NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

RUN ON LESS
ELECTRIC
REPORT

ELECTRIC TRUCKS Have Arrived

Documenting A Real-World Electric Trucking Demonstration

RUN ON LESS ELECTRIC REPORT

ABSTRACT This report documents the planning, execution and findings from the NACFE Run on Less – Electric (RoL-E) commercial battery electric vehicle (CBEV) production vehicle demonstration involving 13 fleets and 13 vehicle models from 13 manufacturers located in eight states or provinces in the US and Canada. Vehicles represented four market segments, Class 3, 4 and 5 vans and step vans, Class 6 box trucks, Class 8 terminal tractors, and Class 8 regional haul tractors. These market segments are estimated to contain 5.2 million vehicles. Annual greenhouse gas emission savings from electrifying these market segments are estimated to exceed 100 million metric tons (or 1 megatonne) of CO_2. The demonstration period was September 2 through September 19, 2021, with continuous tracking of vehicle parameters via Geotab.

"Just four years ago, I was very doubtful that 'batteries would haul freight.' Now we have conducted a Run on Less with only battery electric trucks proving how wrong I was."

— Mike Roeth, NACFE Exeutive Director

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Some of the vehicle-manufacturer pairings that participated in Run on Less – Electric are part of California Climate Investments, a statewide initiative that puts billions of cap-and-trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment—particularly in disadvantaged communities.

ABOUT US

ABOUT RUN ON LESS BY NACFE

Run on Less 2017 was a first-of-its-kind fuel efficiency roadshow that proved 10 MPG is possible with various combinations of commercially available technologies. Seven participating fleets hauled real freight on real routes during the three-week run across North America.

Run on Less Regional was conducted in October of 2019. Ten participating fleets demonstrated a variety of commercially available freight efficiency technologies in the three-week cross-country roadshow, proving that 8.3. MPG is possible in regional haul.

Run on Less – Electric was the first NACFE demonstration to focus on electric vehicles. Thirteen fleet-OEM pairs in the US and Canada participated in the three-week long event. If all US and Canadian medium- and heavy-duty trucks in the market segments — vans and step vans, medium-duty box trucks, terminal tractors and heavy-duty regional haul — studied in the Run became electric, about 100 million metric tons of CO_2 would be saved from entering the atmosphere. Visit runonless.com or follow us on Twitter @RunOnLess.

ABOUT NACFE

The North American Council for Freight Efficiency (NACFE) works to drive the development and adoption of efficiency enhancing, environmentally beneficial, and cost-effective technologies, services, and operational practices in the movement of goods across North America. NACFE provides independent, unbiased research, including Confidence Reports on available technologies and Guidance Reports on emerging ones, which highlight the benefits and consequences of each, and deliver decision-making tools for fleets, manufacturers, and others. NACFE partners with RMI on a variety of projects including the Run on Less demonstration series, electric trucks, emissions reductions, and low-carbon supply chains. Visit NACFE.org or follow us on Twitter @NACFE_Freight.

ABOUT RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. More information on RMI can be found at www.rmi.org or follow them on Twitter @RockyMtnInst.

GET INVOLVED

Frieght Efficiency is an exciting opportunity for fleets, manufacturers, and other trucking industry stakeholders.

Learn more at **www.nacfe.org**
Or contact Mike Roeth at **mike.roeth@nacfe.org**

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ELECTRIC TRUCKS HAVE ARRIVED: Documenting A Real-World Electric Trucking Demonstration

This report documents the Run on Less – Electric (RoL-E) demonstration by the North American Council for Freight Efficiency (NACFE), which was conducted in September of 2021. It shares the methods used to select the participating fleets, routes, and equipment, and metrics that measured the 13 participating pairs of fleets and OEMs.

We expect that this work encourages fleets to explore the deployment of commercial battery electric vehicles (CBEVs) in their operations where they make sense, for manufacturers to improve their products for quicker return on investment, and for others to better support the efforts of the trucking industry to progress the use of CBEVs. Thanks to all of those who contributed to this important work. Run on Less by NACFE is an ongoing effort by NACFE and RMI. Run on Less – Electric is the third event in the series. The first, in 2017, focused primarily on longer haul, a second, in 2019, on regional haul and this one on CBEVs.

NACFE's mission is to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand, and supply. Run on Less is one way to do that, and the plan is to conduct a Run on Less every other year.

