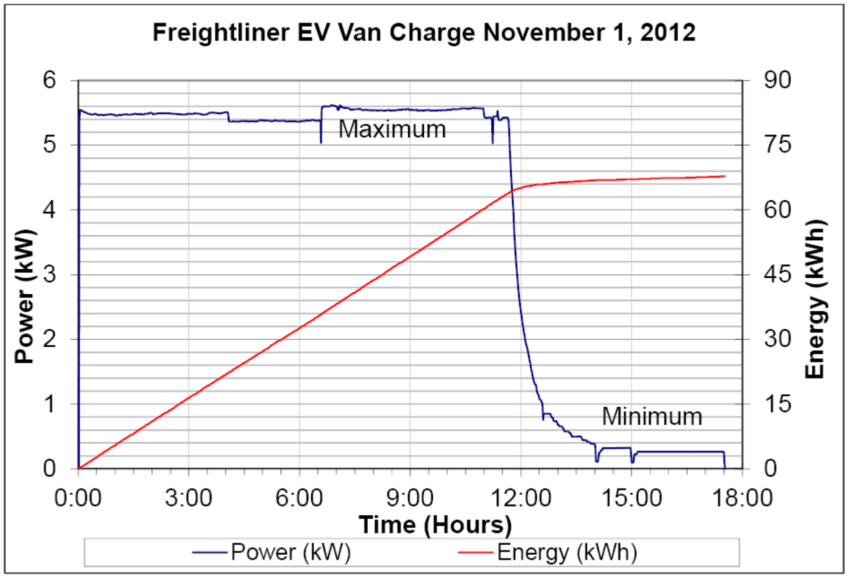


6.2 Frequency and Length of Charging

6.2.1 FCCC MT E-Cell All-Electric Delivery Van

FCCC advertises that the MT E-Cell battery system needs only 6 to 8 hours to reach a full charge if it charges through standard 220V outlet [22]. During the road testing (see Appendix A), a FCCC MT E-Cell was charged at a nominal voltage of 240V from 0% to 100% SOC. Typical charge duration was measured between 12 and 14 hours to achieve the bulk of the charge and over 17 hours to achieve a full charge (Figure 6-5).

Figure 6-5: FCCC MT E-Cell charging profile



Vehicle operating schedules vary per route, but we witnessed at the downtown Los Angeles facility that vehicles were generally in operation from 6am to 6pm during weekdays. This leaves about 12 hours to recharge the vehicle at night, barely adequate to achieve the bulk of the charge. The long charge duration could conflict with vehicle availability in parcel delivery fleet use.

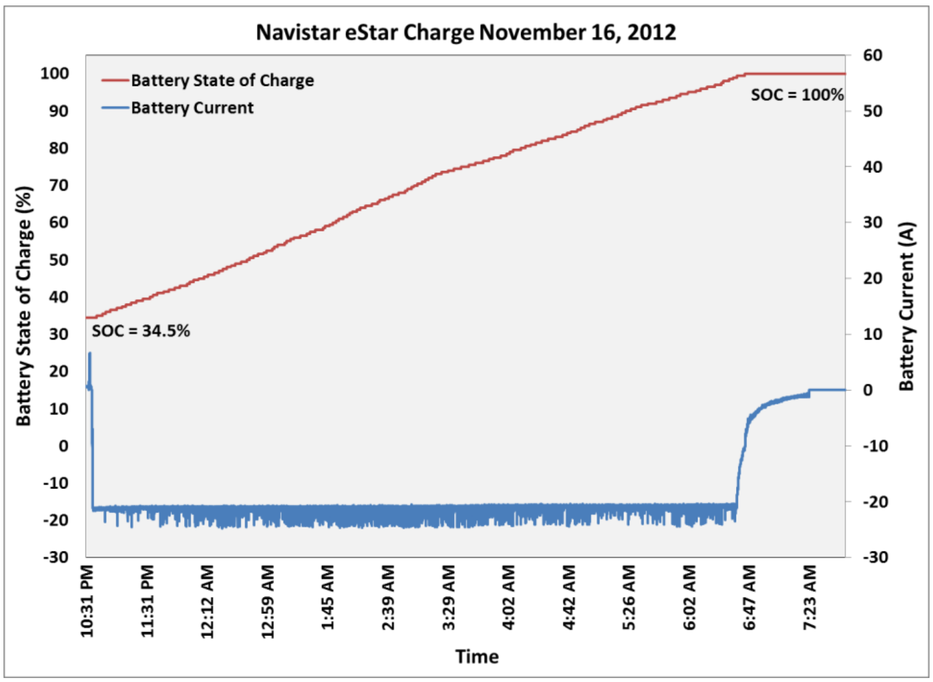
During the road testing, maximum charging current was recorded at 23.2 A (AC) and maximum grid charging power at 5.6 AC kW. A continuous power draw of 260 to 300 W was recorded after the charge was completed and until the vehicle was unplugged. This stand-by power draw can negatively impact the E-Truck overall equivalent fuel economy.

For instance, a vehicle operates for a duration of 10 hours every weekday, recharges for 10 hours each night and stays plugged in the remainder of the time (that is: 4 hours/weekday and 24 hours/weekend day), drawing 300 W of stand-by power. We calculate that in a week, the vehicle would have consumed 20 AC kWh of stand-by energy, adding 0.10 AC kWh/mile to the overall AC energy consumption (an equivalent loss of 3.8 MPG).

6.2.2 Navistar eStar

Navistar advertises that the eStar can recharge in approximately 8 hours [23]. Although we were not able to directly verify that claim, the in-use data collected on the 4 Navistar eStars (see section 3.1.2) indicate that typical charge duration would be more than 8 hours to reach a full charge. For instance, the chart below shows a charging event from 34.5% to 100% SOC for which charge duration was measured at 7 hours and 47 minutes to achieve the bulk of the charge and 8 hours and 29 minutes to achieve a full charge (Figure 6-6). Extrapolating on this example, we estimate the total charging time from 0% to 100% SOC would take between 12 and 13 hours.

Figure 6-6: Navistar eStar charging profile



The long charge duration could conflict with vehicle availability in parcel delivery fleet use. However, the performance evaluation of the eStar estimated the total vehicle range was up to 100 miles (see section 3.5), indicating that the eStar could operate through a wide variety of parcel delivery drive cycles without using the full range capacity and thus requiring a charge duration less than the 12 to 13 hours needed for a full charge from 0 to 100% battery SOC.

Maximum charging current was recorded at 24.3 A (DC) and maximum grid charging power was estimated at 8.8 AC kW[16]. This is higher than for the FCCC MT E-Cell (5.6 AC kW), which explains why the eStar estimated total charging time is lower than the MT E-Cell total charging time despite the fact that the eStar has a larger battery (80 kWh versus 55.5 kWh).

[16] We assumed a charger efficiency of 90%.

We carried out an in-depth analysis of the data collected on the 4 Navistar eStar vehicles available, looking at a period of 6 weeks from August 14 to September 23, 2012, for which data was available for each vehicle. This represented 41 days of continuous data (29 business days and 12 weekend days). Table 6-5 below summarizes vehicle and charging unit usage.

Table 6-5: Summary of eStar charging data for the period of 8/14 to 9/23/2012

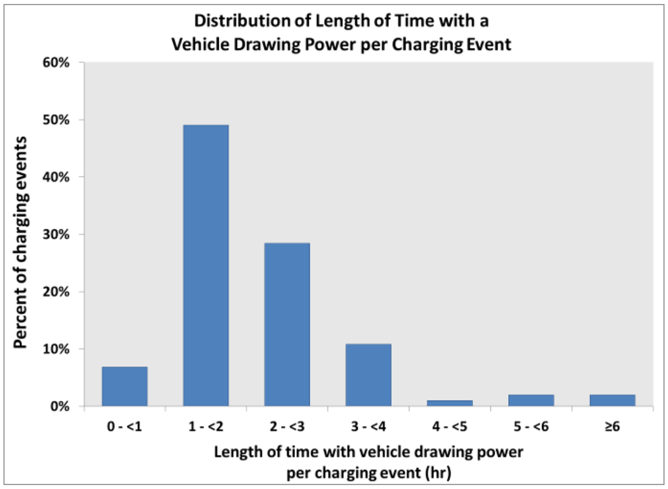
Vehicle & Charging Unit Usage	Period of 08/14/12 to 09/23/12
Number of charging units	4 (Clipper Creek CS-60)
Cumulative number of days in operation	116
Cumulative number of charging events	105
Percent of time with a vehicle connected to charging unit	45%
Percent of time with a vehicle drawing power from charging unit	6%
Average length of time with vehicle drawing power per charging event	2h 08min
Average electricity consumed per charging event (DC kWh)	12.5

Out of 116 cumulative days in operation, only 105 charging events were recorded, which indicates not every vehicle was plugged in to an EVSE at the end of each shift contrary to what was requested to each E-Truck driver. Between August 14 and September 23, vehicles were plugged in to a charging unit 45% of the time and drew power from a charging unit 6% of the time, indicating that the vehicles were plugged in to a charger much longer than what was needed to recharge the batteries. The average charging duration was 2 hours and 8 minutes and the average electricity consumed per charging event was 12.5 DC kWh, equivalent to an estimated 13.9 AC kWh[17].

[17] We assumed a charger efficiency of 90%.

Figure 6-7 below, show that the majority of charging events lasted between 1 and 3 hours and drew between 5 and 15 DC kWh (equivalent to an estimated 6 to 17 AC kWh).

Figure 6-7: Distribution of charging times and charging DC energy for the Navistar eStar



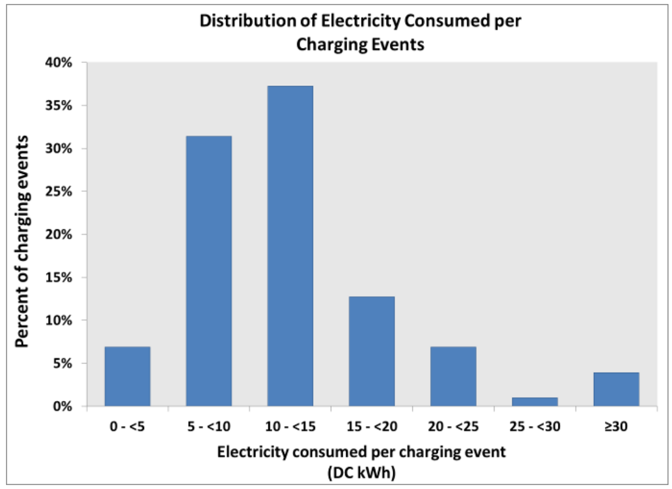


Table 6-6 below breaks down the data in further details, separating weekdays and weekends.

Table 6-6: Comparison of eStar charging data for the period of 8/14 to 9/23/2012 between weekdays and weekend

Vehicle & Charging Unit Usage	Weekday	Weekend
Cumulative number of days in operation	111	5
Cumulative Number of charging events	103	2
Percent of time with a vehicle connected to charging unit	42%	51%
Percent of time with a vehicle drawing power from charging unit	8%	1%

As expected for a parcel delivery fleet, the vehicles were operating and charged mostly on weekdays but we recorded 5 days when vehicles operated on weekends. Between August 14 and September 23, vehicles were plugged in to a charging unit 42% of the time on weekdays and 51% on weekends and drew power from a charging unit 8% of the time on weekdays and 1% on weekends. Again, this indicates that the vehicles were plugged in to a charger much longer than what was needed to recharge the batteries.

Figure 6-8: Cumulative hours with eStars operating and charging versus time of day for the period of 8/14 to 9/23/2012

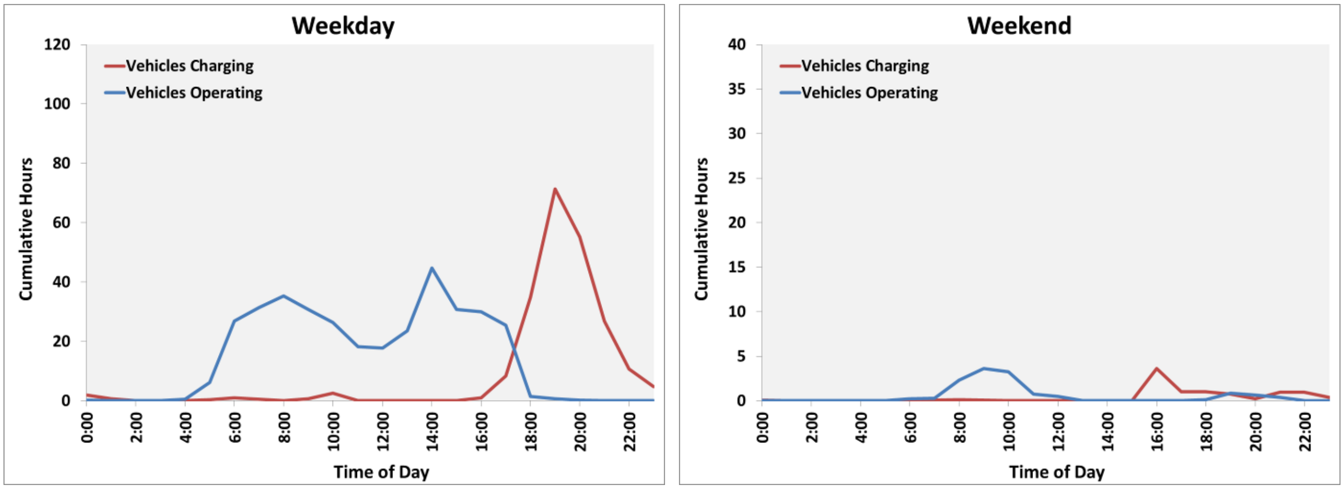


Figure 6-8 above show that the vehicles were mostly operated between 6am and 6pm on weekdays. Some vehicles were occasionally operated on Saturday mornings from 8am to 12pm.

Matching the vehicle operating profile, the wide majority of vehicle charging occurs on weekdays between 5 and 10 pm (at the end of the shift), with the peak happening around 7pm. Little to no charging occurred on weekends.

Figure 6-9: Percent of time with eStars connected to a charger versus time of day for the period of 8/14 to 9/23/2012

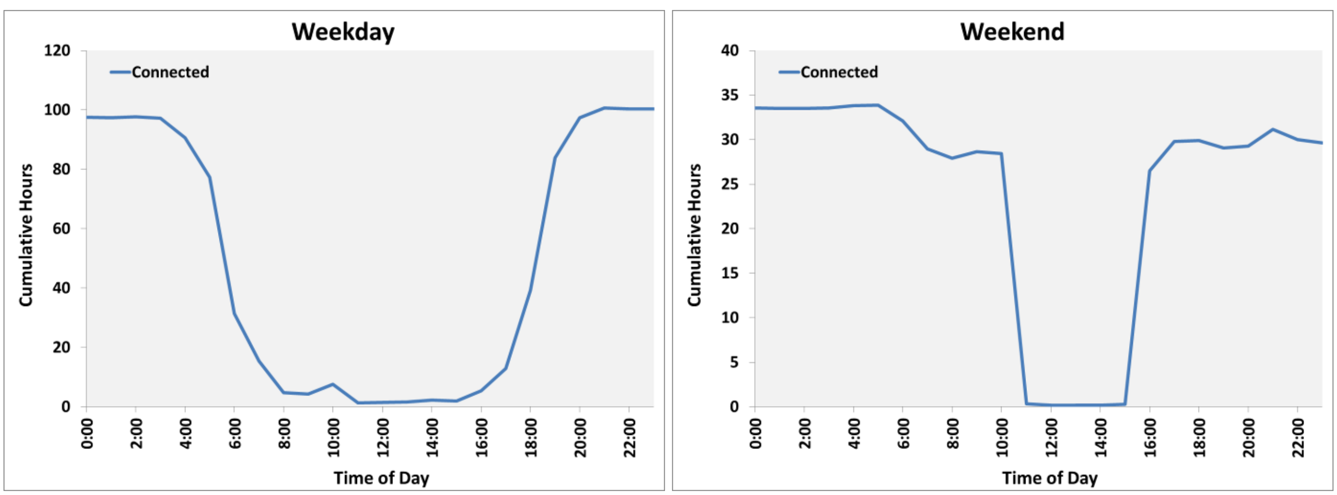
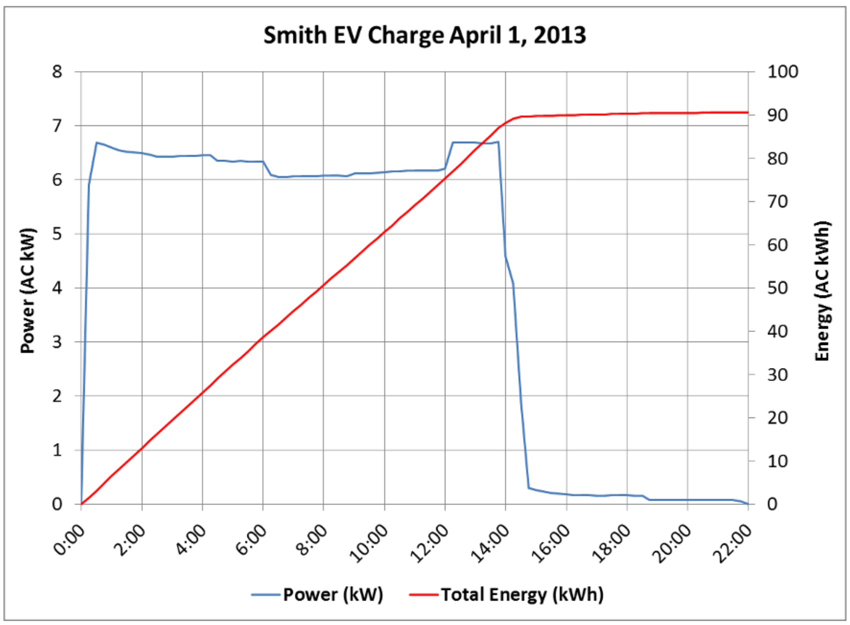


Figure 6-9 above further explain the charger availability profile: most vehicles were plugged to a charging unit between 5pm and 6am on weekdays. Vehicles were never available for charging between 11am and 4pm since the downtown Los Angeles facility uses demand response strategies to decrease the peak electricity demand of the facility by switching off conveyor belts, floor lights and electric vehicles chargers from 11am to 4pm.

6.2.3 Smith Electric Newton Step Van

Smith Electric reported that the Newton Step Van needs 6 to 8 hours to reach a full charge at a continuous current of 75A [24]. For this project, a Smith Electric Newton Step Van was tested on a chassis dynamometer (see Appendix B). 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, we were not able to use the charging current recommended by Smith Electric Vehicles to recharge the Newton Step Van. Therefore, the charging times recorded were longer than what one would expect at a customer site equipped with the recommended charging infrastructure. Typical charge duration from 0% to 100% SOC was measured at about 13 hours to achieve the bulk of the charge and 14 hours and 20 minutes to achieve a full charge (Figure 6-10).

Figure 6-10: Smith Electric Newton Step Van charging profile at 32A current



While this total charging time is long and may conflict with vehicle availability in parcel delivery fleet use, Smith Electric Vehicles has specified the Newton Step Van to be recharged at a much higher current, which would reduce markedly the typical charge duration and guarantee vehicle availability in parcel delivery fleet use.

During the chassis dynamometer testing, maximum charging current was recorded at 17 A (DC) and maximum grid charging power at 6.7 kW. A continuous power draw of 65 to 140W was measured after the charge was completed and until the vehicle was unplugged. This stand-by power draw is lower than the one measured on the FCCC MT E-Cell but can still negatively impact the E-Truck overall equivalent fuel economy.

6.3 Short and Long Term Grid Impacts

6.3.1 California grid impacts

Today, E-Trucks represent a very small share of the truck population in California and within the next five years, this share should remain small. Therefore, their short term impacts on the California grid will be minimal. As E-Trucks are adopted more widely in California in the next 20 years, their impact on the California electric grid will grow. However, we estimate that long term impacts on the California grid will remain minimal.

For instance, if 10% of Class 3-4 urban delivery trucks in California were E-Trucks, it would represent a total energy consumption of 70,000-100,000 MWh per year, assuming that these vehicles drive between 10,000 and 15,000 miles per year at an average of 1.0 AC kWh/mile. This would represent less than 0.10% of total commercial retail sales of electricity in California in 2010[18]. If these 7,000 E-Trucks were all charging at the same time, it would represent a total load of 49 MW, assuming an average charging rate of 7 kW. This would represent 0.10% of the California Independent System Operator peak load in 2012[19].

6.3.2 Local grid impacts

Similarly, E-Trucks will have minimal short and long term impacts on local utility grids. For instance, 1,000 E-Trucks in the Los Angeles Department of Water and Power territory would represent a total energy consumption of 10,000-15,000 MWh per year, assuming that these vehicles drive between 10,000 and 15,000 miles per year at an average of 1.0 AC kWh/mile. This would represent about 0.11% of total commercial retail sales of electricity in LADWP territory in FY 2010-2011[20]. If these 1,000 E-Trucks were all charging at the same time, it would represent a total load of 7 MW, assuming an average charging rate of 7 kW. This would represent about 0.11% of the LADWP peak load[21].

In the short and long term, E-Trucks will impact local distribution infrastructure serving facilities where E-Trucks are deployed. Utilities need to know the location(s) where electric vehicle charging will most likely occur so they can study the local distribution in advance and upgrade the infrastructure if needed. In some cases, battery electric truck charging could require a utility to make infrastructure upgrades to accommodate the added demand (distribution substation and transformers for instance). The question of who pays for electric vehicles utility infrastructure upgrades (utility ratepayers or companies deploying electric vehicles) will need to be answered as more E-Trucks are deployed in California.

[18] Commercial retail sales of electricity for California in 2012 was 121,180,000 MWh [25].

[19] CAISO peak load in 2012 was 46,846 MW on August 31 at 15:53 [26].