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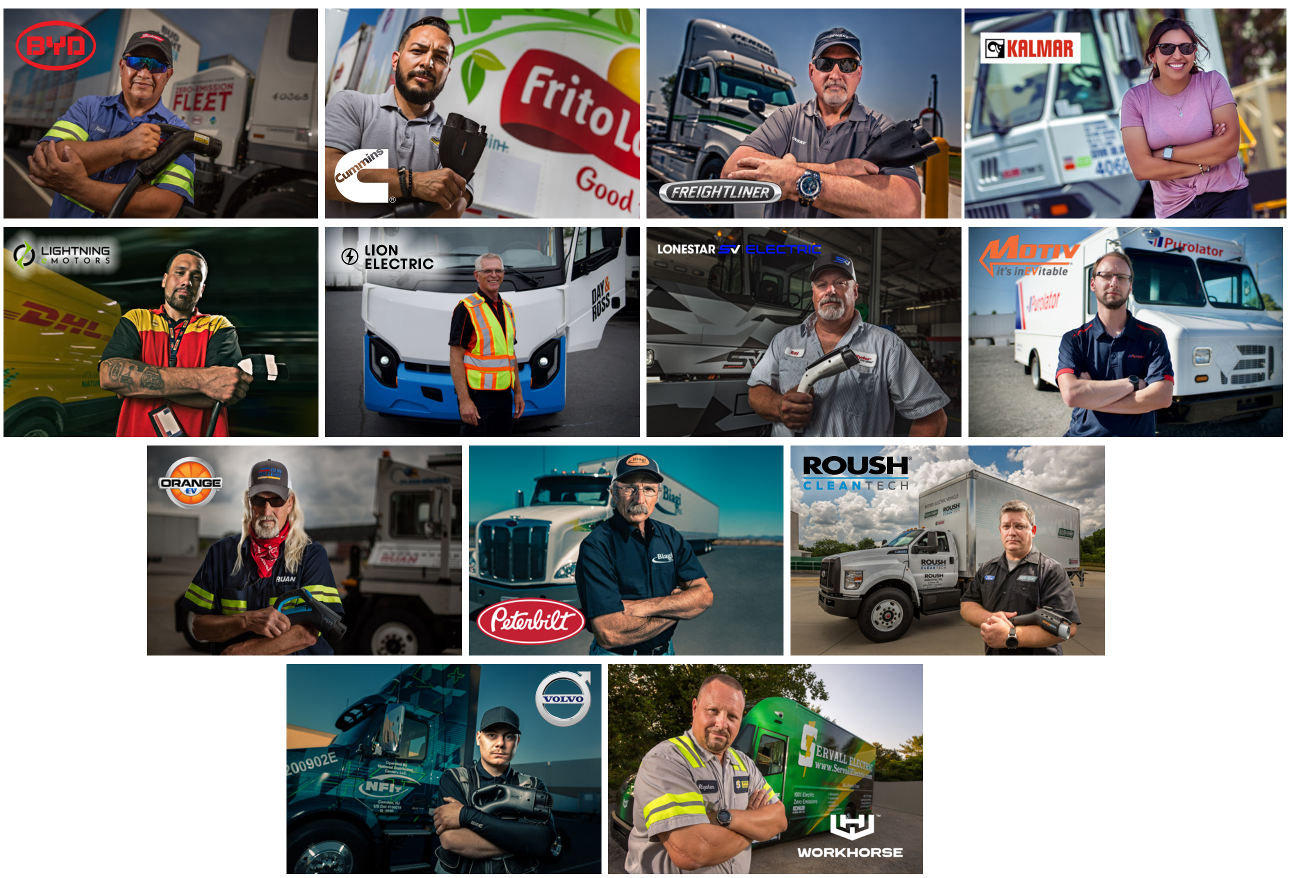
RUN ON LESS ELECTRIC

DRIVERS, FLEETS & OEMS

Rene Solis, Anheuser-Busch, driving a BYD tractor
Joseph Villaneuva, Frito-Lay, driving a Cummins box truck
Donald Disesa, Penske, driving a Freightliner eCascadia
Jazmin Vasquez, NFI, driving a Kalmar Ottawa electric terminal tractor
Antonio Grimila, DHL, driving a Lightning eMotors van
Francis Lajoie, Day & Ross, driving a Lion6 electric truck
Ray Hancock, Ryder System, Inc., driving a Lonestar Specialty Vehicles terminal tractor
Alexander Schaumann, Purolator, driving a Motiv-Powered step van
Conrad Hanson, Ruan, driving an Orange EV terminal tractor
Pat Brandon, Biagi Bros., driving a Peterbilt 579EV
Michael Johnson, Roush Fenway Racing, driving a Roush CleanTech truck
Jeffrey Howard, NFI, driving a Volvo electric VNR
Steve Garrett, Servall Electric, driving a Workhorse C1000



Some of the vehicle-manufacturer pairings that participated in Run on Less – Electric are part of California Climate Investments, a statewide initiative that puts billions of cap-and-trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment—particularly in disadvantaged communities.