[20] Commercial retail sales of electricity for LADWP in FY 2010-11 was 13,345,682 MWh [27].

[21] LADWP peak load in 2010 was 6,142 MW on September 27,2010 [27].

6.3.3 Building impacts

Electric rates vary considerably, depending not only on the utility itself, but also on the electrical characteristics of the specific customer purchasing the power. Rate structures for commercial / industrial customers generally include the following items [28]:

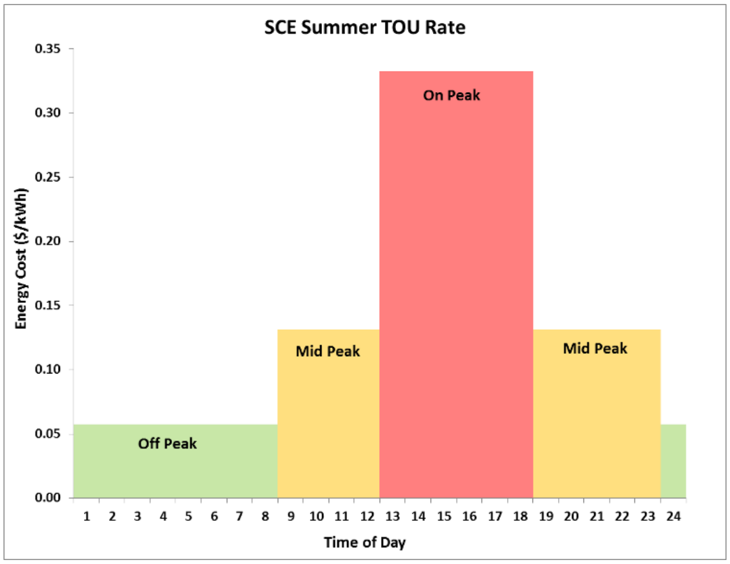
- Account charge,
- Distribution or demand charge,
- Transmission charge,
- Energy charge,
- Power factor adjustment,
- Taxes and fees.

Using battery-electric instead of gasoline or diesel powered trucks will mean an increase in the facility electricity consumption and a decrease in fuel purchases. Due to the complexity of electric rates compared to simple fuel prices, we recommend facility managers implementing E-Trucks review carefully their electric rates to minimize E-Truck charging impacts on the facility electricity bill. To illustrate potential impacts for a facility deploying E-Trucks, we take a closer look at Time-Of-Use pricing and demand charges, two components of electric rate structures that can greatly influence the economic success of E-Trucks.

Time-Of-Use Pricing

Time-Of-Use or TOU pricing is implemented by utilities to encourage customers to shift their loads away from peak demand times (during hot, summer afternoons in California for instance) [28]. Customers will pay more for electricity during on-peak hours. For instance, Southern California Edison's TOU General Service rate charges almost 6 times more per kWh in the summer during on-peak hours than off-peak hours (Figure 6-11) [29].

Figure 6-11: Southern California Edison Summer TOU General Service rate charge



Charging on-peak can have rather dramatic impact on fuel costs savings, even cancelling the advantage E-Trucks have over diesel vehicles in certain cases (Table 6-7).

Table 6-7: E-Truck fuel cost sensitivity analysis to TOU energy pricing

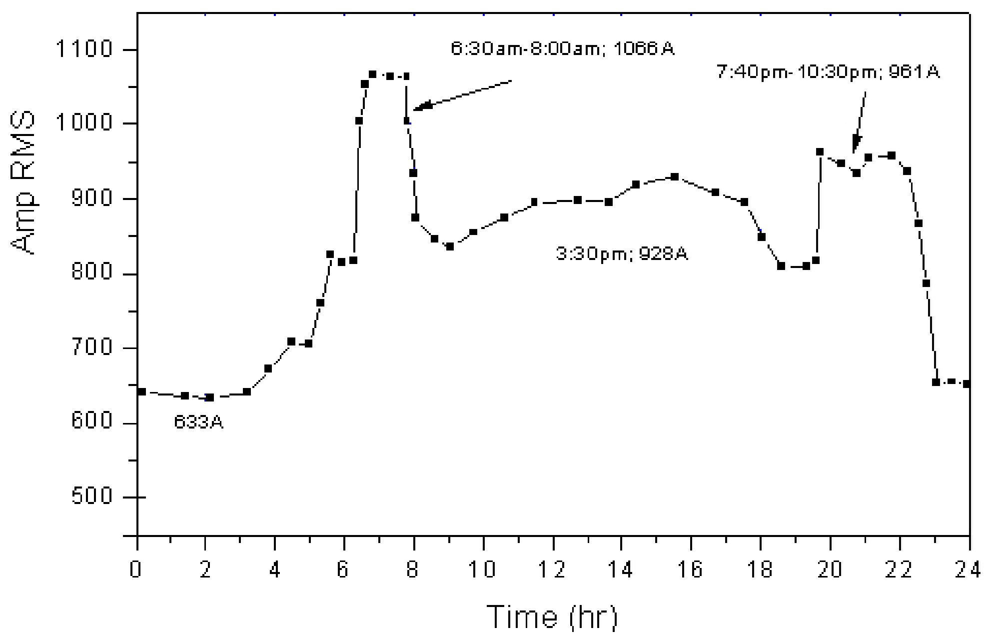
10,000 mi/yr	Vehicle Efficiency	Fuel Prices	Fuel Cost	Charging Off-Peak	Charging Mid-Peak	Charging On-Peak
Diesel	11 MPG	$4.10/gallon	$0.37 / mi.		N / A	
Electric	1.05 AC kWh/mi.	Varies[22]	$0.14 / mi.[23]	$0.06 / mi.	$0.14 / mi.	$0.35 / mi.

Demand charges

Electric utilities generally charge their commercial and industrial customers a monthly demand charge based on the highest amount of power drawn by the facility [28]. A quick review of electric rate schedules for the 5 largest investor-owned utilities in California shows that demand charges vary between $10 and $20 per kW [29 to 33]. For some facilities, demand charges can represent a large part of the electricity bill.

A typical parcel delivery facility, like the one in downtown Los Angeles, usually shows 2 main periods of activities: in the morning between 6 and 8am when packages are loaded onto the delivery trucks and between 6 and 10pm when trucks are unloaded. This increased activity translates into higher facility energy consumption during these periods (Figure 6-12).

Figure 6-12: Building load in ampere from a typical day at a 120-vehicle parcel delivery facility [8]



[22] SCE Summer TOU General Service: Off-Peak = $0.05745/kWh, Mid-Peak = $0.13142/kWh, On-Peak = $0.33236/kWh [29].
[23] We assume $0.13/kWh [15].

Charging E-Trucks right upon returning to the facility can mean adding electrical load to a facility already drawing a large amount of power from the grid. In the worst case scenario, E-Truck charging can increase the peak load of the facility and thus increase demand charges. As Table 6-8 below shows, demand charges can have a significant impact on fuel costs savings, even cancelling the advantage E-Trucks have over diesel vehicles in certain cases.

Table 6-8: E-Truck fuel cost sensitivity analysis to demand charges driving 10,000 miles/year

10,000 mi/yr	Vehicle Efficiency	Fuel Prices	Fuel Cost w/o Demand Charges	Fuel Cost w Demand Charges @ 8.8kW & $10/kW	Fuel Cost w Demand Charges @ 8.8kW & $20/kW
Diesel	11 MPG	$4.10/gallon	$0.37 / mi.	N/A	N/A
Electric	1.05 AC kWh/mi.	$0.13/kWh	$0.14 / mi.	$0.24 / mi.	$0.35 / mi.

6.4 Conclusions

- *Charging infrastructure is an important component of any E-Truck deployment project*

E-Truck charging infrastructure costs can be very high and will depend on a many factors. Fleet managers should carefully plan E-Truck deployments. Resources exist to help fleets plan E-Trucks infrastructure projects such as the E-TTF Infrastructure Planning Guidelines.

- *Charging time depends on charging infrastructure*

From the field data, we noticed that charging time was significantly longer for the MT E-Cell and eStar than what was advertised by their respective manufacturers. The long charge duration could conflict with vehicle availability in parcel delivery fleet use.

In order to decrease charging time, higher charging current can be used, like on the Smith Electric Newton Step Van. The charging current should be specified to guarantee vehicle availability. However, using higher charging currents to charge faster will be more expensive to install. There is a trade-off between charging time and charging infrastructure costs: the lower the charging time, the more expensive the charging infrastructure will be.

- *E-Truck "stand-by" power can negatively impact overall energy consumption*

We noticed that E-Trucks drew a small amount of power from the grid after battery charging was completed and until vehicles were unplugged. This "stand-by" power is likely caused by the low voltage system batteries and the vehicle accessories (fans, battery cooling system, vehicle display) remaining powered on. This stand-by power draw can negatively impact the E-Truck overall equivalent fuel economy and E-Trucks manufacturers should find ways to minimize power draw when the vehicle is plugged in to the grid but not charging.

- *Impacts of E-Truck charging will be focused on building and local grid infrastructure*

The largest grid impacts were identified at the building level. Deploying E-Trucks will require facility managers to understand the electrical load profile of the building where E-Trucks are deployed in order to maximize return on investment. Demand response strategies should be implemented to take advantage of low energy prices such as Time-Of-Use pricing and avoid penalties such as demand charges.

For the downtown Los Angeles facility, we recommend that E-Truck charging be delayed after the second peak of activity between 6 and 10pm. Existing technologies could be used right now to implement this change. For instance, the Navistar eStar is equipped with a charging timer that can delay when charging starts.

We identified local infrastructure upgrades as another short and long term impact of E-Trucks. Electric utilities and companies deploying E-Trucks will need to work together to share the costs of local infrastructure upgrades in a way that is fair for ratepayers and acceptable for utility cost recovery structures but does not deter companies from deploying E-Trucks.

Chapter 7 : Findings and Recommendations

This chapter discusses the business case for E-Trucks, using data presented in this report as inputs for a business case analysis of E-Trucks in parcel delivery applications. We first look at how vehicle usage influences the business case and then assess the role of incentives for purchase at this early stage of the E-Truck market. Next we look at how right-sizing E-Truck battery packs and reducing battery costs can improve the economic success of E-Trucks.

This chapter also explores how Vehicle-To-Grid strategies can benefit E-Trucks in certain cases and help the adoption of commercial electric vehicles.

Lastly, this chapter summarizes the findings and recommendations developed in this report to inform fleets and E-Truck manufacturers on the overall performance of E-Trucks, to provide insights on how the technology can be improved on the one hand and better used on the other hand and to give information to the CalHEAT Roadmap to outline actionable steps on the electrification pathway identified by the Roadmap.

7.1 Business Case for E-Trucks

The business case for high-efficiency vehicles is important to understand in the early stages of market introduction. High-efficiency vehicles and E-Trucks in particular have upfront costs much higher than similar diesel or gasoline trucks but will have lower operation and maintenance costs. The business case for E-Trucks relies on finding the best use profiles that will maximize operational savings and achieve low payback periods.

As part of the E-TTF (introduced in section 6.1.4), a calculator was developed to evaluate the business case of commercial battery electric trucks. The calculator compares the capital and operational costs of an E-Truck to a conventional diesel truck. It includes a comprehensive list of vehicle and infrastructure inputs and is designed to compute sensitivity analyses on key inputs such as vehicle daily range, fuel prices, battery cost, and incentives [34].

Figure 7-1 below shows a screenshot of the calculator. To assess the economic value of E-Trucks, we focused on two economic analysis metrics:

- Simple Payback Period (SPP)
- Net Present Value (NPV)

For more information about the business case analysis methodology, please see [34].

Figure 7-1: Screenshot of the E-TTF Business Case Calculator

To better understand the business case for E-Trucks, we compared a Class 4-5 parcel delivery E-Truck driving different distances. We then compared the business case for E-Trucks with and without current incentives from the California HVIP program. Lastly we analyzed the influence of E-Truck battery size and prices on the business case.

Table 7-1 below lists the input parameters that were used to analyze the business case of a Class 4-5 parcel delivery E-Truck replacing an equivalent conventional diesel vehicle.

Table 7-1: Input parameters for business case analysis of a Class 4-5 parcel delivery E-Truck [34]

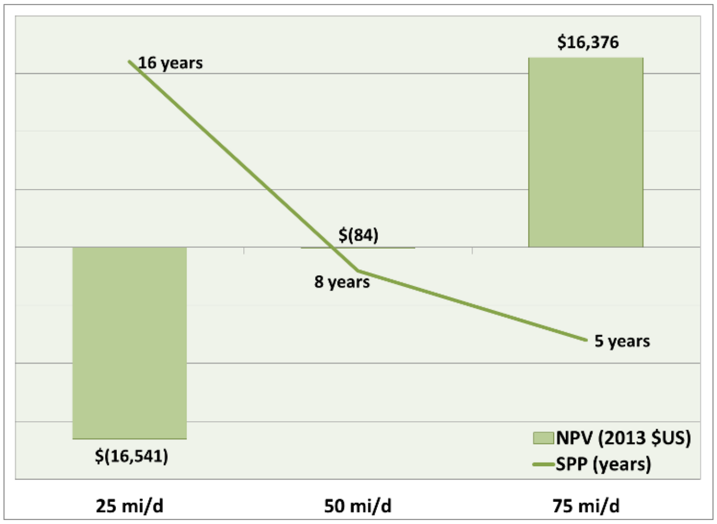
Vehicle Life	10 years
Fuel Economy	Diesel 11 MPG E-Truck 0.9 AC kWh/mile
Vehicle capital cost	Diesel $65,000 E-Truck $135,000
Maintenance cost	$0.05/mile saving for E-Truck
Fuel prices	Diesel $4.1 per gallon Electricity $0.12/kWh
Fuel escalation rate	Diesel 3% Electricity 0%
EVSE capital cost	$3,000
Cost of capital	7%
HVIP Incentive	$40,000

Diesel and E-Truck fuel economy were derived from Chapter 3 and E-Truck maintenance costs savings from Chapter 5. For more information about assumptions and references, please see [34].

7.1.1 Influence of E-Truck usage

Figure 7-2 below shows how daily mileage driven influences the business case for E-Trucks.

Figure 7-2: Influence of daily mileage on business case for a Class 4-5 parcel delivery E-Truck



In this example, we analyzed 3 different cases: a Class 4-5 parcel delivery E-Truck driving 25, 50 and 75 miles per day, 5 days a week and 50 weeks a year, replacing an equivalent conventional diesel truck.

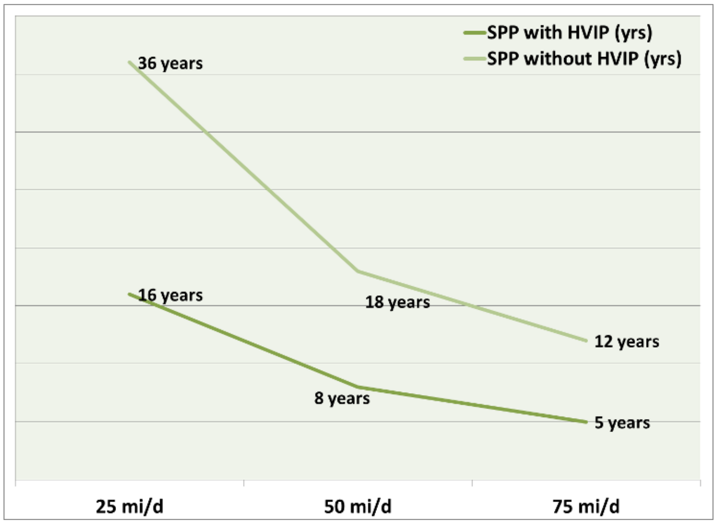
We see that E-Trucks make a good business case when driven 75 miles per day. In that case, the SPP is about 5 years - the higher upfront cost will be repaid in about 5 years. In addition, the NPV of about $16,000 indicates a benefit when using an E-Truck in that application. As the vehicle is driven less miles per day, the business case worsens. At an average of 50 miles driven per day, the SPP is still under the 10-year vehicle lifetime but the negative NPV indicates the investment's lack of financial worth. Lastly, at an average of 25 miles driven per day, the SPP is over the 10-year vehicle lifetime, indicating that the initial upfront investment will not be recouped by fuel and maintenance savings.

These results clearly show that a high utilization of the E-Truck is needed in order to make a compelling business case. By "high" utilization we mean a daily mileage greater than 50 miles. At these high daily utilization rates, a sufficient amount of diesel fuel is displaced by cheaper electricity to make the investment into higher upfront costs E-Trucks worthwhile. However, at lower daily utilization rates (lower than 50 miles), fuel and maintenance savings will not pay for the higher incremental cost that E-Trucks typically show.

7.1.2 Influence of E-Truck purchase incentive

Figure 7-3 below shows how purchase incentives influence the business case for E-Trucks.

Figure 7-3: Influence of California HVIP incentive on business case for a Class 4-5 parcel delivery E-Truck



In this example, we analyzed the same 3 cases described in section 7.1.2 with and without including the California HVIP purchase incentive.

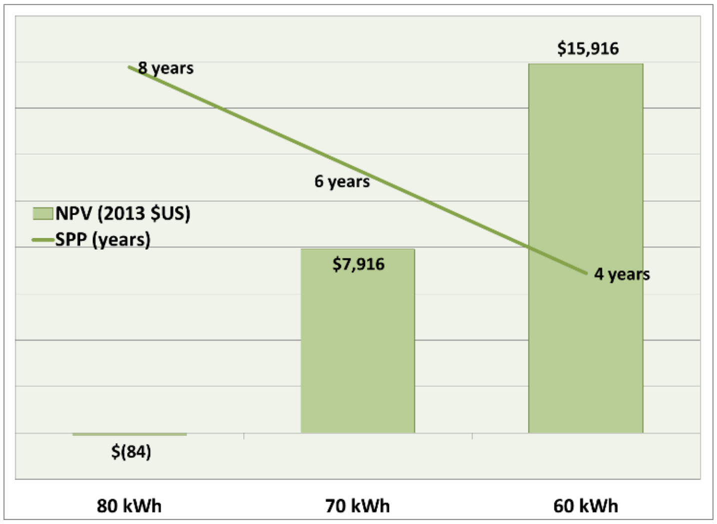
At this early stage of the E-Truck market, purchase incentives play a crucial role for the commercial viability of E-Trucks, as they greatly reduce the simple payback period and thus make E-Trucks more likely to be purchased by commercial fleets.

7.1.3 Influence of E-Truck battery size and prices

As the E-Truck market matures and more vehicles are sold, incentives for purchase are expected to decrease and ultimately disappear. To compensate for this decrease in incentives, E-Trucks incremental costs need to be reduced. We have identified 2 ways we believe will help decrease E-Truck incremental costs: 1) right-sizing E-Truck batteries, and 2) reducing battery costs.

To illustrate the first point, we compare 3 different cases: a Class 4-5 parcel delivery E-Truck with an 80, 70 and 60 kWh battery, driving 50 miles per day, 5 days a week and 50 weeks a year, replacing an equivalent conventional diesel truck. We assume that total driving range is equal to 100 miles with a 80 kWh battery, 85 miles with 70 kWh and 75 miles with 60 kWh. With a 60 kWh battery, the E-Truck would be able to easily cover 50 miles per day and still have a comfortable safety margin to limit range anxiety. The E-TTF estimated current E-Truck battery costs as about $800 per kWh (installed pack), which means a 60 kWh battery would be $16,000 cheaper than an 80 kWh battery [20]. Figure 7-4 below shows how battery size influences the business case for E-Trucks.

Figure 7-4: Influence of battery size on business case for a Class 4-5 parcel delivery E-Truck



Right-sizing E-Truck batteries to better fit how the vehicle is used can greatly increase the business case for E-Trucks and will be an important pathway to explore as incentives for purchase are expected to decrease. Reducing the size of the battery would also reduce the weight of the vehicle and allow for more payload capacity. But because a smaller battery would require more frequent, deeper discharges, battery life could be reduced as a result [20].

Battery prices for electric vehicles are expected to drop in the next 10 years. For instance, the E-TTF identified 3 future average battery costs over time (installed pack) [20]:

- 2015: $500 – 600 / kWh
- 2020: $450 / kWh
- 2025: $300 / kWh

Table 7-2 below shows how battery prices influence E-Truck incremental costs. We used the same E-Truck as we described in earlier examples, with a 60 kWh battery and we assumed that only battery prices decreased and that diesel vehicle costs remained the same.

Table 7-2: Influence of battery prices on a Class 4-5 parcel delivery E-Truck incremental cost

Battery Size	60 kWh
Estimated Range	Up to 75 miles
Incremental Cost @ $800/kWh (current)	$54,000
Incremental Cost @ $600/kWh (2015)	$42,000
Incremental Cost @ $450/kWh (2020)	$33,000
Incremental Cost @ $300/kWh (2025)	$24,000

Lower battery costs, coupled with right-sized battery packs are expected to greatly reduce E-Truck incremental costs from $54,000 to $24,000 in 2025. With such incremental costs, E-Trucks will become very competitive options for conventional diesel and gasoline trucks, especially if other E-Truck component costs become cheaper and fossil fuel prices continue to rise.

7.2 Vehicle to Grid

In addition to driving, E-Trucks could be used as power sources providing power to the electrical grid or to a building while realizing a net profit [34]. Equipped with bidirectional chargers, E-Trucks could be used in Vehicle-To-Grid (V2G) operations to help the adoption of commercial electric vehicles.

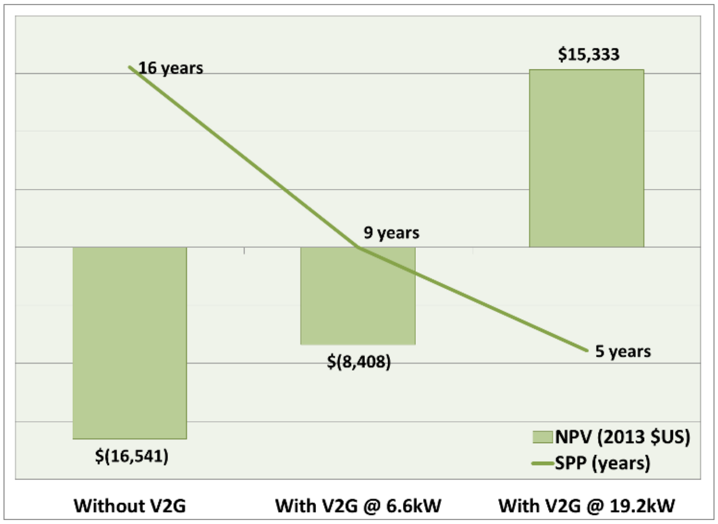
To illustrate the potential of V2G to improve the business case for E-Trucks, we come back to the example described in section 7.1. Table 7-3 below lists the input parameters that we used to analyze the business case of E-Trucks with additional use for V2G. For more information about assumptions and references, please see [34].

Table 7-3: Input parameters for business case analysis of a Class 4-5 parcel delivery E-Truck with additional use for V2G [34]

Daily time plugged in	55% of the day
Battery efficiency	85%
Grid efficiency	93%
Dispatch to contract ratio	10%
Regulation prices	Up $30/MW-h Down $30/MW-h
Power electronics cost	$500
Wireless connection cost	$100
Bidirectional charger cost	$1,500
On-board metering cost	$50

In this example, we evaluate an E-Truck driving an average of 25 miles per day. As we described in section 7.1.1, at this low daily utilization rate, replacing a diesel vehicle by an E-Truck does not make a good business case. We therefore look at using the E-Truck for V2G to provide frequency regulation in addition to regular daily urban driving use. The impacts of the additional use for V2G on the business case are shown in Figure 7-5.

Figure 7-5: Effect of V2G on E-Truck business case



When we include additional use for V2G at a charging/discharging power level of 6.6 kW, the SPP decreases to 9 years and the NPV increases by about $8,000 (in 2013 US Dollars) but remains negative. When we use a power level of 19.2 kW (the upper limit currently used for Level 2 chargers), the financial worth of the investment improves dramatically with a SPP of 5 years and a NPV of over $15,000. We find that V2G could offset the low utilization of the E-Truck by providing additional use of the vehicle battery when plugged-in. Although lower power levels (6.6 kW) provide some benefits, high power levels (19.2 kW) are preferred.

The example above used market regulation prices of $30 per MW-h. Table 7-4 shows that regulation prices for the California Independent System Operator (CAISO) vary widely.

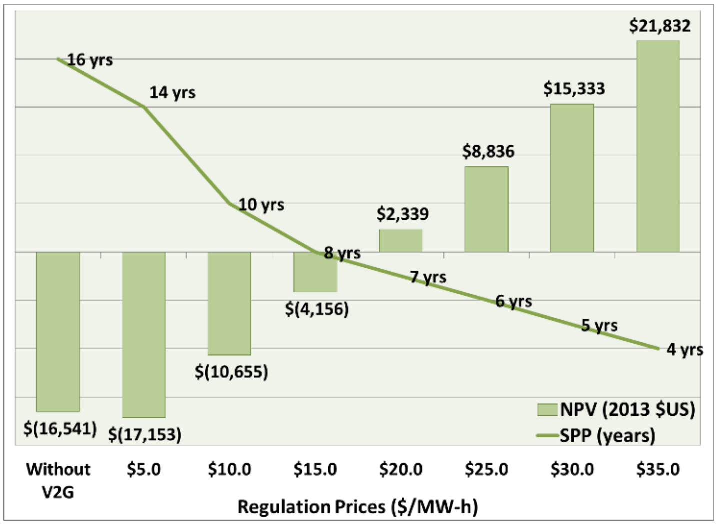
Table 7-4: Annual hourly average CAISO regulation prices [34]

CAISO	Year	Regulation Down	Regulation Up
Annual Hourly Average Price ($/MW)	1999	$20.84	$20.22
	2000	$50.15	$77.28
	2001	$42.33	$66.72
	2002	$13.76	$13.41
	2003	$18.43	$18.08
	2004	$10.95	$17.95
	2005	$16.05	$20.94
	2006	$17.01	$18.94
	2007	$9.97	$16.81
	2008	$15.67	$18.94

To assess the impact of regulation prices on the business case, we carried out a sensitivity analysis, varying regulation prices from $5 to $35 per MW-h.

Figure 7-6 presents the results for the same vehicle with additional use for V2G at a power level of 19.2 kW.

Figure 7-6: Influence of regulation prices on E-Truck business case with V2G



We find that regulations prices would have to be higher than $15 per MW-h in order to make a good business case for using E-Trucks in V2G.

Using E-Trucks for V2G, specifically for frequency regulation, increases the E-Truck battery usage and can dramatically improve the business case for commercial electric vehicles.

As we identified in section 6.3.3, demand charges can represent a large part of the electricity bill of a facility and can also have a significant impact on the business case for E-Trucks. In addition to frequency regulation, E-Trucks could be used for other V2G strategies such as demand response and peak shaving.

7.3 E-Trucks in Parcel Delivery Applications

This report presents a comprehensive performance evaluation of three E-Truck models using information and data from in-use data collection, on-road testing and chassis dynamometer testing. The findings of this report confirm the good fit of E-Trucks for parcel delivery applications previously identified by the CalHEAT Roadmap:

- *Vehicles operate in dense urban areas characterized by low speeds and stop-and-go operation.*

The 4 Navistar eStars and the FCCC MT E-Cell were deployed by the parcel delivery fleet in the downtown Los Angeles area, a dense urban area. The routes these vehicles operated on were characterized by low average speeds and stop-and-go operation.

- *Vehicles operate on a fixed route covering less than 100 miles per day.*

The routes the E-Trucks operated on were fixed routes covering on average between 18 and 27 miles per day. Both the Navistar eStar and the Smith Electric Newton Step Van met total driving range expectation of about 100 miles but the total driving range of the FCCC MT E-Cell was measured below 70 miles. This report identified operating conditions, such as payload and route characteristics as impacting E-Truck performance and ultimately total driving range.

- *Vehicles return to the same depot every day where they can be recharged.*

The E-Trucks returned to the same depot every day where they were recharged.

- *Vehicles can be recharged overnight.*

The 5 E-Trucks were recharged overnight but the performance evaluation estimated that if the vehicles were used on much longer driving routes, long charge duration could conflict with vehicle availability. For routes close to an E-Truck total driving range, charging current may need to be increased to insure vehicle availability.

- *Electric motors are able to produce maximum torque at low speeds, giving E-Trucks strong driving characteristics, particularly in stop-and-go or urban driving situation.*

E-Truck performance was evaluated as comparable as or better than similar conventional diesel vehicles. While the drivers reported design issues on the Navistar eStar, the three E-Truck models showed strong driving characteristics and the performance evaluation recognized the vehicles' potential for successful delivery vehicles.

- *Electric motors also offer the ability to operate with very low noise, an advantage in certain delivery applications.*

On one particular route, one E-Truck operated on a university campus where very low noise proved to be an advantage over other vehicles.

This report also informs fleets and E-Truck manufacturers on the overall performance of E-Trucks, provides insights on how the technology can be improved on the one hand and better used on the other hand and gives information to the CalHEAT Roadmap to outline actionable steps on the electrification pathway identified by the Roadmap. The key findings and recommendations of this report fall into five major categories:

- Performance,
- Maintenance,
- Fleet deployment,
- Charging,
- Business case.

The next sections discuss these five categories in greater detail, listing several key findings and discussing recommendations and next steps.

7.3.1 E-Truck performance

Chapter 3 presented a comprehensive performance evaluation of E-Trucks in parcel delivery, including a review of information from in-use data collection, on-road testing and chassis dynamometer testing. Table 7-5 below summarizes the E-Truck performance key findings.

Table 7-5: Summary of E-Truck performance key findings

E-Truck Performance Key Findings	Report Section(s)
Operating conditions impact E-Truck performance	3.2 – 3.3
AC energy consumption is a better measure of overall vehicle efficiency	3.1 – 3.3
E-Trucks are more efficient and cheaper to operate	3.3 – 3.4
E-Trucks are cleaner to operate on a well-to-wheels basis	3.3 – 3.4
Different data collection methods exist to evaluate E-Truck performance	3.1 – 3.2 – 3.3

The on-road and chassis dynamometer testing showed that payload and drive cycle influenced vehicle energy consumption and ultimately total driving range. While we were not able to test the impact of vehicle accessories utilization such as air conditioning and cabin fan, vehicle accessories usage will use energy from the batteries and impact total driving range. Lastly, Lithium-ion batteries used on E-Trucks generally perform differently depending on ambient temperature. Weather conditions will also impact E-Truck performance.

We recommend that further testing be carried out to better understand the impact of operating conditions on E-Truck performance.

AC energy represents the energy charging the battery from the point where electricity is introduced from the electric outlet to the battery charger. DC energy represents the energy charging the battery from the point where electricity is introduced from the battery charger to the battery. The conversion from AC to DC is not perfect and a certain amount of energy is lost in the process so that the AC energy consumption is always greater than the DC energy consumption.

While DC kWh/mile is a good indicator of the efficiency of the drivetrain, AC kWh/mile is a better indicator of the overall efficiency of the vehicle and should be used to compare the efficiency of E-Trucks with other vehicles.

The performance evaluation carried out for this project used a wide range of data collection techniques, from manual readings of vehicle odometers and electric meters to chassis dynamometer testing. Each data collection technique presented different benefits and drawbacks.

We recommend that these data collection techniques be used as appropriate to provide better performance data on E-Truck deployment projects.

7.3.2 E-Truck maintenance

Chapter 5 presented a preliminary reliability and maintenance evaluation of E-Trucks. Table 7-6 below summarizes the E-Truck maintenance key findings.

Table 7-6: Summary of E-Truck maintenance key findings

E-Truck Maintenance Key Findings	Report Section(s)
E-Trucks need strong maintenance repair networks	5.1
E-Trucks have lower maintenance costs	5.2

Although vehicle availability was expected to be lower for these early production vehicles, maintenance issues led to long vehicle downtime because fleet mechanics had limited experience with E-Truck maintenance procedure and thus, all major repairs had to be handled by the E-Truck manufacturers maintenance repair network. In addition, E-Truck manufacturers carried a limited inventory of spare parts, which added to the time it took to service E-Trucks.

Local and regional maintenance repair networks as well as spare parts inventories need to be developed in correlation with E-Truck sales. In addition, fleet mechanics need to be trained to diagnose and service E-Truck maintenance issues.

From general maintenance costs and maintenance intervals data, a first look at E-Truck maintenance savings was defined and showed a potential for lower maintenance costs. We expect E-Truck maintenance savings to vary widely with driving conditions such as miles driven and number of stops per day.

A more complete analysis is needed to further investigate and understand the potential maintenance savings of E-Trucks.

7.3.3 E-Truck fleet deployment

Chapter 3 presented a comprehensive performance evaluation of E-Trucks, including a review of information from in-use data collection. Chapter 4 detailed E-Truck user acceptance. Table 7-7 below summarizes the E-Truck fleet deployment key findings.

Table 7-7: Summary of E-Truck fleet deployment key findings

E-Truck Fleet Deployment Key Findings	Report Section(s)
Train E-Truck drivers	3.5 – 4.2
Assign E-Trucks to "early-adopter" drivers	4.2

E-Trucks can present a challenge to drivers as they have more than a few new operating steps to assimilate. Drivers are more likely to adopt and accept a vehicle if they are better trained on its operation. We recommend that drivers operating E-Trucks be trained and coached to adapt their driving techniques to E-Trucks to take advantage of regenerative braking for instance. Driver training is essential to ensure better acceptance of E-Trucks and successful E-Truck deployments overall.

User acceptance data showed that some drivers were more willing and able to deal with the changes involved in driving an E-Truck. Driver assignment is important to ensure a successful deployment of advanced technology vehicles such as E-Trucks and "early adopters" drivers should be selected first for E-Truck deployment project in order to build a positive experience.

7.3.4 E-Truck charging

Chapter 3 presented a comprehensive performance evaluation of E-Trucks, including a review of information from on-road testing and chassis dynamometer testing. Chapter 6 covered in detail E-Truck charging. Table 7-8 below summarizes the E-Truck charging key findings.

Table 7-8: Summary of E-Truck charging key findings

E-Truck Charging Key Findings	Report Section(s)
Charging infrastructure is an important component of any E-Truck deployment project	6.1
Charging time depends on charging infrastructure	6.2
E-Truck "stand-by" power can negatively impact overall energy consumption	3.2 – 3.3 – 6.2
Impacts of E-Truck charging will be focused on building and local grid infrastructure	6.3

E-Truck charging infrastructure costs can be very high and will depend on many factors. Fleet managers should carefully plan E-Truck deployments.

From the field data, we noticed that charging time was significantly longer for the MT E-Cell and eStar than what was advertised by their respective manufacturers. The long charge duration could conflict with vehicle availability in parcel delivery fleet use.

In order to decrease charging time, higher charging current can be used. The charging current should be specified to guarantee vehicle availability. However, using higher charging currents to charge faster will be more expensive to install.

A current draw was measured on both the MT E-Cell and Newton Step Van after the charge was completed and until the vehicle was unplugged. In addition, data from the eStar indicates that a similar current draw may exist on this vehicle as well. This stand-by power draw can negatively impact the E-Truck overall equivalent fuel economy.

We recommend that further testing be carried out to better understand the origin of the stand-by current draw of E-Trucks when plugged in but not charging and explore ways to reduce its impact on overall E-Truck efficiency.

The largest grid impacts were identified at the building level. Deploying E-Trucks will require facility managers to understand the electrical load profile of the building where E-Trucks are deployed in order to maximize return on investment. Demand response strategies should be implemented to take advantage of low energy prices such as Time-Of-Use pricing and avoid penalties such as demand charges.

We identified local infrastructure upgrades as another short and long term impact of E-Trucks. Electric utilities and companies deploying E-Trucks will need to work together to share the costs of local infrastructure upgrades in a way that is fair for ratepayers and acceptable for utility cost recovery structures but does not deter companies from deploying E-Trucks.

7.3.5 E-Truck business case

Chapter 3 presented a comprehensive performance evaluation of E-Trucks, including a review of information from in-use data collection. Chapter 7 detailed a business case analysis for E-Trucks. Table 7-9 below summarizes the E-Truck business case key findings.

Table 7-9: Summary of E-Truck business case key findings

E-Truck Business Case Key Findings	Report Section(s)
Use E-Trucks on higher mileage routes	3.1 - 7.1
Incentives for purchase play a crucial role for the early E-Truck market	7.1
Right-sizing E-Truck battery is a viable cost reduction pathway	7.1
Future battery prices will make E-Trucks more cost competitive	7.1
Vehicle-To-Grid could improve the business case for E-Trucks	7.2

The E-Trucks deployed at the downtown Los Angeles facility were used on low mileage routes. At these low daily utilization rates (lower than 50 miles), fuel and maintenance savings will not pay for the higher incremental cost that E-Trucks typically show.

We recommend that E-Trucks be deployed on longer routes with daily mileage greater than 50 miles. At these high daily utilization rates, a sufficient amount of diesel fuel is displaced by cheaper electricity to make the investment into higher upfront costs E-Trucks worthwhile.

Incentives for purchase of E-Trucks greatly reduce the simple payback period and thus make E-Trucks more likely to be purchased by commercial fleets.

We recommend that incentive funding be available at this early stage of the E-Truck market.

Right-sizing E-Truck batteries to better fit how the vehicle is used can greatly increase the business case for E-Trucks and will be an important pathway to explore as incentives for purchase are expected to decrease.

We recommend that fleets, battery and E-Truck manufacturers work together to develop, test and demonstrate E-Trucks with scalable battery packs.

Lower battery costs are expected to greatly reduce E-Truck incremental costs. We recommend that fleets, battery and E-Truck manufacturers work together to reduce battery costs.

Using E-Trucks for V2G such as frequency regulation, demand response and peak shaving, increases battery usage and can dramatically improve the business case for commercial electric vehicles.

We recommend that fleets, battery and E-Truck manufacturers work together to develop, test and demonstrate V2G options for E-Trucks in delivery applications.

7.3.6 Summary of key recommendations

The list below summarizes the key recommendations that were developed in the previous parts:

1. Further testing should be carried out to better understand the impact of operating conditions on E-Truck performance.
2. AC kWh/mile should be used to compare the efficiency of E-Trucks with other vehicles.
3. Appropriate data collection techniques should be used to provide better performance data on E-Truck deployment projects.
4. Fleet managers should carefully plan E-Truck deployments to minimize charging infrastructure costs.
5. The charging current should be specified to guarantee vehicle availability.
6. Further testing should be carried out to better understand the origin of the stand-by current draw of E-Trucks when plugged in but not charging and explore ways to reduce its impact on overall E-Truck efficiency.
7. Demand response strategies should be implemented to take advantage of low energy prices such as Time-Of-Use pricing and avoid penalties such as demand charges.
8. Electric utilities and companies deploying E-Trucks need to work together to share the costs of local infrastructure upgrades in a way that is fair for ratepayers and acceptable for utility cost recovery structures but does not deter companies from deploying E-Trucks.
9. Drivers operating E-Trucks should be trained and coached to adapt their driving techniques to E-Trucks to take advantage of regenerative braking for instance.
10. "Early adopters" drivers should be selected first for E-Truck deployment project in order to build a positive experience.
11. Local and regional maintenance repair networks as well as spare parts inventories need to be developed in correlation with E-Truck sales. In addition, fleet mechanics need to be trained to diagnose and service E-Truck maintenance issues.
12. A more complete analysis is needed to further investigate and understand the potential maintenance savings of E-Trucks.
13. E-Trucks should be deployed on longer routes with daily mileage greater than 50 miles.
14. Incentive funding needs to be available at this early stage of the E-Truck market.
15. Fleets, battery and E-Truck manufacturers should work together to develop, test and demonstrate E-Trucks with scalable battery packs.
16. Fleets, battery and E-Truck manufacturers should work together to reduce battery costs.
17. Fleets, battery and E-Truck manufacturers should work together to develop, test and demonstrate V2G options for E-Trucks in delivery applications.

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APPENDIX A: Battery Electric Truck On-Road Testing Report

INTERNAL

CALSTART EV Delivery Van
Freightliner Custom Chassis MT E-Cell

Project Report No. TC-12-249-TR01
Revision No. 1

Performance Characterization Report, April 2013

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

Certified System
ISO 9001

Electric Vehicle Technical Center
An ISO 9001 Registered Facility

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1.0 EXECUTIVE SUMMARY

1.1 Background

The Freightliner Custom Chassis MT E-cell is an all-electric delivery van undergoing evaluation with the project partner as a delivery vehicle. CALSTART is providing the data analysis for the project under the CalHEAT initiative for the California Energy Commission (CEC). Southern California Edison, a CALSTART member, is providing CALSTART with a controlled test evaluation.

1.2 Key Results

The key test-based results outlined in the statement of work with CALSTART are summarized in Table 1-1 below.

Table 1-1 Key Results

Test	Result
Payload	4,740 +/- 80 lb
Urban range, unloaded	54 miles until low battery indicator light came on, 66 miles until vehicle began limiting power.
Urban Range, loaded	45 miles until low indicator light came on, 56 miles until vehicle began limiting power.
Delivery route range	46 miles until low battery indicator came on, 57 miles until vehicle began limiting power.
Charge Duration, typical	The bulk of the charge took 13 to 14 hours drawing 5.6 kW, however, the vehicle continued to draw 260 to 300 watts until it was unplugged.
Charge Energy, typical	67 AC kWh
SOC meter Evaluation	SOC (state of charge) meter is difficult to read: the lack of gradations makes it hard for the driver to estimate the remaining range. There is no separate range meter.
12 V systems	DC/DC converter provides enough power to keep battery charged during all operational modes

2.0 INTRODUCTION

CALSTART is an organization that promotes clean transportation for industry. CALSTART has over 140 corporate members, including Southern California Edison. As part of a CalHEAT Center project to evaluate EV drive trains in delivery vehicles, funded by the California Energy Commission, CALSTART is supporting the data acquisition for the project. The project includes the Freightliner Custom Chassis MT E-cell and Navistar's eStar EV delivery van. The vehicles have been in a demonstration in the project partner fleet, and EVTC testing will provide standardized testing data that CALSTART can use for comparison on range, performance, and effectiveness of the platforms, as well as the system impacts of charging of large electric vehicles. These vehicles may potentially be used more extensively in the project partner fleet, and used by other fleets, including the SCE fleet. This report covers the testing of the Freightliner Custom Chassis MT E-cell delivery van. This particular unit was not part of the project partner fleet, but was loaned from Freightliner because the project partner unit was out of service.

The Freightliner van supports an all-aluminum body by Morgan Olson, an Enova drivetrain, and three 20 kWh Tesla Motors packs, for a total of 60 kWh of battery capacity. The body is outfitted for package delivery.

3.0 OBJECTIVES

3.1 Tasks and Deliverables

The key tasks and deliverables as laid out in the statement of work with CALSTART are given in Table 3-1.