Why Battery Electric Trucks Now?

Battery electric trucks have existed for more than 100 years. Until recently, the technology made only small inroads in freight movement such as forklifts and carts and saw limited use in delivery vehicles and special purpose vehicles.

In 2010, some early entrants for the long-delayed second life of electric trucks began work on commercial battery electric vehicles (CBEVs). [1] [2] [3] [4] [5] Electric and hybrid electric buses also were being introduced in that time frame. After 2010, as electric vehicle components began evolving into commodities, several small manufacturers saw opportunities to take production chassis deliveries and upfit them with electric drivetrains.

The established large OEMs were largely silent in public on their research and development of battery electric medium- and heavy-duty trucks. However, in October 2017, Tesla's Elon Musk introduced a long-range battery electric Class 8 semi-tractor. The established truck manufacturers all started discussing electric trucks in public. Many began introducing prototype and grant vehicles laying out plans for production.

The growing focus on sustainability by companies, investors, the public and regulators spurred fleet and manufacturer interest in CBEVs.

In October 2020, NACFE determined that the trucking industry was ready to introduce production level CBEVs and concluded that the timing was right for a Run on Less demonstration featuring CBEVs. A new logo was created for the event, as shown in Figure ES1.

In September 2021, 13 trucks from across the United States and Canada participated in Run on Less – Electric, a three week, real-world battery electric truck demonstration. The event proved that four market segments — vans and step vans, medium-duty box trucks, terminal tractors, and heavy-duty regional haul tractors — are ready to go electric. And that if they did, US and Canadian fleets could eliminate about 100 million metric tons (or 1 megatonne) of CO_2 emissions.

FIGURE ES1

NEW RUN ON LESS – ELECTRIC LOGO

Prior To Run

In preparation for RoL-E from April through August 2021, The Electric Truck Bootcamp, a 10-week webinar series, was conducted involving 45 subject matter experts on a variety of critical aspects of electric trucks. It reached more than 2,500 industry stakeholders and had 3,500 attendees.

During January through April, NACFE interviewed more than 30 prospect pairings and selected 13 fleets and OEMs capable of supplying drivers, vehicles and routes for the September three-week demonstration. Vehicles crossed the spectrum from Class 3 to Class 8. A NACFE objective was to showcase not only where CBEVs were in use in California but in regions outside of California including Canada. The challenges of securing fleet and OEM participation for vehicles just entering production amid the pandemic caused NACFE to revise the RoL-E participants as the demonstration came closer to starting

Throughout the summer of 2021, NACFE staff members visited each fleet for one to two days of recording interviews and filming. The driver, fleet management, representatives from the OEMs and in some cases utility company representatives were at those site visits.

Prior to the event, each fleet was introduced on the Run on Less website with 13 short profile videos. During RoL-E, 15 daily short topic videos called Stories from the Road

"Run on Less – Electric takes the 'nervousness' out of electric trucks for fleets. They can see these trucks are out there running today and not just something you see on the trade show floor."

— Amanda Phillips, General Manager of OEM Sales, Meritor

were published from interviews with 91 subject matter experts. In total, 31 videos were produced and issued in 60 days and were viewed more than 5,000 times online with downloads exceeding 50,000.

Event Details

The emerging nature of CBEVs in 2021 provided challenges in finding production intent vehicles for RoL-E. In December 2020, NACFE identified more than 30 vehicle models to consider in planning the event.

The initial goal was to secure 10 fleets with 10 different battery electric models covering Class 3 through 8 early production unit freight-carrying vehicles. Early production units are intended to allow fleets to fully evaluate operational use of production representative vehicles. The fleets and the OEMs are working closely together for the success of emerging technology deployment. NACFE required both the fleets and the OEMs to agree to be participants for each RoL-E entry and to have their vehicles outfitted with Geotab devices in order to collect data on the vehicle's operation. Of the 13 vehicles in the Run, 12 were instrumented with a Geotab telematics device, and one had its data collected via the manufacturer's own telematics device.