Table 3-1 Tasks and Deliverables

Item #	Tasks and Deliverables Description
1	Receiving and inspection
2	Performance Testing – Acceleration, max speed and braking
3	UR1 - Urban Range Test at Minimum Payload
4	UR3 - Urban Range Test at Maximum Payload
5	Delivery Route
6	Charger Performance Test
7	SOC Meter Evaluation
8	12 V standby testing
9	Report

3.2 Key parameters

This report will include the following key parameters:

- Range (mi)
- Energy recharge (AC kWh)
- Energy economy (kWh/mi)
- Recharge power quality parameters (system impact) (charge time, power, current, voltage, power conversion efficiency, PF, THD)
- Stand-by (hotel) load
- 12V system characterization
- Subjective evaluation

3.3 Inspection Requirements:

Inspection shall consist of, but is not limited to:

- Initial condition of vehicle
- Nameplate data
- Weight
- Overall dimensions
- Turning circle, "curb to curb" and "wall to wall"
- Ground Clearance

3.4 Measurement Requirements and Uncertainty

The key metrics to be reported include:

- Range (mi) ± 5%
- Energy Recharge (kWh) ± 0.5%
- Energy Economy (kWh/mi)
- Performance ± 1%
- Power Quality ± 0.5%
- Current THD ± 0.5%
- Voltage THD ± 0.5%
- Power Factor ± 0.5%

4.0 TEST SET-UP/PROCEDURE

4.1 Performance Testing – Acceleration, max speed and braking

The performance testing consisted of two acceleration tests, one starting at 80% SOC, and the other starting at 40% SOC. In both tests the vehicle was accelerated from rest until it reached 55 mph and the times required to reach 30 mph and 55 mph were recorded. Each test consisted of alternating runs in opposite directions (north and south) to compensate for grade. Between these two acceleration tests, a braking test was performed. The vehicle was driven at a constant 25 mph and then brought to a complete stop; the stopping distance was recorded in feet.

4.2 Range Tests

All range tests were performed by an experienced driver, driving the vehicle in a moderate style that was not too aggressive or too soft, and as compatible as possible with the flow of traffic. The distance driven when the low battery SOC (state of charge) warning came on was recorded as well as the distance when power limiting occurred and the final distance. The distance of the low warning indicator is used to determine the useful range, and the total distance was used to calculate the energy economy (AC kWh/mi). The urban route distances were recorded from the vehicle odometer and correlated with the SCE tabulated distances (Appendix A) to determine the accuracy of the vehicle odometer and a correction factor.

4.2.1 UR1 - Urban Range Test at Minimum Payload

For the Urban Range at Minimum Payload (driver and test equipment only) test, the MT E-cell was driven on the "Urban Pomona Loop" without using auxiliary loads. The data needed to determine distance per charge and AC kWh/mile were recorded. The DC data were not recorded.

The "Urban Pomona Loop" is a local street route of about 20 miles with approximately 60 stop signs and traffic lights. Refer to Appendix A for a map and elevation profile. The actual distance around the loop was used for range results, not the odometer reading, and is referred to as the corrected distance in the results.

4.2.2 UR3 - Urban Range Test at Maximum Payload

For the Urban Range Test at Maximum Payload, the MT E-cell was driven on the "Urban Pomona Loop" without using auxiliary loads and with an almost full payload of 4520 pounds. The data needed to determine distance per charge and AC kWh/mile were recorded. The DC data were not recorded.

4.2.3 Delivery Route

The delivery route was designed to simulate a more intensive duty cycle, similar to a newspaper delivery route, with more stops and starts in a given distance than the SCE urban loop. The delivery loop was driven without using auxiliary loads and at minimal payload.

4.3 Charger Performance Test

After a test drive, the MT E-cell was charged normally, and the charge was monitored with power quality instrumentation. SCE did not have access to any DC data or measurements; therefore we did not analyze the charger efficiency.

4.4 SOC Meter Evaluation

The SOC meter on the FCCC NT E-cell was read and recorded over the course of a delivery route test drive.

The MT E-cell meter did not have gradations or a numeric readout, so to improve readability SCE had to use the expedient of marking a clear piece of plastic and measuring the SOC in terms of 1/16 of an inch. Normally, this would not be done in a fleet setting.

4.5 12 V standby testing

The 12 V standby testing was accomplished by measuring the current flowing into and out of the 12 V auxiliary battery under five conditions: With the vehicle plugged in after finishing charging, with the vehicle off and not plugged in, with the vehicle on and idling, with the vehicle charging before the cooling fans came on, and with the vehicle charging after the cooling fans came on.

5.0 RESULTS AND ANALYSIS

5.1 Receiving and Inspection

The only damage found upon receipt of the vehicle was on the charge cord, which is detailed in Section 5.5.1. The MT E-cell weighed 9460 pounds as delivered, and with its GVWR of 14,200 pounds, had a payload of 4740 pounds. More inspection results are in Table 5-1.

Table 5-1 Inspection Results

Gross Vehicle Weight Rating (lb)	14,200
Curb Weight (lb)	9460 ± 80
Available payload (lb)	4740 ± 80
Turning Circle (curb to curb) (ft)	46
Turning Circle (body path) (ft)	49
Length (in)	248
Width (in)	114
Height (in)	117
Wheelbase (in)	139
Ground Clearance (in)	8

5.2 Ergonomics and driver response

5.2.1 Major Ergonomic Factors

Figure 5-1 View of right-hand mirror

The view of the exterior mirrors was partially blocked by the door frames, leaving large blind spots that could pose a challenge when changing lanes (Figures 5-1 and 5-2).

Figure 5-2 View of left hand mirror

5.2.2 Driver Comments

The following comments are the subjective evaluation of the SCE technician assigned to the MT E-cell test.

Figure 5-3 View of gages

- "The steering wheel doesn't tilt all the way down, and it obstructs the view of the bottom half of the cluster." See Figure 5-3.

Figure 5-4 SOC gage

- "When depleting the battery the SOC gauge drops down in very small increments making it harder to read the SOC."
- "At low SOC the only warning light you get is the "Low" sign at about 20% SOC; after that vehicle goes into Limiting Power Mode."

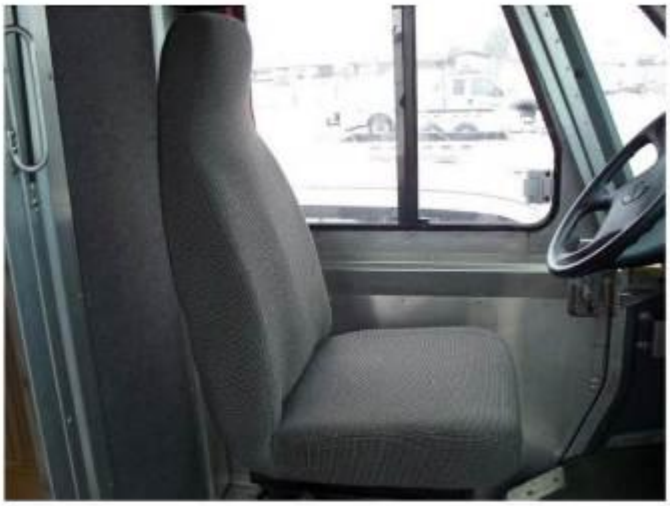

Figure 5-5 Cabin interior

- "I really like the driver seat. It is very comfortable and reduces the bouncing that comes with a stiff suspension that most work vans/trucks have."
- "I also like the regenerative braking. It's noticeable but not too aggressive. Hardly used the service brakes due to it and in turn it prolongs the life of the brakes."
- "I did notice that after about 50% SOC there is a very noticeable loss in power. This was proven when doing the 0-55 mph test and on urban drives going up the Carnelian Hill."

5.3 Performance Testing – Acceleration, max speed and braking

The MT E-cell showed an increase in acceleration times as the SOC decreased. This can be seen when comparing the results in Table 5-2 and Table 5-3. In Table 5-2 the north and southboundtimes for the 0-55 mph test differ by approximately 10 seconds. In Table 5-3 the north and southbound times for the same test differ by nearly 30 seconds. The maximum speed of the MT E-cell was 66 mph on a level road.

Table 5-2 Acceleration Times, 80% SOC

Starting SOC:~80%		Ending SOC:60%	
Run	**0-30 mph time (sec)**	**0-55 mph time (sec)**	**Direction**
1	6.52	42.34	North
2	6.02	31.13	South
3	6.59	44.58	North
4	6.31	33.64	South
Average	**6.4**	**38**	

Table 5-3 Acceleration Times, 40% SOC

Starting SOC: 40%		Ending SOC: 30%	
Run	**0-30 mph time (sec)**	**0-55 mph time (sec)**	**Direction**
1	7.22	64.14	North
2	6.42	36.89	South
3	7.37	67.59	North
4	6.59	34.98	South
Average	**6.9**	**51**	

The MT E-cell had an average braking distance of 42.5 feet from 25 mph to a complete stop.

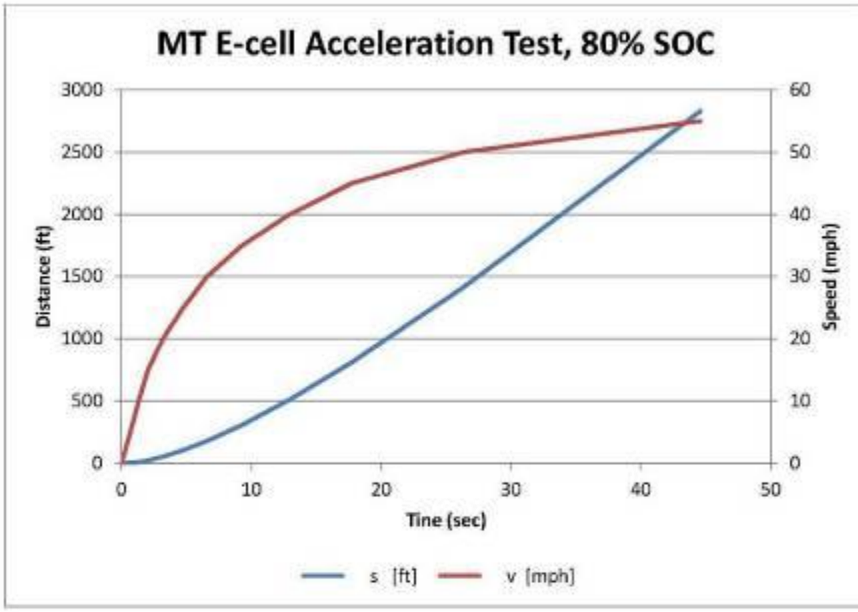

Figure 5-6 Typical acceleration profile

Figure 5-6 shows a typical acceleration profile when the vehicle is near 80% SOC.

5.4 Range Testing

5.4.1 UR1 - Urban Range Test at Minimum Payload

Table 5-4 Urban 1 Range Test Results

Test	UR1
Duration of Drive (hr:min)	2:52
Net Odometer (mi)	70.4
Corrected Distance, miles	67.6
SOC Start	100%
SOC END	0%
Flashing Low Indicator Light (mi)	55.8
Corrected Low Indicator Range (mi)	53.6
Power Limiting (mi)	68.9
Power Limiting (mi) Corrected	66.1
Total Distance Traveled (mi)	67.6
Charge Duration (bulk of charge, h:mm)	13:15
Charge AC kWh	66.8
AC kWh/mi Overall	0.99

The charge durations in Table 5-4 and Table 5-5 are approximations. The FCCC MT E-cell continued to draw about 260 to 300 watts until it was unplugged. This is a significant hotel load and the total energy consumed by it depended upon when the user unplugged the vehicle. The energy presented in this table is for the bulk of the charge, until it dropped to a steady value for the hotel load.

5.4.2 UR3 - Urban Range Test at Maximum Payload

Table 5-5 Urban 3 Range Results

Test	UR3
Payload (lbs)	4520
Duration of Drive (hr:min)	2:15
Net Odometer	58.6
Corrected Distance, miles	56.2
SOC Start	100%
SOC END	0%
Low Indicator Light ON (mi)	46.8
low Indicator Light ON (mi) Corrected	44.9
Power Limiting (mi)	58.15
Power Limiting (mi) Corrected	55.8
Charge Duration (bulk of charge, h:mm)	13:45
Charge AC kWh	67.51
AC kWh/mi Overall	1.2

As with Table 5-4, Table 5-5 reports the energy consumed during the bulk of the charge. For every hour the vehicle remains plugged in after completing the charge, it consumes another 0.3 AC kWh of electricity. The range when the low SOC indicator light came on during the UR3 test was 16% lower than in the UR1test while the energy consumption (AC kWh/mi) was 21% higher.

5.4.3 Delivery Route

Table 5-6 shows the results of the Delivery Route test. The range result for the low SOC indicator was 15% lower than the UR1 test while the energy consumption (AC kWh/mi) was 16% higher. The AC energy needed to charge the vehicle was 0.8% higher for the delivery route.

Table 5-6 Delivery Route Range Results

Test	Del. Route
Duration of Drive (hr:min)	3:28
Net Odometer (mi)	58.8
Corrected Distance, miles	56.5
SOC Start	100%
SOC END	0%
Low Indicator Light ON (mi)	47.5
Low Indicator Light ON (mi) corrected	45.6
Power Limiting (mi)	56.8
Power Limiting (mi) corrected	54.5
Charge Duration (bulk of charge, hr:min)	13:20
Charge AC kWh	67.36
AC kWh/mi Overall	1.15

5.5 *Charger Performance Test*

5.5.1 Safety

5.5.1.1 Electrical safety

The Freightliner MT E-cell was delivered with a charge cord that did not meet the voluntary Society of Automotive Engineers J1772™ standard. This means the E-cell is not compatible with most of the EVSEs (electric vehicle supply equipment) on the market. The MT E-cell as delivered did not support Article 625 of the National Electric Code because it did not meet the following requirements[1]:

- Interlock that de-energizes the electric vehicle connector when disconnected from vehicle. The E-cell can be unplugged at full current flow. This may cause a spark or shock hazard.
- Automatic de-energization of cable upon over-exposure to strain.
- Overcurrent protection. There is nothing to limit the amount of current if the vehicle is plugged into a lower rated circuit, as with an adapter.

[1] National Electric Code Handbook, 2008, Article 625

- Personnel protection system against electric shock. There is no GFCI incorporated into the EVSE provided with the E-cell.

The EVSE provided with the MT E-cell was simply a section of cord with a twist-lock plug wired directly into the charger. The cord was wound around a fluid reservoir and the hood of the E-cell had to be opened to access it. Furthermore, the cord as shipped was damaged by extensive crushing, which resulted in arcing and overheating. The cord had been plugged into an extension cord, which is definitely not recommended, and SCE technicians initially noticed the heating discoloration on the extension cord socket. See Figure 5-7.

Figure 5-7 Heating damage to extension cord socket.

The SCE technicians then inspected the plug attached to the vehicle cord and found further evidence of heating. One of prongs had recessed when the plastic supporting it had melted. See Figure 5-8.

Figure 5-8 Exterior of damaged plug

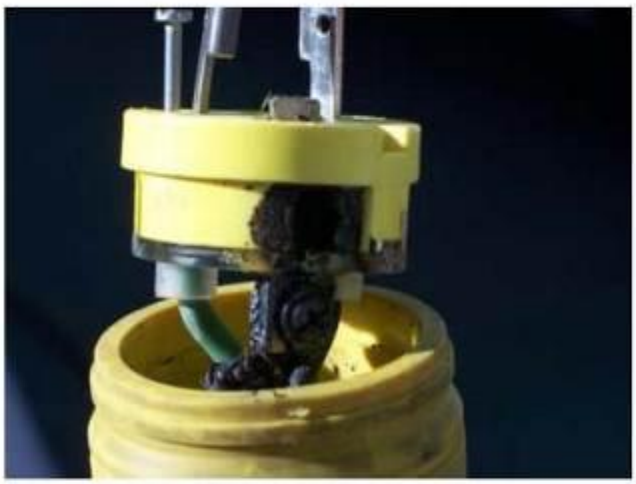

Figure 5-9 Interior of damaged plug.

Figure 5-9 shows the interior of the damaged plug, where the extent of the melting is more evident. If the vehicle had been plugged directly into a socket built into a building, there would have been potential for a structure fire.

5.5.1.2 Drive away protection

Another important safety feature is drive-away protection. The MT E-cell had drive-away protection that engaged when voltage was present and prevented the vehicle from turning on. When the voltage was removed and the vehicle still plugged in, the E-cell could be started and driven away. This could cause structural damage in a fleet setting in the event of a circuit trip or power outage.

5.5.2 Power Quality

The results of the charger characterization are given in Table 5-7. At maximum power, the power factor is 1.0 and both the current and voltage total harmonic distortions (THD) are well below the SAE J2894/1™ recommended values of 10% (see Table 5-8). At minimum power, the power factor drops to 0.85 and the current total harmonic distortion rises to 24%, but the power level is low at 0.26 kW. This may cause some difficulty with sensitive equipment if a large number of such vehicles were connected at a single location.

Table 5-7 Freightliner MT E-Cell Charger Power Quality

Test Info	
Test date	11/1/2012
Nominal Voltage (V)	240
Energy Consumption (AC kWh)	67.80
Min. Voltage (V)	235.08
Max. Voltage (V)	242.85
Charge Duration (hr:min)	17:32

Power Quality Parameters	**Maximum Power**	**Minimum Power**
Voltage (V)	242.34	241.10
Current A (A)	23.24	1.30
Frequency (Hz)	60.00	59.99
Active Power (kW)	5.61	0.26
Reactive Power (kVAR)	-0.35	-0.15
Apparent Power (kVA)	5.63	0.31
Power Factor	1.00	-0.85
Max Voltage THD (%)	1.43	1.34
Max Current THD (%)	3.31	23.91

Note:
**All max power values are 5 min average around selected data point*

Table 5-8 SAE J2894 Power Quality Requirements for Plug-In Electric Vehicle Chargers[2]

Power Quality Parameters	Level 1	Level 2
Total Power Factor (minimum)	95%	95%
Power Conversion Efficiency	90%	90%
Total Harmonic Current Distortion (maximum)	10%	10%

SCE did not have access to the DC data and was not able to provide information on the charger efficiency.

5.5.3 Charge duration

The Freightliner literature on the MT E-cell claims a charge time of 6 to 8 hours, but the vehicle provided to SCE had a charge duration of up to 17 ½ hours, with the bulk of the charge taking 12-14 hours. The E-cell continued to draw power in the range of 250 W to 300 W until it was unplugged. See Figure 5-10 for a typical charge profile. In fleet use, the E-cell may not have time to fully recharge before the next day, especially in a scenario of demand-response or off-peak charge control, and this could lead to a situation where the vehicle doesn't have the range to complete its tasks. SCE prefers to see a vehicle that can recharge in less than 8-hours.

[2] SAEJ2894/1 EV Power Quality Requirements for Plug-In Electric Vehicle Chargers, 2011-12-08

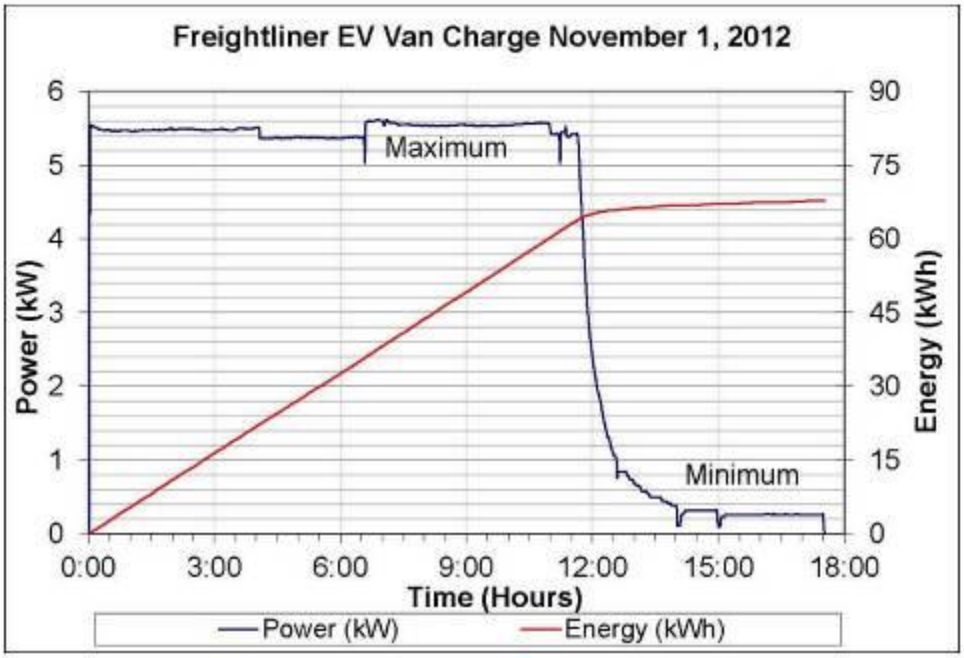

Figure 5-10 Freightliner MT E-Cell charging profile.

5.6 SOC Meter Evaluation

The Freightliner MT E-cell uses a LCD display to show an analog representation of the state of charge (See Figure 5-4). This representation has no gradations and is difficult for a driver to read and estimate the remaining range. In order to perform the SOC meter evaluation, SCE divided the meter into 9 parts, each 1/8 of inch wide (Figure 5-11). This made it easier for the driver to estimate the SOC (to the nearest 1/16 of an inch), although it was still far from perfect. In the same space as the current SOC meter, the MT E-cell could use a large-format numerical SOC gage that would be much easier to read.

Figure 5-11 SOC meter with gradations added.

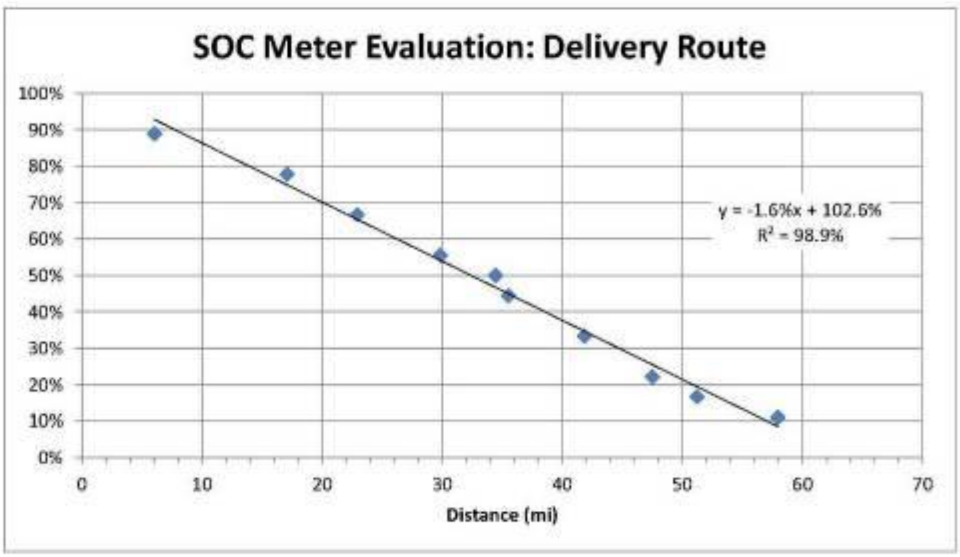

Figure 5-12 SOC Meter evaluation

Figure 5-12 shows the results of the meter evaluation during the delivery route driving test. The decrease in SOC is fairly linear, given the difficulty in reading the meter. A driver can estimate that every mile will reduce the SOC by 1.6%, or that each 10% of SOC can result in 6.3 miles of range. The mileage used in Figure 5-12 is the corrected mileage, not the odometer reading.

5.7 *12 V standby testing*

SCE monitored the current into and out of the 12 V battery under the conditions listed in Table 5-9. The DC/DC converter provided sufficient power in all test conditions to support the voltage. Any communications systems used by the project partner fleet for delivery were not active, so SCE was not able to test the effect of that demand on the 12 V system. Note that the system maintains the 12 V battery under both driving and charging states, but not in the charge maintenance mode.

Table 5-9 12 V Standby Tests

Condition	Net current (Amps)
EVSE/Charger (Plugged-in after finished charging/Maintain Mode)	0.0
Vehicle off (not plugged-in)	0.0
Vehicle on (Idling)	2.3
Vehicle Charging (Before fans off)	4.8
Vehicle Charging (Fans on)	1.3

6.0 CONCLUSION AND RECOMMENDATIONS

The Freightliner MT E-cell has potential for a successful delivery vehicle with good cargo volume and payload but has significant issues that must be addressed prior to inclusion as a main fleet vehicle.

6.1 Conclusions

1. The MT E-cell is capable of delivering payload of up to 4700 pounds with an energy economy of 1.0 to 1.2 AC kWh/mi.
2. It has a useful range of 57 to 69 miles, depending on the payload and duty cycle.
3. It has acceptable power quality at a high rate of charge. At lower power, the current THD rises above 20%.
4. It has a 13 hour to 14 hour charge time and a continuous power draw of 260 W to 300 W after the charge has completed, until it was unplugged. The long duration of this charge could cause problems with vehicle availability in fleet use.
5. As delivered it did not meet the SAE J1772 recommendations for vehicle charging. The MT E-cell did not support the requirements of Article 625 of the National Electric Code because it did not properly incorporate sufficient ground fault and drive-away protection in the EVSE.

6.2 Recommendations

1. The manufacturer of the MT E-cell should ensure that the E-cell supports the requirements of NEC Article 625 for safety.
2. SCE would prefer that the MT E-cell adhere to the SAE J1772 standards for vehicle charging. This would have the advantage of allowing the MT E-cell to use infrastructure in common with other electric vehicles.
3. The charging rate should be increased to reduce the charge time to less than 8 hours.

APPENDIX A. SCE TEST LOOPS

C.1 Urban Loop Map and elevation profile

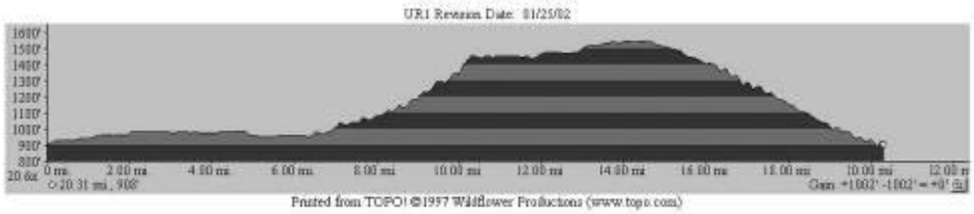

Figure C-1 Urban Loop Elevation Profile

Figure C-2 Pomona Loop Map

Table C-1 Urban Loop Tabulated Data

Stop No.	Distance from Start (miles)	Type	Distance from Previous stop	Comments
0	0.0	light	0.00	East End & Holt
1	0.1	light	0.10	
2	0.2	light	0.05	Mills & Holt
3	0.8	light	0.65	
4	1.3	light	0.50	
5	1.8	light	0.50	
6	2.3	light	0.50	
7	2.9	light	0.60	
8	3.5	light	0.60	
9	3.7	light	0.20	
10	4.0	light	0.30	
11	4.0	light	0.01	
12	4.3	light	0.29	
13	4.6	light	0.30	
14	4.8	light	0.20	
15	4.8	light	0.02	
16	5.3	light	0.48	
17	6.3	light	1.00	Vineyard & Holt
18	6.7	light	0.36	
19	6.7	light	0.04	
20	6.8	light	0.10	
21	6.9	light	0.10	
22	7.3	light	0.40	
23	7.8	light	0.50	
24	8.3	light	0.50	
25	8.6	light	0.30	
26	8.8	light	0.20	
27	9.3	light	0.50	
28	9.5	light	0.20	
29	9.6	light	0.10	
30	9.7	light	0.10	
31	10.4	light	0.70	Carnelian & Baseline
32	10.7	light	0.30	
33	10.9	light	0.20	
34	11.6	light	0.70	
35	11.9	light	0.30	
36	12.3	light	0.40	
37	12.5	light	0.20	
38	12.7	light	0.20	
39	13.0	light	0.30	
40	13.6	light	0.60	
41	14.1	light	0.50	Baseline & Benson
42	14.9	light	0.78	Baseline & CA-210
43	15.1	light	0.22	Baseline & Padua
44	15.6	light	0.50	Baseline & Mills
45	16.4	light	0.75	Indian Hill
46	16.6	light	0.23	IH & Radcliff
47	16.9	light	0.29	

Stop No.	Distance from Start (miles)	Type	Distance from Previous stop	Comments
48	17.4	light	0.48	Indian Hill & Foothill
49	17.6	light	0.26	
50	17.7	light	0.13	IH & 8th St
51	18.0	light	0.22	
52	18.1	light	0.14	IH & Bonita
53	18.2	light	0.06	
54	18.2	light	0.06	IH & 1st St
55	18.3	light	0.05	
56	18.5	light	0.24	IH & Arrow
57	18.8	light	0.25	
58	19.0	light	0.25	
59	19.1	light	0.07	IH & WB I-10 ramp
60	19.1	light	0.05	IH & EB I-10 ramp
61	19.2	light	0.05	
62	19.3	light	0.08	IH & W. American
63	19.3	light	0.07	
64	19.5	light	0.18	IH & San Bernardino Ave.
65	19.9	light	0.34	IH & Lincoln
66	20.1	light	0.27	IH & Kingsley
67	20.4	light	0.26	IH & Holt

C.3 Delivery Route

Figure C-3 Delivery route map

APPENDIX B: Battery Electric Truck Chassis Dynamometer Testing Report

Final Report

Assessment of the Performance of a Class 5 Battery Electric Commercial Truck

Chassis Dynamometer Testing

June 2013

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Disclaimer

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Executive Summary

Battery-electric vehicles hold significant promise for reducing emissions and fuel consumption in package delivery vehicles. To assess the benefits and operational impacts of battery-electric vehicles, the California Hybrid, Efficient and Advanced Truck (CalHEAT) research center contracted with the Center for Environmental Research and Technology (CE-CERT) of the University of California, Riverside's College of Engineering to evaluate the performance and energy use of a Class 5 battery electric urban delivery vehicle over 2 standardized driving cycles and a steady state range test on a chassis dynamometer. Funding for this project was provided by the California Energy Commission.

The test vehicle, a Smith Electric Newton Step Van, was tested on 2 standardized drive cycles (the Hybrid Truck Users Forum Parcel Delivery Class 4 and the Orange County Bus Cycle) and a steady state range test. Testing was carried out on the University of California, Riverside Heavy-Duty Chassis Dynamometer. Table E-1 summarizes the results of the chassis dynamometer testing.

Test Cycle	Total Test Miles	Total Charging Time	Overall AC Energy Consumption	Overall DC Energy Consumption
HTUF4	36.06 miles	4 hours 49 minutes	0.81 AC kWh/mile	0.67 DC kWh/mile
OCBC	32.34 miles	4 hours 38 minutes	0.88 AC kWh/mile	0.72 DC kWh/mile
Steady State	91.62 miles	14 hours 21 minutes	0.98 AC kWh/mile	0.80 DC kWh/mile

Table E-1: Summary of chassis dynamometer test results.

From the steady state range test, the total battery capacity was estimated as 89.64 AC kWh.

Please note that due to testing site infrastructure limitations, we were not able to use the charging current recommended by Smith Electric Vehicles to recharge the Newton Step Van. 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 calculated in this report may be larger than if the vehicle had been charged at the recommended charging rate.

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. We recommend that further testing be carried on to analyze all factors influencing actual electric range and overall energy consumption.

1. Overview

The California Hybrid, Efficient and Advanced Truck (CalHEAT) Research Center (www.calheat.org) 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 study was to evaluate the performance and energy use of a Class 5 battery electric urban delivery vehicle over 2 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 when electricity is introduced from the electrical outlet (AC energy, kWh);
- the total time to recharge the vehicle battery; and
- the estimated 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.

2. Vehicle

The vehicle tested was a Smith Electric Newton Step Van (see Figure 1 below), provided by a parcel delivery fleet, partner for this project. 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 220V / 63A or 208V / 75A. Additional information about the vehicle is shown in Table 1.

Figure 1: The Smith Electric Newton Step Van

Model	Newton Step Van
Model Year	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)
Nominal Battery Voltage	343V
Maximum Battery Voltage	354V
Charger	On-board, fully automatic SAE J1772
Charging Time (From 0 to 100% SOC)	At 75A: 6 to 8 hours[1] At 30A: about 20 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 Length	268 in.
Overall Height	94 in.
Overall Width	87 in.
Wheelbase	154 in.
Chassis Configuration	4 x 2 (Rear Wheel Drive)
Range	Up to 80 miles
Top Speed	~63 MPH

Table 1: Specifications of the test vehicle.

[1] Charging current recommended by Smith Electric Vehicles.

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

3. Heavy-Duty Diesel Chassis Dynamometer Test Facility

Testing was carried out on the University of California, Riverside Heavy-Duty Chassis Dynamometer (HDCD) (see Appendix A for details). 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 (see Figure 2). The dynamometer applies appropriate loads to a vehicle to simulate factors such as the friction of the roadway and wind resistance that it would experience under typical driving. A driver accelerates and decelerates following a driving trace while the vehicle is chained to the dynamometer.

- Performance
  - 5,000 lb 0-15 mph
  - 600 hp 45-80 mph
  - 200 hp 15 mph
- Acceleration 6 mph/sec
- Inertia Simulation
  - 10 lb increments
  - 10,000 lb – 80,000 lb range
  - 45,000 lb base inertia
- Speed accuracy +/- 0.01 mph
- Acceleration accuracy +/- 0.02 mph/sec
- Response time 44 to 100 ms

Figure 2: Selected Data for the UCR HDCD

4. Drive Cycles Used for Testing

4.1 Hybrid Truck Users Forum Parcel Delivery Class 4

Testing was conducted on the vehicle using two drive cycles: 1) the Hybrid Truck Users Forum Parcel Delivery Class 4 (HTUF4) driving schedule and, 2) the Orange County Bus Cycle (OCBC). These drive cycles have been used in a previous study we conducted in partnership with the National Renewable Energy Laboratory (NREL) to evaluate gasoline/electric hybrid parcel delivery trucks[3].

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 and NREL chose to run only phase 1 and 2. CE-CERT also chose to run only phase 1 and 2. The drive cycle, which includes 5 periods of engine off time, is shown in Figure 3.

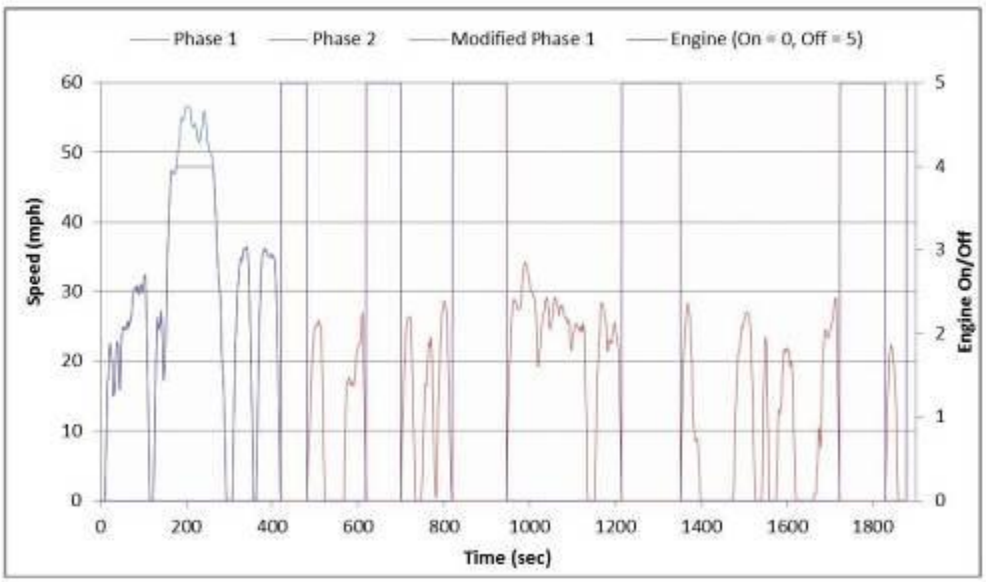


Figure 3: HTUF Class 4 Driving Schedule

[3] Barnitt R., "FedEx Express Gasoline Hybrid Electric Delivery Truck Evaluation: 12-Month Report", National Renewable Energy Laboratory, December 2010

4.2 Orange County Bus Cycle

The second cycle is the Orange County Bus Cycle (OCBC). This 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 4.

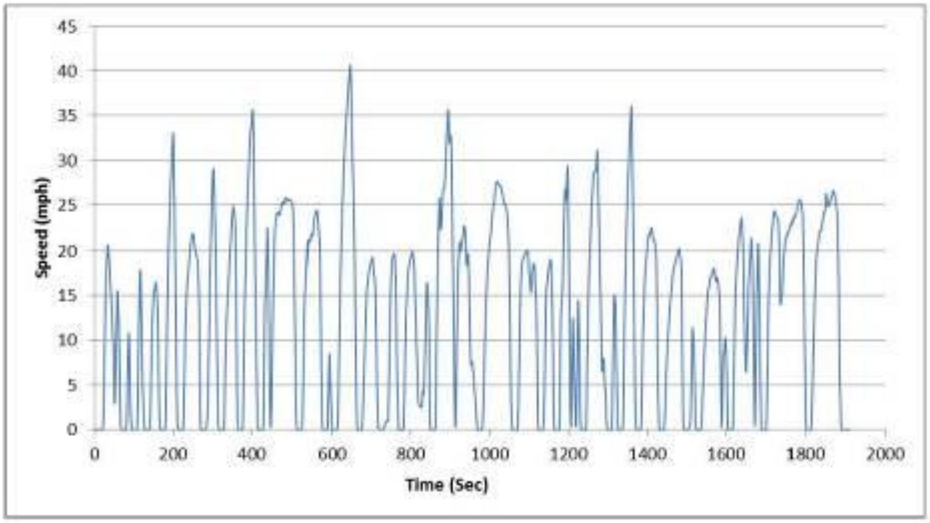


Figure 4: Orange County Bus Cycle

4.3 Steady-State Range Test

The CARB 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 [...]"[4]. Given the drive cycles that we selected for this test and the vehicle range, this would prove impractical. For instance, if we assume that the vehicle has a total range of 100 miles, the vehicle will need to run 16 OCBC drive cycles consecutively to fully deplete the battery. Including 15 10-minute soak between tests, it would take a total of 10 hours and 59 minutes to complete this test.

[4] *California Environmental Protection Agency - Air Resources Board*, "California Exhaust Emission Standards and Test Procedures for 2009 and Subsequent Model Zero-Emission Vehicles and Hybrid Electric Vehicles, in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes", December 2, 2009

In order to circumvent this long test time, we decided to follow a different approach described by Lohse-Busch[5]. We decided to run the vehicle on a 1909-second steady-state drive cycle at 55 MPH (see Figure 5 below).

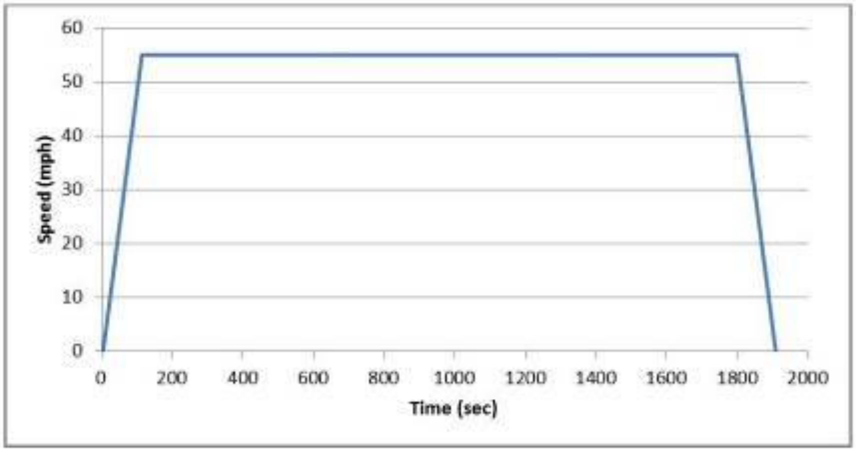


Figure 5: CALSTART Steady State Range Test

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. The following parameters were recorded to estimate the total battery capacity:

- AC energy required to fully charge the battery after the Steady State Range Test from the point where electricity is introduced from the electric outlet to the battery charger,
- DC energy required to fully charge the battery after the Steady State Range Test from the point where electricity is introduced from the battery charger to the battery.

Using the overall energy consumption (kWh/mile) for the HTUF4 and OCBC drive cycles and the estimate of total battery capacity (kWh), the total vehicle range for the HTUF4 and OCBC drive cycles can be estimated.

[5] Lohse-Busch, Henning, "Testing and Evaluation Challenges of Electrified Vehicles", Argonne National Laboratory, April 2011

Table 2 below presents some metrics of the 3 drive cycles used:

	HTUF4 (no engine off)	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

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

4.4 Note about Vehicle Accessories and Weather Conditions

While the Newton Step Van was tested on 2 different standardized driving cycles and a steady state range test, 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 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. We recommend that further testing be carried out to analyze all factors influencing actual electric range and overall energy consumption.

5. Methodology

5.1. Coast down data

Coast down parameters were calculated using the frontal area calculation approach[6]. 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 and the dynamometer coefficients for the tests in Table 4.

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

Table 3: Calculated Coast Down Data

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

Table 4: Dynamometer Coefficients for the Tests

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

5.2. Regenerative braking

The Smith Electric Newton Step Van is equipped with a 2-stage regenerative braking system that puts energy back into the battery pack during coasting and braking. In addition, the vehicle has a regenerative braking switch to activate/deactivate the regenerative braking system (see Figure 6). 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.

Figure 6: The Newton Step Van control panel

[6] Draft test plan, "In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines", Prepared for Adewale Oshinuga, South Coast Air Quality Management District, RFP #P2011-6, October 2011

5.3. 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 1Hz 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.

5.4. Vehicle charging data

A portable J1772 EVSE (see Figure 7 on the left) 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 7: 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, we were not able to use the charging current recommended by Smith Electric Vehicles to recharge the Newton Step Van. 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 (see Figure 8).

Figure 8: 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 manually read from the digital display of the meter attached behind the portable EVSE (see Figure 7 on the right) before plugging and unplugging the portable EVSE.

5.5. Definition of calculated parameters

Using the test cycle data and the vehicle charging data described in sections 5.3 and 5.4 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 3 test cycles (HTUF4, OCBC or Steady State).

- *Test Day*

A test day represents a complete chassis dynamometer test for one of the 3 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:

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

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

- *Total Dyno. Miles*

The total miles driven during a particular test run recorded by the chassis dynamometer instruments.

- *Total ECM Miles*

The total miles driven during a particular test run calculated from the Vehicle Speed using equation (2) below:

$$\text{Total ECM Miles} = \sum_{i=1}^{n} \frac{\text{Vehicle Speed (MPH)}}{3600\ (\frac{\text{sec}}{\text{hr}})} \qquad (2)$$

Where *n* is the number of seconds in the test run.

- *Net DC Energy*

The total DC energy in kWh that was sent to and from the vehicle battery for a particular test run, calculated from the Battery Current and Battery Voltage using equation (3) below:

$$\text{Net DC Energy (DC kWh)} = \frac{\text{Battery Current (A)} \times \text{Battery Voltage (V)}}{1000\ (\frac{\text{W}}{\text{kW}}) \times 3600\ (\frac{\text{seconds}}{\text{hour}})} \qquad (3)$$

- *DC Energy Output (kWh)*

The negative DC energy in kWh that was sent from the vehicle battery for a particular test run, calculated from the Battery Current and Battery Voltage using equation (4) below:

$$\text{DC Energy Output (DC kWh)} = \text{Min}(0, \frac{\text{Battery Current (A)} \times \text{Battery Voltage (V)}}{1000\left(\frac{\text{W}}{\text{kW}}\right) \times 3600\left(\frac{\text{seconds}}{\text{hour}}\right)}) \qquad (4)$$

- *DC Energy Input (kWh)*

The positive DC energy in kWh that was sent to the vehicle battery for a particular test run, calculated from the Battery Current and Battery Voltage using equation (5) below:

$$\text{DC Energy Input (DC kWh)} = \text{Max}(0, \frac{\text{Battery Current (A)} \times \text{Battery Voltage (V)}}{1000\left(\frac{\text{W}}{\text{kW}}\right) \times 3600\left(\frac{\text{seconds}}{\text{hour}}\right)}) \qquad (5)$$

- *SOC Test Start*

The Battery State Of Charge when a particular test run starts.

- *SOC Test End*

The Battery State Of Charge when a particular test run ends.

- *Net DC Energy Consumption*

The energy consumption rate in DC kWh/mile for a particular test run, calculated from the Net DC Energy (kWh) and the Total Dyno. Miles using equation (6) below:

$$\text{Net DC Energy Consumption (DC kWh/mile)} = \frac{Net\ DC\ Energy\ (kWh)}{Total\ Dyno\ Miles} \qquad (6)$$

- *DC Energy Output (kWh/mile)*

The negative DC energy in kWh/mile that was sent from the vehicle battery for a particular test run, calculated from the DC Energy Output (kWh) and the Total Dyno. Miles using equation (7) below:

$$\text{DC Energy Output (DC kWh/mile)} = \frac{DC\ Energy\ Output\ (kWh)}{Total\ Dyno\ Miles} \qquad (7)$$

- *DC Energy Input (kWh/mile)*

The positive DC energy in kWh/mile that was sent to the vehicle battery for a particular test run, calculated from the DC Energy Input (kWh) and the Total Dyno. Miles using equation (8) below:

$$\text{DC Energy Input (DC kWh/mile)} = \frac{DC\ Energy\ Input\ (kWh)}{Total\ Dyno\ Miles} \qquad (8)$$

- *Charge Starting*

The moment when the vehicle is plugged-in to the portable EVSE, identified on the battery current by a change from a null or negative value to a positive value. By convention, the time when the charge is starting is assigned to 0:00:00.

- *Bulk Charging*

Bulk Charging is achieved when the Battery SOC first reaches 100%.

- *Total Charging*

Total Charging is achieved when the Battery SOC first reaches 100% and the Battery Current first drops to 0.

- *Vehicle Unplugged*

Vehicle Unplugged is achieved when the battery management system mode goes from 1 to 0 or 2. It represents the instant when the vehicle is unplugged from the portable EVSE.

- *Recorded Time*

The time (in hh:mm:ss PDT) that was recorded at a particular event.

- *Cumulative Time*

The cumulative time (in hh:mm:ss) since the charge started.

- *AC Energy Charged*

The total energy in AC kWh recorded by the revenue grade meter at the back of the portable EVSE for a particular charging event (i.e. from the Charge Starting Recorded Time to the Bulk / Total Charging or Vehicle Unplugged Recorded Time). Since the meter recorded at 15-minute intervals, we used the nearest superior 15-minute reading. For instance, if the Bulk Charging Time was 21:47:00, we used the AC kWh reading for 22:00:00.

- *AC Energy Charged (manual reading)*

The total energy in AC kWh manually read from the meter before and after the vehicle was plugged to the portable EVSE.

- *DC Energy Charged*

The total DC energy in kWh that was sent to the vehicle battery for a particular charging event (i.e. from the Charge Starting Recorded Time to the Bulk / Total Charging or Vehicle Unplugged Recorded Time). It is calculated from the Battery Current and Battery Voltage using equations (9) and (10) below:

$$\text{DC Energy (kWh)} = \frac{\text{Battery Current (A)} \times \text{Battery Voltage (V)}}{1000\left(\frac{\text{W}}{\text{kW}}\right) \times 3600\left(\frac{\text{seconds}}{\text{hour}}\right)} \quad (9)$$

$$\text{DC Energy Charged (kWh)} = \sum_{i=1}^{n} DC \text{ Energy (kWh)} \quad (10)$$

Where *n* is the number of seconds in the test run.

- *Overall AC Energy Consumption*

The energy consumption rate in AC kWh/mile for a particular test day, calculated from the AC Energy Charged recorded at Total Charging and the sum of Total Dyno. Miles for all test runs using equation (11) below:

$$\text{Overall AC Energy Consumption (AC kWh/mile)} = \frac{AC\ Energy\ Charged\ (kWh)}{\sum_{i}^{n}(Total\ Dyno\ Miles)i} \quad (11)$$

Where *n* is the number of test runs done for each particular test day.

- *Overall DC Energy Consumption*

The energy consumption in DC kWh/mile for a particular test day, calculated from the DC Energy Charged recorded at Total Charging and the sum of Total Dyno. Miles for all test runs using equation (12) below:

$$\text{Overall DC Energy Consumption (DC kWh/mile)} = \frac{DC\ Energy\ Charged\ (kWh)}{\sum_{i}^{n}(Total\ Dyno\ Miles)i} \quad (12)$$

Where *n* is the number of test runs done for each particular test day.

- *Maximum Charging Power*[7]

The maximum grid power in kW recorded by the revenue grade meter at the back of the portable EVSE for a particular charging event (i.e. from the Charge Starting Recorded Time to the Vehicle Unplugged Recorded Time).

[7] Please note that this was limited by the charging infrastructure available for this testing.

5.6. Soak Period

A 10-minute soak period was included between each test run. During this soak period, it was decided to leave the vehicle in the key-on position to avoid loss of data from the Smith Link data acquisition system. We noticed that the vehicle drew a small amount of energy from the vehicle battery while idling. We estimated this energy consumption at idle between 0.50 and 1.00 AC kWh per an entire test day (including 4 10-minute soak periods).

The grid energy supplied to recharge the vehicle after each test day (AC Energy Charged and DC Energy Charged) does include this energy consumption during the soak periods in addition to the energy expended during the test runs.

6. Test Results

6.1. HTUF4 (Test #1)

The HTUF4 test #1 was completed on March 27th, 2013. The test day consisted of 5 consecutive HTUF4 test runs and a 10-minute soak in between each run. The first run started at 7:17:33 AM and the 5th run ended at 10:35:55 AM. The entire test day took 3:18:22. Average ambient temperature during each run varied from 59.4°F to 71.9°F. Battery charging began about 36 minutes after the completion of the last HTUF4 test run.

After the HTUF4 test, the engineer from Smith Electric Vehicles reported issues in the data that was collected by the Smith Link data acquisition system. During the long periods of idle, the vehicle was keyed-off to represent more realistic fleet operations. Due to data buffering issues, data "froze" to the last valid number recorded a few seconds before and after the key-off event. Therefore, the recorded Smith Link data was deemed invalid and is not reported in this section.

The HTUF4 test was repeated on March 28th, 2013 following the OCBC test without turning the key off. In addition, to ensure there was no data loss, the vehicle was keyed-on 1-2 minutes before beginning any test run and up to 10 minutes at the end of the test day.

Table 5 below summarizes the charging data for this test.

	Charge Starting	Bulk Charging	Total Charging	Vehicle Unplugged
Recorded Time (hh:mm:ss PDT)	11:11:55 (3/27)	15:41:30 (3/27)	15:59:39 (3/27)	7:21:47 (3/28)
Cumulative Time (hh:mm:ss)	0:00:00	4:29:35	4:47:44	20:09:52
AC Energy Charged	0.0000	29.0145	29.8476	30.8937
AC Energy Charged (manual reading)	0	-	-	31
DC Energy Charged	0.00	23.49	24.36	24.36

Table 5: Summary of charging data following the HTUF4 Test #1 on 3/27/13

The chassis dynamometer recorded a total of 36.06 miles driven for the 5 test runs. From Table 5, the Overall AC Energy Consumption was calculated as **0.83 AC kWh/mile** and the Overall DC Energy Consumption as **0.68 DC kWh/mile**.

Figure 9 below shows the cumulative AC and DC energy consumed to recharge the battery, the vehicle SOC and the AC charging rate in kW.

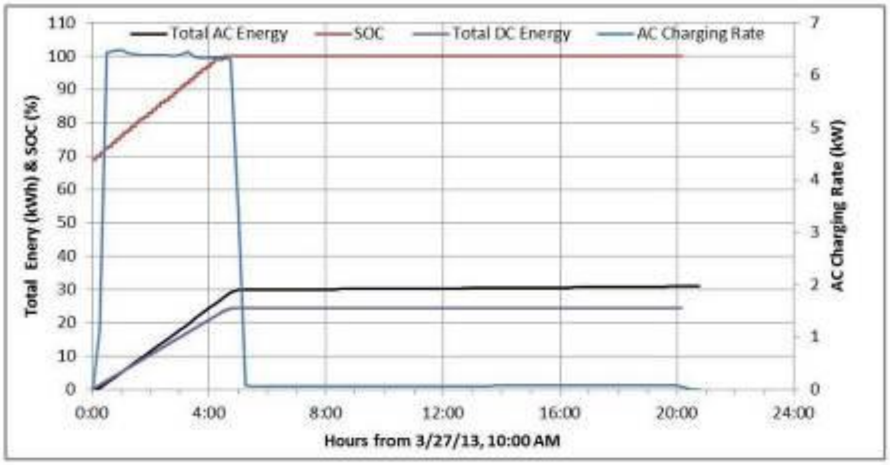


Figure 9: Total AC Energy, SOC, Total DC Energy, and AC Charging Rate for HTUF4 Test

Maximum charging power was recorded as **6.49 AC kW**. Once the SOC reached 100% and the battery current dropped to 0 (indicating total charge time), the vehicle continued to draw a small amount of current from the grid until it was unplugged. A total of 1.05 AC kWh was consumed from the time the vehicle reached the total charging time and the time the vehicle was unplugged from the charger.

6.2. OCBC & HTUF4 (Test #2)

The OCBC test was completed on March 28th, 2013. The testing consisted of 5 consecutive OCBC runs and a 10-minute soak in between each run. The first run started at 7:21:47 AM and the 5th run ended at 10:53:33 AM. The entire OCBC testing took 3:18:22. Average ambient temperature during each run varied from 59.0°F to 76.9°F. The HTUF4 test cycle was repeated after a 10-minute soak following OCBC Run #5. Therefore, battery charging was not started after the completion of the last OCBC test run

Table 6 below summarizes the results for each of the 5 consecutive runs, the average for the 5 runs and the 95% confidence interval.

	OCBC – 3/28/13							
	Run #1	Run #2	Run #3	Run #4	Run #5	Total	Avg. Cycle	95% CI
Total Dyno. Miles (miles)	6.51	6.32	6.48	6.51	6.52	32.34	6.47	0.10
Total ECM Miles (miles)	6.56	6.43	6.56	6.56	6.55	32.67	6.53	0.07
Net DC Energy (kWh)	-4.33	-4.08	-3.91	-3.78	-3.77	-19.86	-3.97	0.29
DC Energy Output (kWh)	-6.60	-6.41	-6.29	-6.13	-6.10	-31.53	-6.31	0.25
DC Energy Input (kWh)	2.27	2.33	2.38	2.35	2.34	11.67	2.33	0.05
SOC Test Start (%)	99	93	88	83	78	-	-	-
SOC Test End (%)	93	88	83	78	73	-	-	-
Net DC Energy Consumption (kWh/mile)	-0.67	-0.65	-0.60	-0.58	-0.58	-	-0.61	0.05
DC Energy Output (kWh/mile)	-1.01	-1.01	-0.97	-0.94	-0.94	-	-0.97	0.05
DC Energy Input (kWh/mile)	0.35	0.37	0.37	0.36	0.36	-	0.36	0.01

Table 6: Summary of results for the OCBC test on 3/28/13

Figures 10 to 14 below show battery current, voltage and SOC, vehicle speed and time for each OCBC test run.

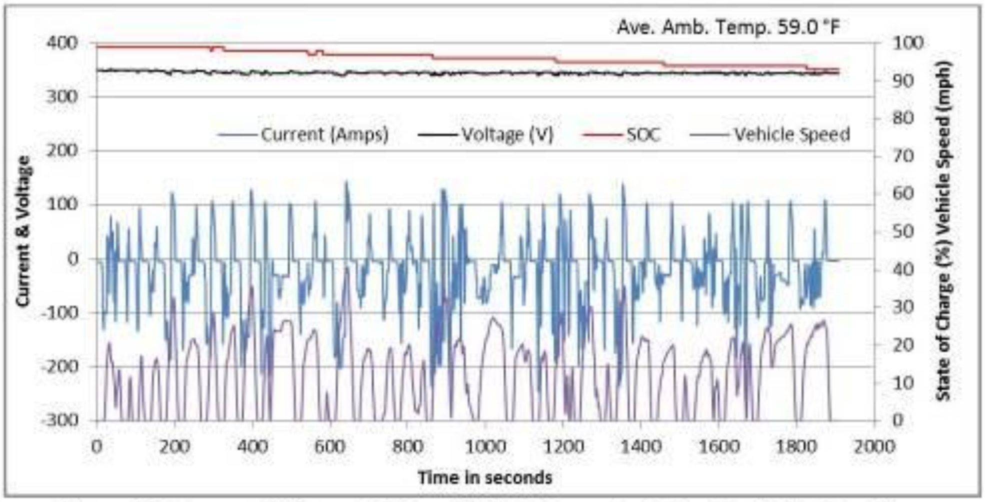


Figure 10: Current, Voltage, SOC, and Vehicle Speed vs. Time for OCBC Run #1

During the 2nd test run through the OCBC cycle on March 28th, 2013, the vehicle lost power for 61 seconds after 2/3 of the cycle was completed.

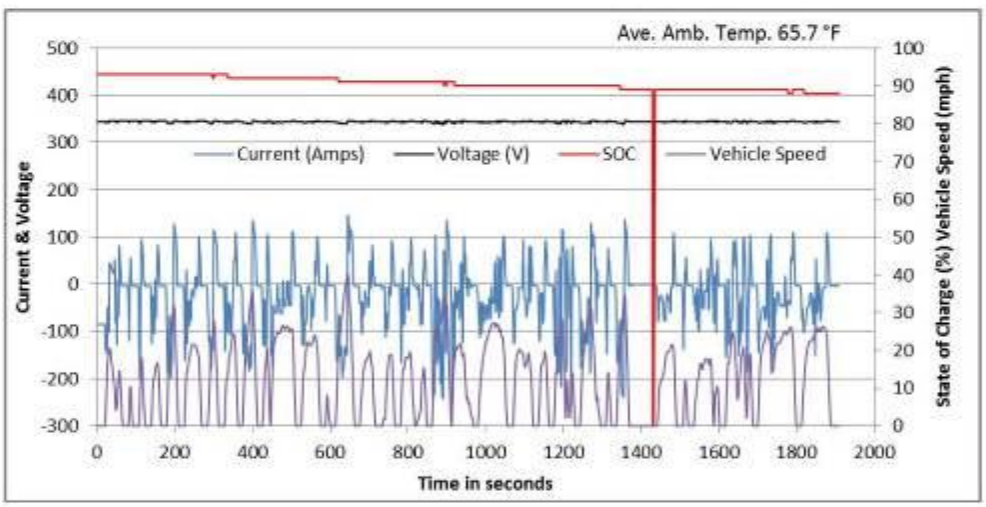


Figure 11: Current, Voltage, SOC, and Vehicle Speed vs. Time for OCBC Run #2

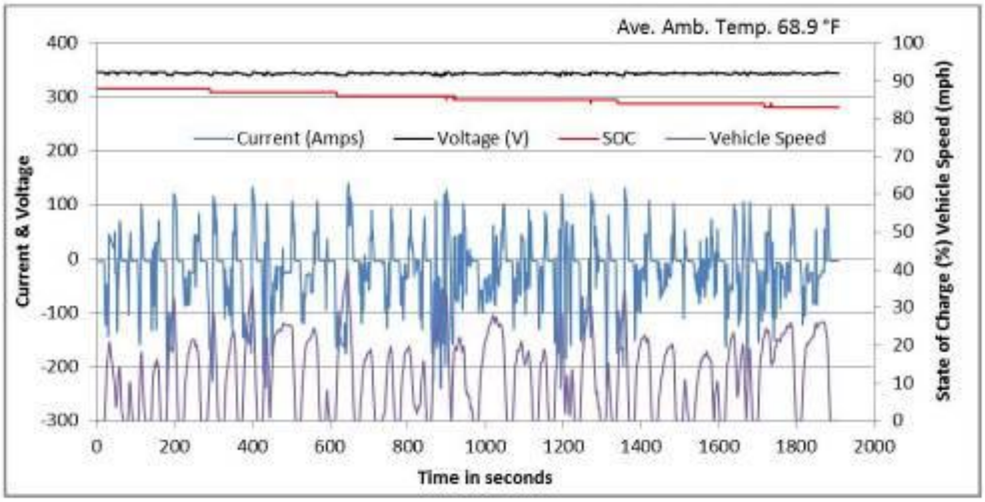


Figure 12: Current, Voltage, SOC, and Vehicle Speed vs. Time for OCBC Run #3

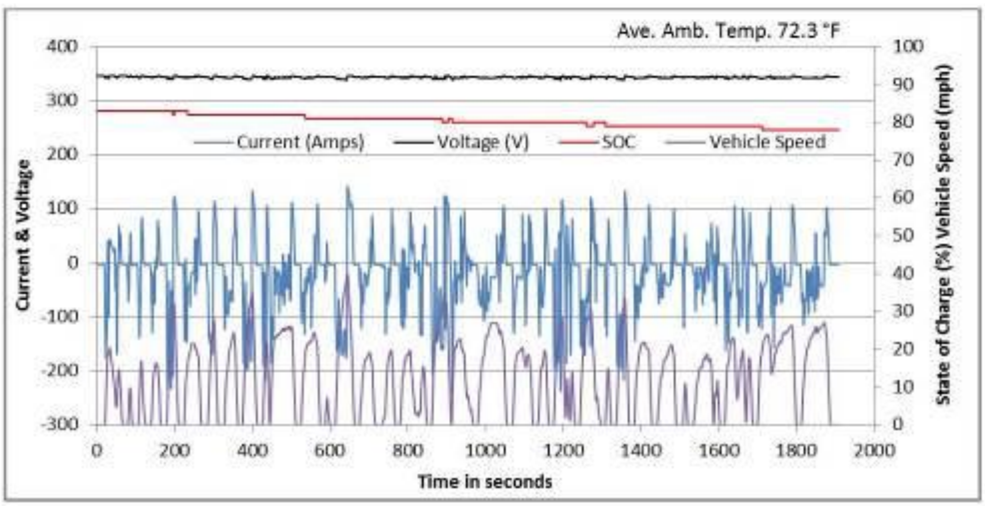


Figure 13: Current, Voltage, SOC, and Vehicle Speed vs. Time for OCBC Run #4

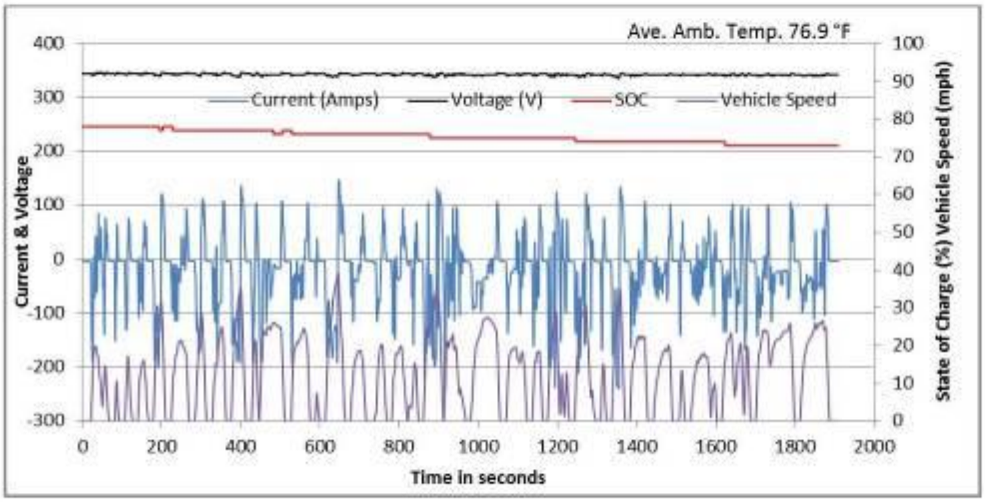


Figure 14: Current, Voltage, SOC, and Vehicle Speed vs. Time for OCBC Run #5

The HTUF4 test #2 was completed on March 28th, 2013. The testing consisted of 5 consecutive HTUF4 runs and a 10-minute soak in between each run. The first run started at 11:34:42 AM and the 5th run ended at 14:55:45 PM. The entire HTUF 4 testing took 3:21:03. Average ambient temperature during each run varied from 79.9°F to 87.2°F. Battery charging began less than 7 minutes after the completion of the last HTUF4 test run.

Table 7 below summarizes the results for each of the 5 consecutive runs, the average for the 5 runs and the 95% confidence interval.

	HTUF4 (Test #2) – 3/28/13							
	Run #1	Run #2	Run #3	Run #4	Run #5	Total	Avg. Cycle	95% CI
Total Dyno. Miles (miles)	7.24	7.22	7.20	7.17	7.23	36.06	7.21	0.03
Total ECM Miles (miles)	7.30	7.28	7.29	7.25	7.30	36.42	7.28	0.03
Net DC Energy (kWh)	-3.82	-4.56	-4.48	-4.57	-4.77	-22.20	-4.44	0.45
DC Energy Output (kWh)	-6.09	-6.51	-6.53	-6.53	-6.95	-32.62	-6.52	0.38
DC Energy Input (kWh)	2.27	1.94	2.05	1.96	2.18	10.42	2.08	0.18
SOC Test Start (%)	73	67	61	54	48	-	-	-
SOC Test End (%)	67	61	54	48	42	-	-	-
Net DC Energy Consumption (kWh/mile)	-0.53	-0.63	-0.62	-0.64	-0.66	-	-0.62	0.06
DC Energy Output (kWh/mile)	-0.84	-0.90	-0.91	-0.91	-0.96	-	-0.90	0.05
DC Energy Input (kWh/mile)	0.31	0.27	0.29	0.27	0.30	-	0.29	0.02

Table 7: Summary of results for the HTUF4 test #2 on 3/28/13

Figures 15 to 19 below show battery current, voltage and SOC, vehicle speed and time for each HTUF4 test run.

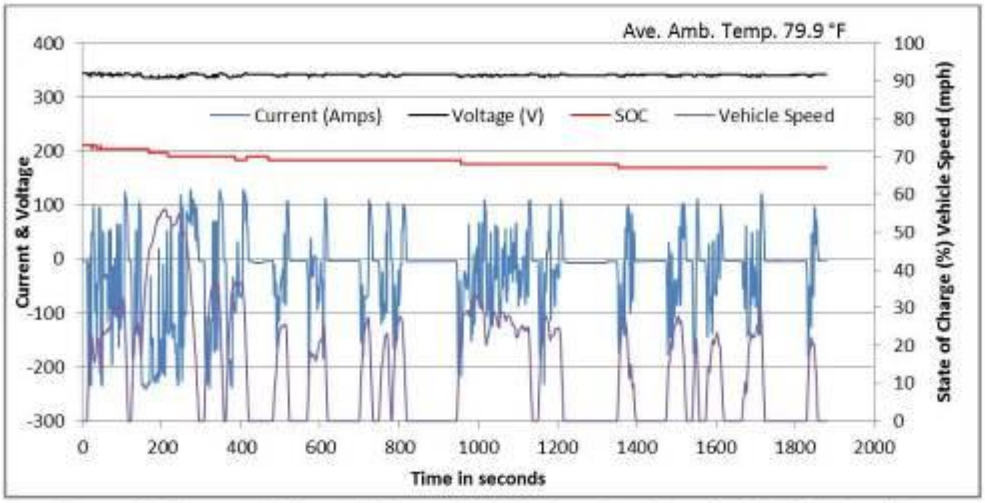


Figure 15: Current, Voltage, SOC, and Vehicle Speed vs. Time for HTUF4 Run #1

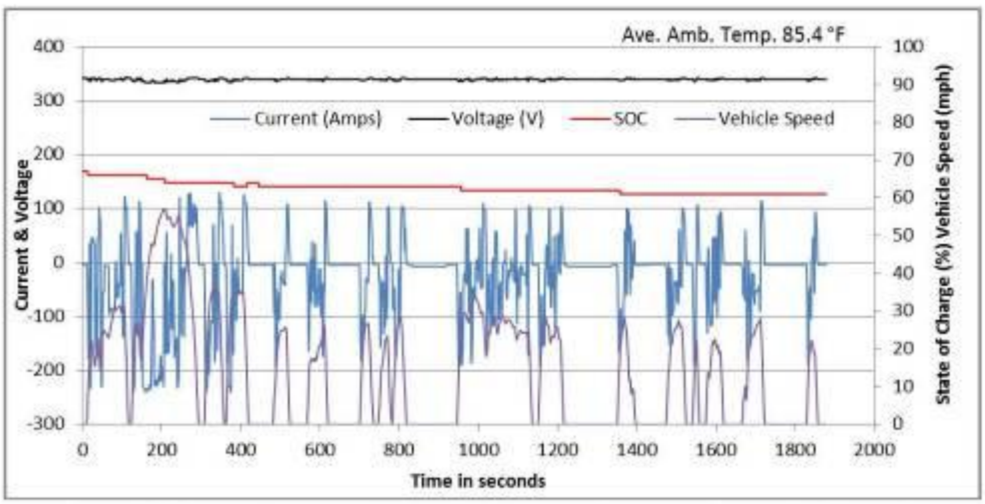


Figure 16: Current, Voltage, SOC, and Vehicle Speed vs. Time for HTUF4 Run #2

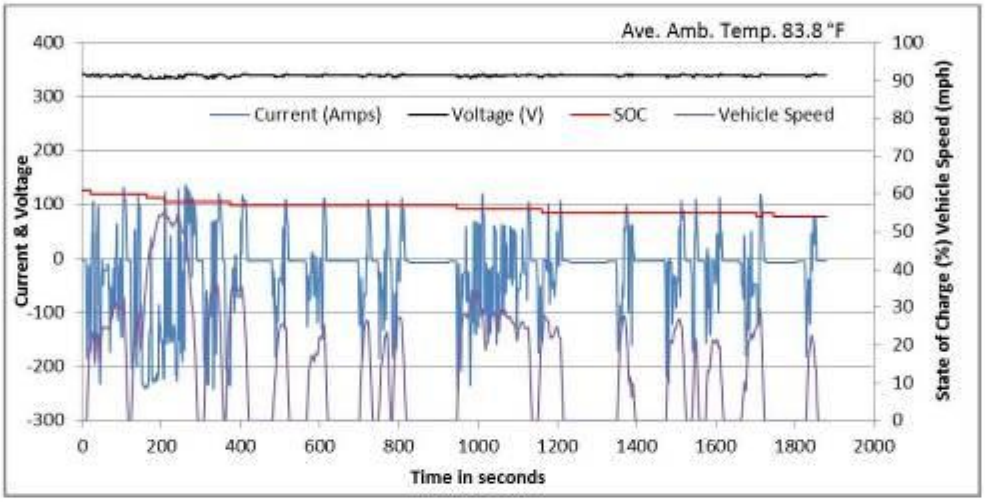


Figure 17: Current, Voltage, SOC, and Vehicle Speed vs. Time for HTUF4 Run #3

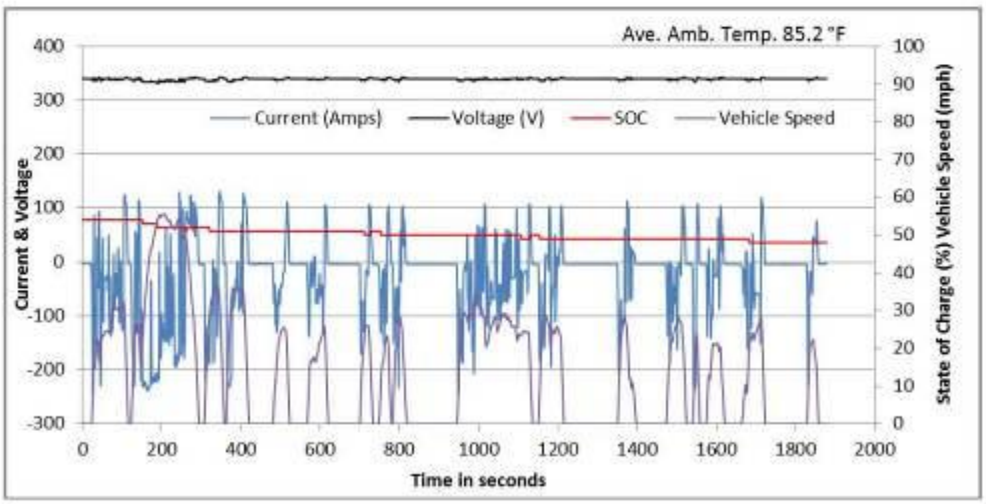


Figure 18: Current, Voltage, SOC, and Vehicle Speed vs. Time for HTUF4 Run #4

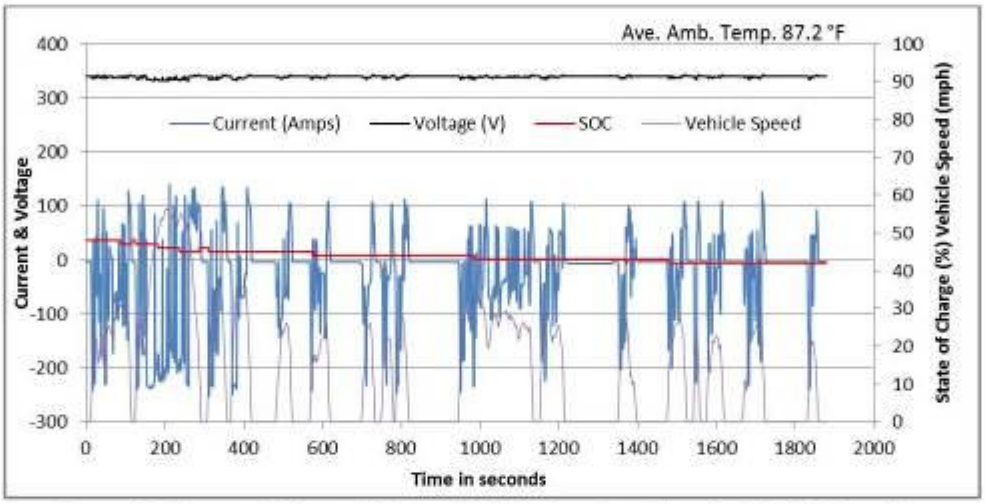


Figure 19: Current, Voltage, SOC, and Vehicle Speed vs. Time for HTUF4 Run #5

Table 8 below summarizes the charging data for the full day of testing (including the OCBC and repeat of the HTUF4 cycle test).

For OCBC / HTUF4(#2)	Charge Starting	Bulk Charging	Total Charging	Vehicle Unplugged
Recorded Time (hh:mm:ss PDT)	15:02:00 (3/28)	23:25:23 (3/28)	23:57:42 (3/28)	7:21:56 (4/1)
Cumulative Time (hh:mm:ss)	0:00:00	8:23:23	8:55:42	88:19:56
AC Energy Charged	0.0000	53.6313	55.5936	63.7089
AC Energy Charged (manual reading)	0	-	-	64
DC Energy Charged	0.00	43.54	45.56	N/A

Table 8: Summary of charging data following the OCBC & HTUF4 test #2 on 3/28/13

From Tables 6, 7 and 8, the Overall AC Energy Consumption was calculated as **0.81 AC kWh/mile** and the Overall DC Energy Consumption as **0.67 DC kWh/mile**. Please note that these numbers are for the full day of testing, including the OCBC and repeat of the HTUF4 cycle test.

Figure 20 below shows the cumulative AC and DC energy consumed to recharge the battery, as well as the vehicle SOC and the AC charging rate in kW.

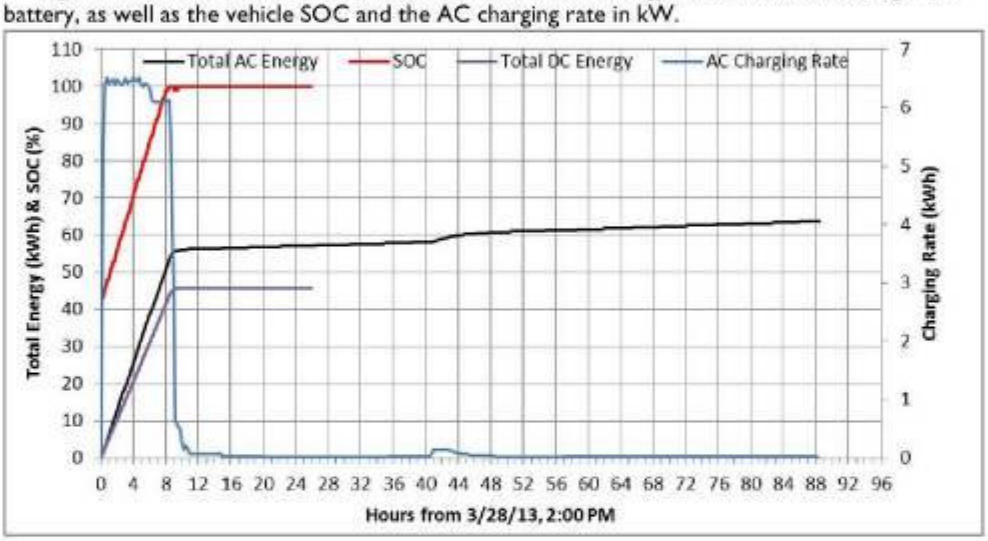


Figure 20: Total AC Energy, SOC, Total DC Energy, and AC Charging Rate for OCBC & HTUF4 Test #2

Maximum charging power was recorded as **6.53 AC kW**. Once the SOC reached 100% and the battery current dropped to 0 (indicating total charge time), the vehicle continued to draw a small amount of current from the grid until it was unplugged. A total of 8.12 AC kWh was consumed from the time the vehicle reached the total charging time to the time the vehicle was unplugged.

As the OCBC and HTUF4 tests were conducted consecutively before recharging the vehicle, we needed to estimate from the total energy used to recharge the batteries, which portion corresponds to the energy used for the OCBC test and which one corresponds to the energy used for the HTUF4 test. Table 7 shows that the HTUF4 test occurred between 73% and 42% battery SOC, while Table 6 shows that the OCBC test occurred between 100% and 73% SOC. In order to estimate the charging energy corresponding to each test (OCBC and HTUF4), we made the following assumptions summarized in Figure 21 below:

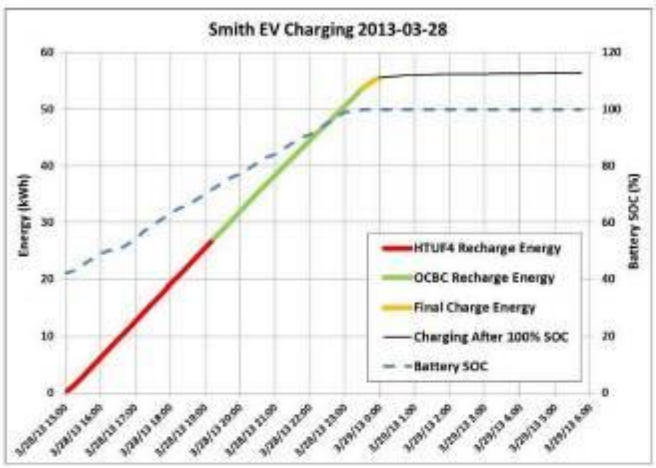


Figure 21: Allocation of Cumulative Charging Energy on 3/28/2013

- The portion in red in Figure 21 corresponds to the energy used to recharge the battery from a SOC of 42% until it first reaches 73%. It represents the bulk charging energy for the HTUF4 test.

Recorded Time (hh:mm:ss PDT)	19:19:11 (3/28)
AC Energy Charged	27.1386
DC Energy Charged	22.13

Table 9: Summary of charging data for the HTUF4 test #2 on 3/28/13

- The portion in green in Figure 21 corresponds to the energy used to recharge the battery from a SOC of 73% until it first reaches 100%. It represents the bulk charging energy for the OCBC test.

Recorded Time (hh:mm:ss PDT)	23:25:23 (3/28)
AC Energy Charged	26.4927
DC Energy Charged	21.41

Table 10: Summary of charging data for the OCBC test on 3/28/13

- The portion in orange in Figure 21 corresponds to the energy used to recharge the battery from a SOC of 100% until the battery current first reaches 0. It represents the final charge energy and we assume this final charge energy is needed each time the vehicle is recharged.

Recorded Time (hh:mm:ss PDT)	23:57:42 (3/28)
AC Energy Charged	1.9623
DC Energy Charged	2.01

Table 11: Summary of charging data for final charge on 3/28/13

- The total charging energy used to recharge the vehicle batteries after the HTUF4 test is the bulk charging energy for the HTUF4 test plus the final charge energy.

For HTUF4 (Test #2)	Charge Starting	Bulk Charging	Total Charging Start	Total Charging End
Recorded Time (hh:mm:ss PDT)	15:02:00 (3/28)	19:19:11 (3/28)	23:25:24 (3/28)	23:57:42 (3/28)
Cumulative Time (hh:mm:ss)	0:00:00	4:17:11	4:17:12	4:49:30
AC Energy Charged	0.0000	27.1386	27.1386	29.1009
DC Energy Charged	0.00	22.13	22.13	24.14

Table 12: Summary of estimated charging data for the HTUF4 test #2 on 3/28/13

From tables 9, 11 and 12, the Overall AC Energy Consumption for the HTUF4 test was calculated as **0.81 AC kWh/mile** and the Overall DC Energy Consumption for the HTUF4 test as **0.67 DC kWh/mile**.

- Similarly, the total charging energy for the OCBC test is the OCBC recharge energy plus the final charge energy.

For OCBC	Charge Starting	Bulk Charging	Total Charging Start	Total Charging End
Recorded Time (hh:mm:ss PDT)	19:19:11 (3/28)	23:25:23 (3/28)	23:25:24 (3/28)	23:57:42 (3/28)
Cumulative Time (hh:mm:ss)	0:00:00	4:06:12	4:06:13	4:38:31
AC Energy Charged	0.0000	26.4927	26.4927	28.455
DC Energy Charged	0.00	21.41	21.41	23.42

Table 13: Summary of estimated charging data for the OCBC test on 3/28/13

From tables 10, 11 and 13, the Overall AC Energy Consumption for the OCBC test was calculated as **0.88 AC kWh/mile** and the Overall DC Energy Consumption for the OCBC test as **0.72 DC kWh/mile.**

6.3. Steady State Range Test

The steady state range test was completed on April 1st, 2013. Testing continued until the vehicle was no longer able to maintain the speed in the test schedule. The test day consisted of 4 consecutive steady state runs and a 10-minute soak in between each run. The first run started at 7:21:57 AM and the 4th run ended at 9:42:19 AM. The entire test (going from 100 to 0% SOC) took 2:20:22. Average ambient temperature during each run varied from 67.5°F to 79.9°F. Battery charging began less than 4 minutes after the completion of the last steady state test run.

Table 14 below summarizes the results for each of the 4 consecutive runs, the average for the 4 runs and the 95% confidence interval.

	Steady State Range Test – 4/1/13						
	Run #1	Run #2	Run #3	Run #4	Total	Avg. Cycle	95% CI
Total Dyno. Miles (miles)	27.48	27.33	27.35	9.46	91.62	22.90	14.26
Total ECM Miles (miles)	27.89	27.33	27.67	9.60	92.48	23.12	14.35
Net DC Energy (kWh)	-22.05	-19.70	-19.71	-6.83	-68.29	-17.07	11.01
DC Energy Output (kWh)	-22.25	-19.87	-19.93	-6.83	-68.88	-17.22	11.16
DC Energy Input (kWh)	0.20	0.16	0.22	0.00	0.59	0.15	0.16
SOC Test Start (%)	100	70	44	17	-	-	-
SOC Test End (%)	70	44	17	0	-	-	-
Net DC Energy Consumption (kWh/mile)	-0.80	-0.72	-0.72	-0.72	-	-0.75	0.06
DC Energy Output (kWh/mile)	-0.81	-0.73	-0.73	-0.72	-	-0.75	0.07
DC Energy Input (kWh/mile)	0.01	0.01	0.01	0.00	-	0.01	0.01

Table 14: Summary of results for the Steady State test on 4/1/13

The large values for confidence intervals calculated for this test were caused by run #4 which was interrupted at vehicle SOC equal to 0% before it could be completed.

Table 15 below summarizes the charging data for this test.

	Charge Starting	Bulk Charging	Total Charging	Vehicle Unplugged
Recorded Time (hh:mm:ss PDT)	9:46:15 (4/1)	22:45:04 (4/1)	0:07:00 (4/2)	7:24:34 (4/2)
Cumulative Time (hh:mm:ss)	0:00:00	12:58:49	14:20:45	21:38:19
AC Energy Charged	0.0000	81.9813	89.6412	90.6456
AC Energy Charged (manual reading)	0	-	-	90
DC Energy Charged	0.00	67.50	73.29	73.29

Table 15: Summary of charging data following the Steady State test on 4/1/13

From tables 14 and 15, the Overall AC Energy Consumption was calculated as **0.98 AC kWh/mile** and the Overall DC Energy Consumption as **0.80 DC kWh/mile**.

Figures 22 to 25 below show battery current, voltage and SOC, vehicle speed and time for each steady state test run.

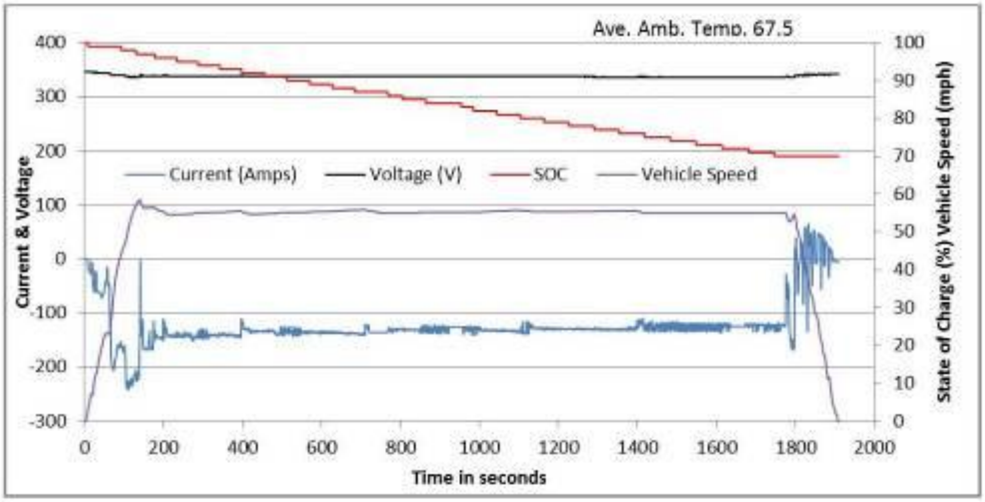


Figure 22: Current, Voltage, SOC, and Vehicle Speed vs. Time for Steady State Run #1

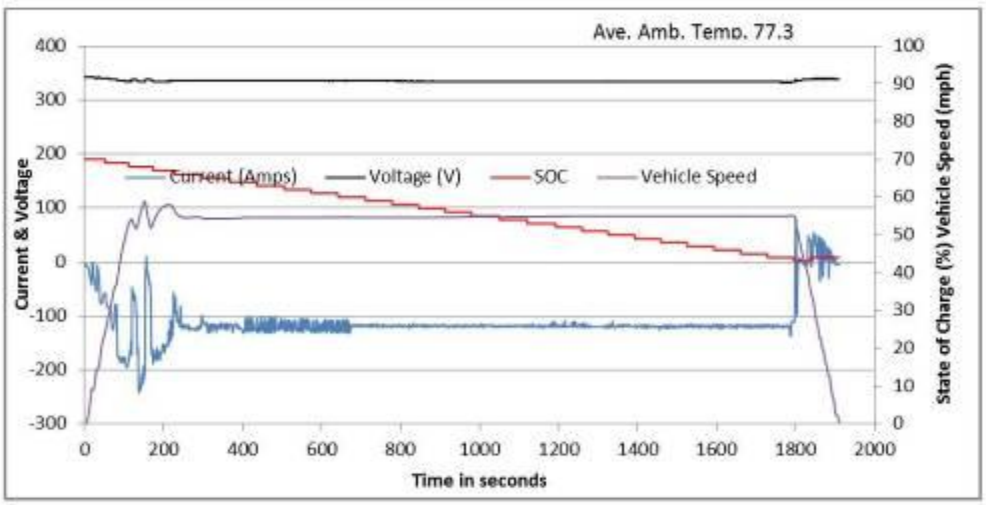


Figure 23: Current, Voltage, SOC, and Vehicle Speed vs. Time for Steady State Run #2

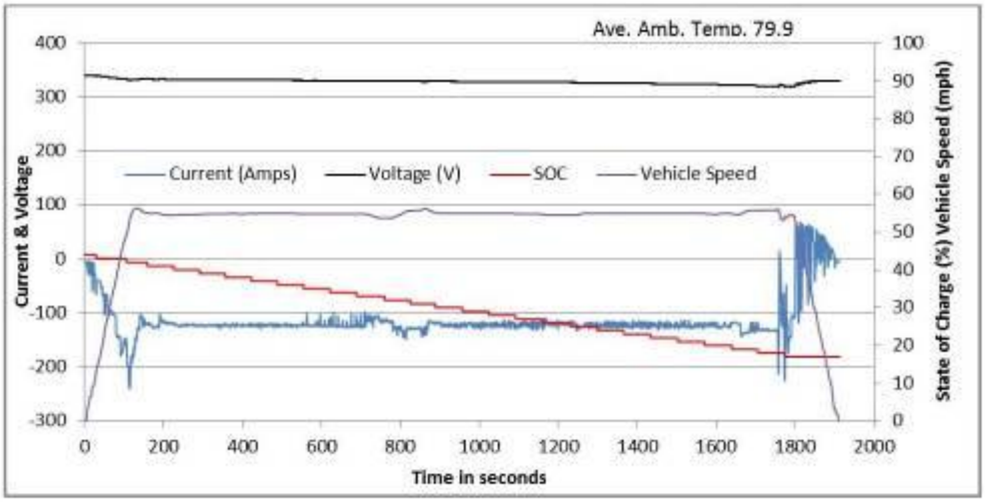


Figure 24: Current, Voltage, SOC, and Vehicle Speed vs. Time for Steady State Run #3

During the 4th run (see figure 25 below), the battery current and voltage dropped to 0 before the test could be completed.

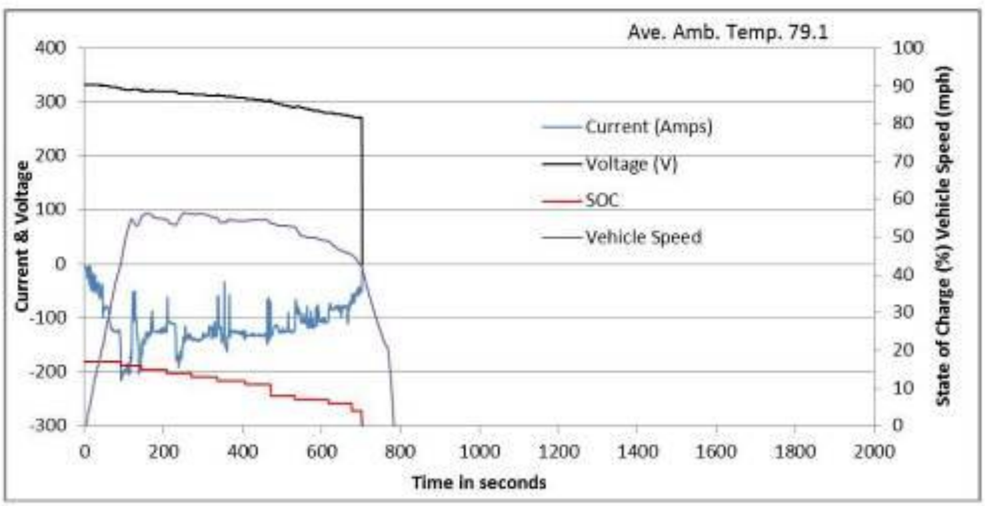


Figure 25: Current, Voltage, SOC, and Vehicle Speed vs. Time for Steady State Run #4

Figure 26 below shows the cumulative AC and DC energy consumed to recharge the battery, as well as the vehicle SOC and the AC charging rate in kW.

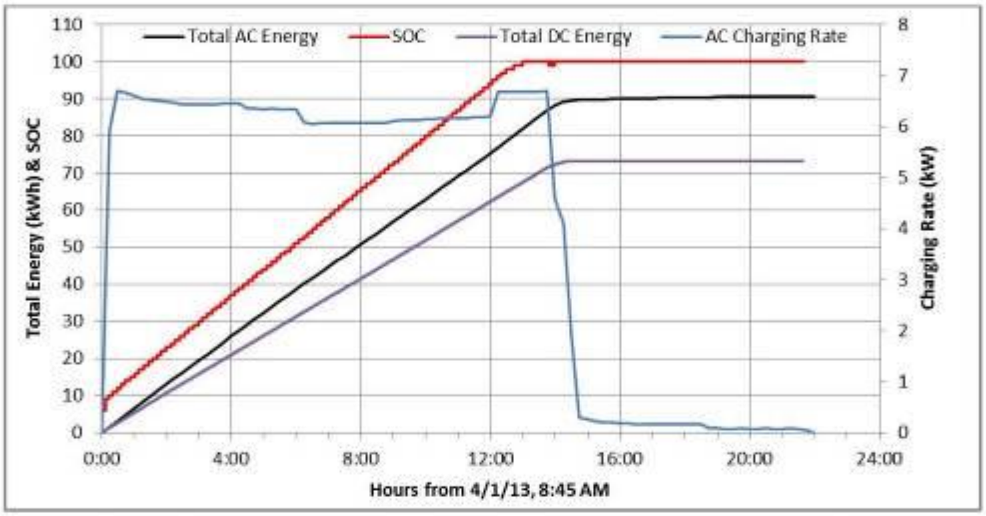


Figure 26: Total AC Energy, SOC, Total DC Energy, and AC Charging Rate for Steady State Test

Maximum charging power was recorded as **6.70 AC kW**. Once the SOC reached 100% and the battery current dropped to 0 (indicating total charge time), the vehicle continued to draw a small amount of current from the grid until it was unplugged. A total of 1.00 AC kWh was consumed from the time the vehicle reached the total charging time and the time the vehicle was unplugged from the charger.

APPENDIX A: Specifications for UCR Motored Chassis Dynamometer

From Mustang Publication "Project Spotlights" March 2010:

Mustang Advanced Engineering delivers a newly designed 48" Electric AC Heavy-Duty Truck Chassis Dynamometer with dual, direct-connected 300-hp AC motors to The University of California - Riverside, College of Engineering - Center for Environmental Research and Technology (CE-CERT).

The science of measuring emissions from mobile and other sources has evolved significantly over the past several years. The most important changes in the nature of emissions measurement science has been a shift to examining emissions from diesel sources and to understanding emissions under in-use driving conditions.

The Bourns College of Engineering – Center for Environmental Research and Technology (CE-CERT) at The University of California Riverside has recently installed a heavy-duty tandem axle truck chassis dynamometer in the facility's research area. Designed and manufactured by Mustang Advanced Engineering, the development of this chassis dynamometer design was based on targeting vehicles in the medium to heavy-duty diesel vehicle range. Heavy-duty applications that can be tested at the facility include on-highway trucks, buses, waste haulers, yard tractors, and more - under test conditions representative of their specific in-use operations. The facility couples the new heavy-duty chassis dynamometer from Mustang Advanced Engineering with CE-CERT's Mobile Emissions Laboratory (MEL), to perform precise vehicle simulation and in-operation emissions measurements.

The first research conducted on the new facility will be a comparison of federally mandated diesel fuel formulas versus the stricter formulation required in California. The program calls for 10 heavy-duty trucks to be tested with several different fuels.

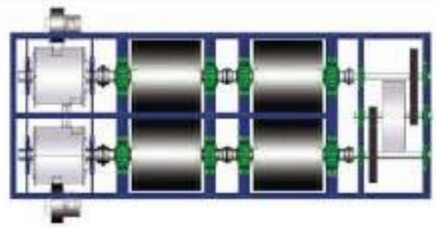
The new dynamometer will simulate on-road driving conditions for any big rig using its 48" precision rollers with dual, direct connected, 300 horsepower motors attached to each roll set. The dynamometer applies the appropriate loading to a vehicle to simulate factors such as the friction of the roadway and wind resistance that it would experience under typical driving conditions. An additional large inertia weight was incorporated into the dynamometer to increase the base mechanical inertia and enable the dynamometer to provide precise on-road simulation for a wide range of vehicle weights. The driver accelerates and decelerates according to a driving trace which specifies the speed and time over a wide range of vehicle simulation cycles. As the on-road driving conditions are being simulated on the dynamometer, emissions measurements will be collected with CE-CERT's Mobile Emissions Laboratory (MEL).

"This adds new capabilities in California that are only available at a limited number of facilities around the country," said Tom Durbin, who with J. Wayne Miller, are the principle investigators for the project. At both the state and federal levels, scientific requirements for emissions testing are trending away from steady state engine testing in favor of transient conditions found in typical driving, Durbin explained. "This addition will significantly expand our laboratory and measurement capabilities and help us continue our role as leading experts in the field of emissions research," said CE-CERT Director Matthew Barth.

CE-CERT's new heavy-duty chassis dynamometer will allow the testing of a variety of heavy vehicles under loaded and transient in-use conditions with corresponding emissions measurements. The dynamometer configuration is capable of meeting the inertia simulation range requirements of 10,000 to 80,000 lb for each of the cycles listed below. This includes acceleration rates up-to 6 mph/sec, as found in the UDDS Section D Drive Schedule and deceleration rates of up to 7 mph/sec as required for the WHM Refuse Drive Schedule. The dynamometer can also provide a load in excess of 600 HP @ 70 mph. The dynamometer also has the ability to continuously handle 200 Hp @ 15 mph for applications such as yard tractors.

The Dynamometer system is designed to meet the Heavy Duty Drive Schedules for diesel trucks in the weight range of 10,000 to 80,000 lb with acceleration rates for the following cycles:

- CARB HHDDT Cruise Mode Drive Schedule
- UDDS (Urban Dynamometer Drive Schedule)
- CARB 50 mph HHDDT Cruise Cycle
- HHDDT Transient Mode Drive Schedule
- WHM Refuse Drive Schedule
- Bus cycles such as, the CBD, OC Bus cycle, NY bus cycle
- In-use cycles for applications such as yard tractors.



"As part of our strategic plan, Mustang has developed a cost effective series of diesel, petroleum and hybrid certification grade dynamometer systems to address the needs of the global emissions and R&D market. There is a clear and present demand for a full performance cost effective dynamometer systems that offer all of the capabilities and confidence of a certification system at a price point that makes it no longer cost-prohibitive for organization to perform critical emissions studies, hybrid system calibration development, performance evaluation and other cutting edge research technologies. Researchers are in need of dynamometer systems to develop the next generation technologies which mimic the capabilities of the certification requirements, but at a fraction of the cost of a true certification system. That is what we are developing with this series of dynamometers and universities are lining up for them", said Executive Vice President, Donald Ganzhorn.

APPENDIX C: Battery Electric Truck Driver Evaluation Survey

As part of the electric trucks (e-truck) deployment and testing period we would like to hear your input and evaluation of the e-truck. It will help us evaluate the performance of the e-truck and identify areas that need improvement. Please take 15 minutes to provide your evaluation of the e-truck by answering the following questions. For each question check the box that best fits your rating.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Jean-Baptiste Gallo, (626) 744-5605 or jgallo@calstart.org.

First Name: ____________________

Last Name: ____________________

Occupation/Position: ____________________

Location: ______________________

Today's Date: ___________________

1) **Please provide a brief description of the route the EV is operating on:**

Average miles / Number of stops / Hours of operation / Type of customers / Drive to the airport / Other

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2) Performance

Property of the e-truck compared to a similar conventional truck	**Much worse**	**Somewh at worse**	**Same**	**Better**	**Much better**
Initial launch from stand still	☐	☐	☐	☐	☐
Maneuverability at slow speeds	☐	☐	☐	☐	☐
Acceleration	☐	☐	☐	☐	☐
Shift quality of the transmission	☐	☐	☐	☐	☐
Pulling power with load	☐	☐	☐	☐	☐
Coasting / Deceleration	☐	☐	☐	☐	☐
Overall braking behavior	☐	☐	☐	☐	☐
Productivity (able to cover routes quicker)	☐	☐	☐	☐	☐

3) Operation

Property of the e-truck compared to a similar conventional truck	**Much worse**	**Somewh at worse**	**Same**	**Better**	**Much better**
Cold Start	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Inside noise level	☐	☐	☐	☐	☐
Outside noise level	☐	☐	☐	☐	☐
Issues with pedestrian traffic	☐	☐	☐	☐	☐
In-cab ergonomics (control, switches, access doors…)	☐	☐	☐	☐	☐

4) Did you have any issues with electric range (ran out of battery, battery running low at the end of the shift…)?

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5) **Did you have any issues with charging (vehicle not charging when plugged in, vehicle discharged in the morning, vehicle not fully charged in the morning…)**

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6) **Please provide an overall rating of the e-truck.**

Very poor	Poor	Good	Very good	Excellent
☐	☐	☐	☐	☐

Suggestions and Comments

7) Please provide suggestions or recommendations of performance areas that need improvement in the e-truck.

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8) Please share any additional comments you have concerning the e-truck.

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(Thank you for your participation!)

APPENDIX D: Battery Electric Truck Fleet Maintenance Evaluation Survey

As part of the electric trucks (e-truck) deployment and testing period we would like to hear your input and evaluation of the e-truck. It will help us evaluate the performance of the e-truck and identify areas that need improvement. Please take 10 minutes to provide your evaluation of the e-truck by answering the following questions. For each question check the box that best fits your rating.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Jean-Baptiste Gallo, (626) 744-5605 or jgallo@calstart.org.

First Name: ___________________

Last Name: ___________________

Occupation/Position: ___________________

Location: _____________________

Telephone: ____________________

Today's Date: __________________

1) Performance

Property of the e-truck compared to a similar conventional truck	**Much worse**	**Somewh at worse**	**Same**	**Better**	**Much better**
Initial launch from stand still	☐	☐	☐	☐	☐
Maneuverability at slow speeds	☐	☐	☐	☐	☐
Acceleration	☐	☐	☐	☐	☐
Shift quality of the transmission	☐	☐	☐	☐	☐
Pulling power with load	☐	☐	☐	☐	☐
Coasting / Deceleration	☐	☐	☐	☐	☐
Overall braking behavior	☐	☐	☐	☐	☐
Productivity (able to cover routes quicker)	☐	☐	☐	☐	☐

2) Operation

Property of the e-truck compared to a similar conventional truck	Much worse	Somewh at worse	Same	Better	Much better
Cold Start	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Inside noise level	☐	☐	☐	☐	☐
Outside noise level	☐	☐	☐	☐	☐
Driver Acceptance	☐	☐	☐	☐	☐
In-cab ergonomics (control, switches, access doors…)	☐	☐	☐	☐	☐

3) Describe any e-truck problems observed during the early part of the demonstration period that were subsequently corrected by the manufacturer:

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4) Maintenance

Please rate the following issues related to e-truck maintenance on a scale of 1 to 5, where 1 means unacceptable and 5 means excellent (circle the appropriate number):

	Unacceptable				*Excellent*
❖ e-truck system and component training:	1	2	3	4	5
❖ Design for Maintainability:	1	2	3	4	5
❖ Design for Serviceability:	1	2	3	4	5
❖ Overall frequency of e-truck related problems:	1	2	3	4	5
❖ Ease of repair of e-truck related problems:	1	2	3	4	5
❖ e-truck system manufacturer support:	1	2	3	4	5

5) **Describe any e-truck problems observed during the early part of the demonstration period that were subsequently corrected by the manufacturer:**

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6) **Please provide an overall rating of the e-truck.**

Very poor	Poor	Good	Very good	Excellent
☐	☐	☐	☐	☐

Suggestions and Comments

7) Please provide suggestions or recommendations of performance areas that need improvement in the e-truck.

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8) Please share any additional comments you have concerning the e-truck.

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(Thank you for your participation!)

APPENDIX E: Battery Electric Truck Fleet Manager Evaluation Survey

As part of the electric trucks (e-truck) deployment and testing period we would like to hear your input and evaluation of the e-truck. It will help us evaluate the performance of the e-truck and identify areas that need improvement. Please take 10 minutes to provide your evaluation of the e-truck by answering the following questions. For each question check the box that best fits your rating.

We appreciate your time and assistance with this evaluation. If you have any questions about the content of this survey, please contact Jean-Baptiste Gallo, (626) 744-5605 or jgallo@calstart.org.

First Name: ____________________

Last Name: ____________________

Occupation/Position: ____________________

Today's Date: ____________________

1) General performance

Property of the e-truck compared to a similar conventional truck	**Much worse**	**Somewh at worse**	**Same**	**Better**	**Much better**
Driver Acceptance	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐
Availability for job assignments	☐	☐	☐	☐	☐
Productivity (able to cover routes quicker)	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Maintenance Issues	☐	☐	☐	☐	☐
Maintenance Costs	☐	☐	☐	☐	☐

2) Please provide an overall rating of the e-truck.

Very poor	Poor	Good	Very good	Excellent
☐	☐	☐	☐	☐

Suggestions and Comments

3) Please provide suggestions or recommendations of performance areas that need improvement in the e-truck.

4) Please share any additional comments you have concerning the e-truck.

(Thank you for your participation!)

APPENDIX F: Battery Performance and State of Health Report

This Appendix discusses the battery health in the E-trucks that we evaluated. While the evaluation was not long enough to measure degradation of the battery the period of the testing, there are observations from the usage and testing that provide insights about the battery systems on the E-trucks. The batteries on all the three trucks are Li-ion type batteries with different energy storage capacity. The E-Cell has a 55.5 kWh battery, the eStar a 80 kWh battery, and the Smith electric has a 80 kWh battery. The battery packs are liquid cooled. The battery health was evaluated from several sources during the demonstration and testing:

1) Charging data and logs
2) Road test from at the Southern California Edison EV Test Center
3) Chassis dynamometer battery SOC data

The charging times for the trucks are related to the size of the batteries as well as to the charging rate. During the road testing a FCCC MT E-Cell was charged at a nominal voltage of 240V from 0% to 100% SOC. Typical charge duration was measured between 12 and 14 hours to achieve the bulk of the charge and over 17 hours to achieve a full charge. During the road testing, maximum charging current was recorded at 23.2 A (AC) and maximum grid charging power at 5.6 AC kW. Given the total vehicle range determined by the road testing (between 56.2 and 67.6 miles), we estimate that 1 hour of charging represents 4.0 to 4.8 miles of range

Navistar advertises that the eStar can recharge in approximately 8 hours. Although we were not able to directly verify that claim, the in-use data collected on the 4 Navistar eStars indicate that typical charge duration would be more than 8 hours to reach a full charge.

Smith Electric reported that the Newton Step Van needs 6 to 8 hours to reach a full charge at a continuous current of 75A. For this project, a Smith Electric Newton Step Van was tested on a chassis dynamometer. Both the facility electrical system and the EVSE used for this testing were limited in the grid current that could be used for charging. During the chassis dynamometer testing, maximum charging current was recorded at 17 A (DC) and maximum grid charging power at 6.7 kW. Therefore, the charging times recorded were longer than what one would expect at a customer site equipped with the recommended charging infrastructure. Typical charge duration from 0% to 100% SOC was measured at about 13 hours to achieve the bulk of the charge and 14 hours and 20 minutes to achieve a full charge. From the steady state range test conducted during the chassis dynamometer testing, the total battery capacity was measured at 89.64 AC kWh.

The eStar vehicles tested were a second generation model and had some improvements in the battery packaging. Use of lighter material (reinforced fiberglass) made the battery pack lighter by about 300 lbs. The other modification that occurred in second generation model was also the addition of a separate lead-acid battery to power the air conditioning system which leaves more of the energy in the traction battery intact. This was a good improvement as we heard from the user fleet. We did not have data on the first generation of vehicles in order to document the specific effects this had on the overall efficiency of the vehicles

Finally, in terms of maintenance reports we did note record significant maintenance issues with respect to the batteries. We note that one battery pack had to be replaced on the E-cell vehicle in November 2011. In terms of overall health, the batteries functioned well on the E-trucks and did not report any overheating or power loss that sometimes is associated with hot weather. In the future it would be valuable to perform more detailed evaluation of the battery performance and durability testing over time.