Ultimately NACFE settled on 13 fleet-OEM pairs because they represented a broad mix of vehicles in four market segments — three vans and step vans, three terminal tractors, three medium-duty box trucks and four heavy-duty regional haul tractors. This cross section of vehicle types and manufacturers gave NACFE an excellent snapshot of the state of the CBEV industry.

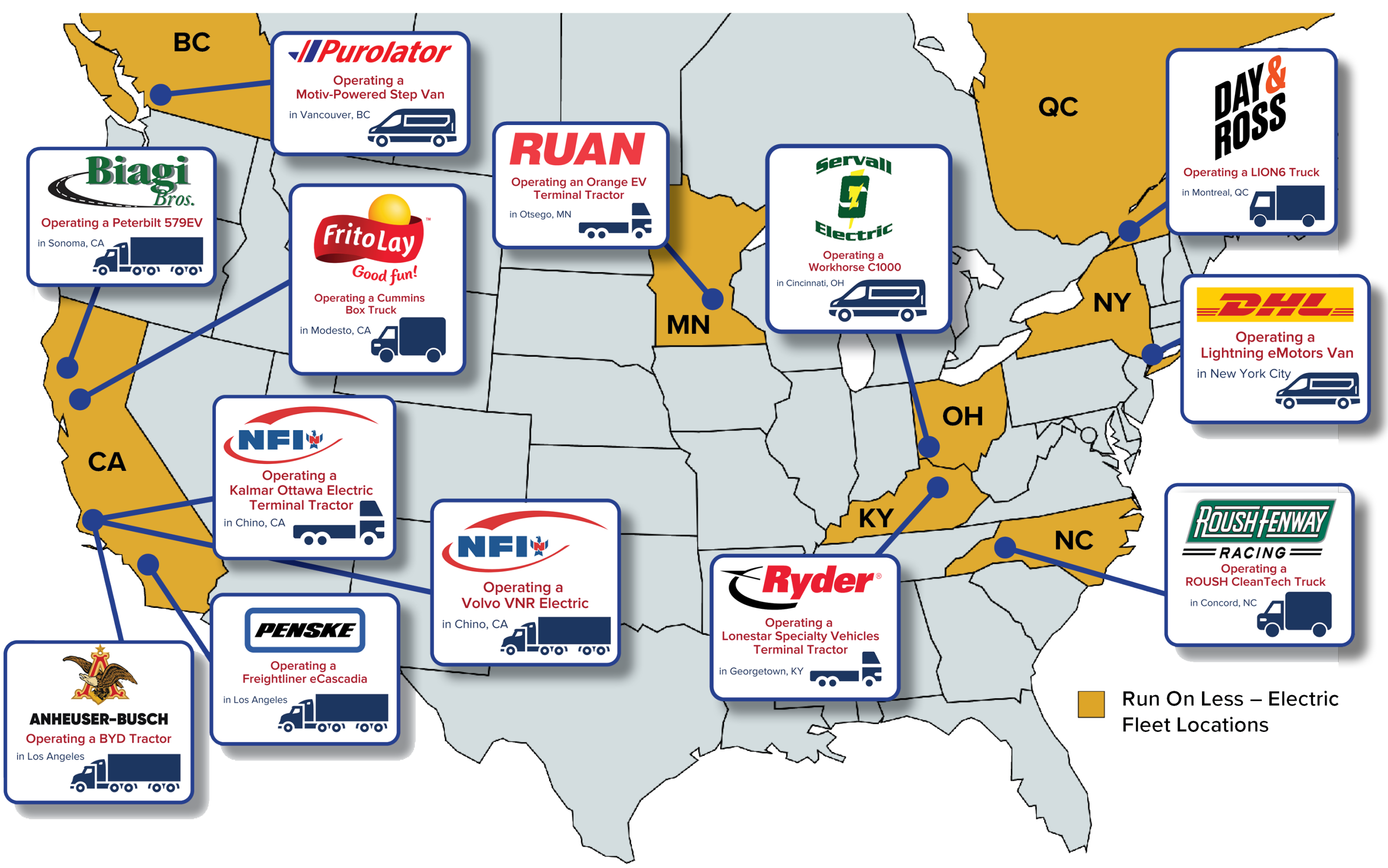
The 13 fleet-OEM pairs that participated in RoL-E are:

1. Anheuser-Busch with a BYD tractor
2. Frito-Lay with a Cummins box truck
3. Penske with a Freightliner eCascadia
4. NFI with a Kalmar Ottawa electric terminal tractor
5. DHL with a Lightning eMotors van
6. Day & Ross with a Lion6 electric truck
7. Ryder with a Lonestar Specialty Vehicles terminal tractor
8. Purolator with a Motiv-Powered step van
9. Ruan with an Orange EV terminal tractor
10. Biagi Bros. with a Peterbilt 579EV
11. Roush Fenway Racing with a Roush CleanTech truck
12. NFI with a Volvo electric VNR
13. Servall Electric with a Workhorse C1000

These vehicles made their regular deliveries over a three-week period in September 2021 in a variety of regions across the US and Canada as shown in Figure ES2.

FIGURE ES2

RUN ON LESS – ELECTRIC FLEETS, TRUCK TYPE AND LOCATIONS.



A Closer Look at Market Segments

RoL-E participants fell into four distinct market segments.

Vans and Step Vans: Urban delivery duty cycles using Class 3 to 6 vans and step vans is an ideal duty cycle for battery electric powertrains. These vehicles generally do not have issues with vehicle tare weight impacting freight weight. Range also is generally not a concern with these duty cycles which tend to be below 100 miles a day, and often below 50 miles per day. The urban traffic and street driving also permit energy recovery through regenerative braking. Charging times and electricity rates also are not that demanding as these vehicles are used in one-shift operations with long overnight dwell times making it possible to use low charging rates, more inexpensive chargers, and low-cost electricity. For a more in-depth look at this market segment read the Vans and Step Vans: Market Segment & Fleet Profile Fact Sheet.

Medium-duty Box Trucks: Urban delivery duty cycles using Class 6 box trucks also are ideal duty cycles for battery electric powertrains. These vehicles are more likely to have payload weight concerns. However, many loads carried by these vehicles tend to cube out, i.e., fill up the volume of the vehicle freight compartment, not weigh out, i.e., use the entire allowance of legal gross vehicle weight. Range also is generally not a concern with these duty cycles which tend to be below 100 miles a day, and often below 80 miles per day. The urban traffic and street driving permit energy recovery through regenerative braking systems. Charging times and electricity rates also are not that demanding as these vehicles generally are used in one-shift operations with long overnight dwell times making it possible to use low charging rates, more inexpensive chargers, and low-cost electricity. For a more in-depth look at this market segment read the MD Box Trucks: Market Segment & Fleet Profile Fact Sheet.

Terminal Tractors: Terminal tractors are purpose-built vehicles for moving trailers around warehouses, distribution centers and other terminals. The terminal operations tend to be demanding with short dwell times when drivers take breaks and often slip-seating for multi-shift operations. The vehicles accumulate a surprising number of daily miles considering they rarely if ever leave their facilities. Several factors in the operation of a terminal tractor make CBEVs a logical fit. The vehicles always are at the depot, so always are near charging facilities. Weight is generally not an issue since the vehicles are usually 4x2 configurations with very spartan, lightweight one-person cabs. Terminal driving is very stop-and-go, which is appealing to the acceleration and regenerative braking advantages of the electric drivetrain. For a more in-depth look at this market segment read the Terminal Tractors: Market Segment & Fleet Profile Fact Sheet.

Heavy-duty Regional Haul Tractors: Heavy-duty day cab regional haul is more challenging for CBEVs because duty cycles are more sensitive to range and payload weight needs. The discussion on range splits into distinct topics of individual trip range, the driver's one-shift range, and the truck's one-day range. Vehicles may be able to easily do some number of round trips before recharging, but they may not be able to do all the multiple round trips over one driver's entire shift. In the case of slip-seat operations, the vehicle may need to do two or three driver shifts per day with little dwell time at the depot available for charging. However, where the trip distance is short, and/or operations have lengthy delivery dwell times, CBEVs can adequately handle the entirety of one-shift operations. Payload weight also factors into capability to accomplish a day's work for the truck. Lighter payloads place lower demands on power, but even heavy beverage loads may be fine if the net daily mileage is not very demanding of the batteries. For a more in-depth look at this market segment read the HD Regional Haul Tractors: Market Segment & Fleet Profile Fact Sheet.

The Metrics

Throughout the run, NACFE tracked vehicle operations continuously via a digital tracking device, and updated metrics daily via a public website with the ability to view results by day or over a span of days. The website showed the metrics in near real time as illustrated in Figure ES3.

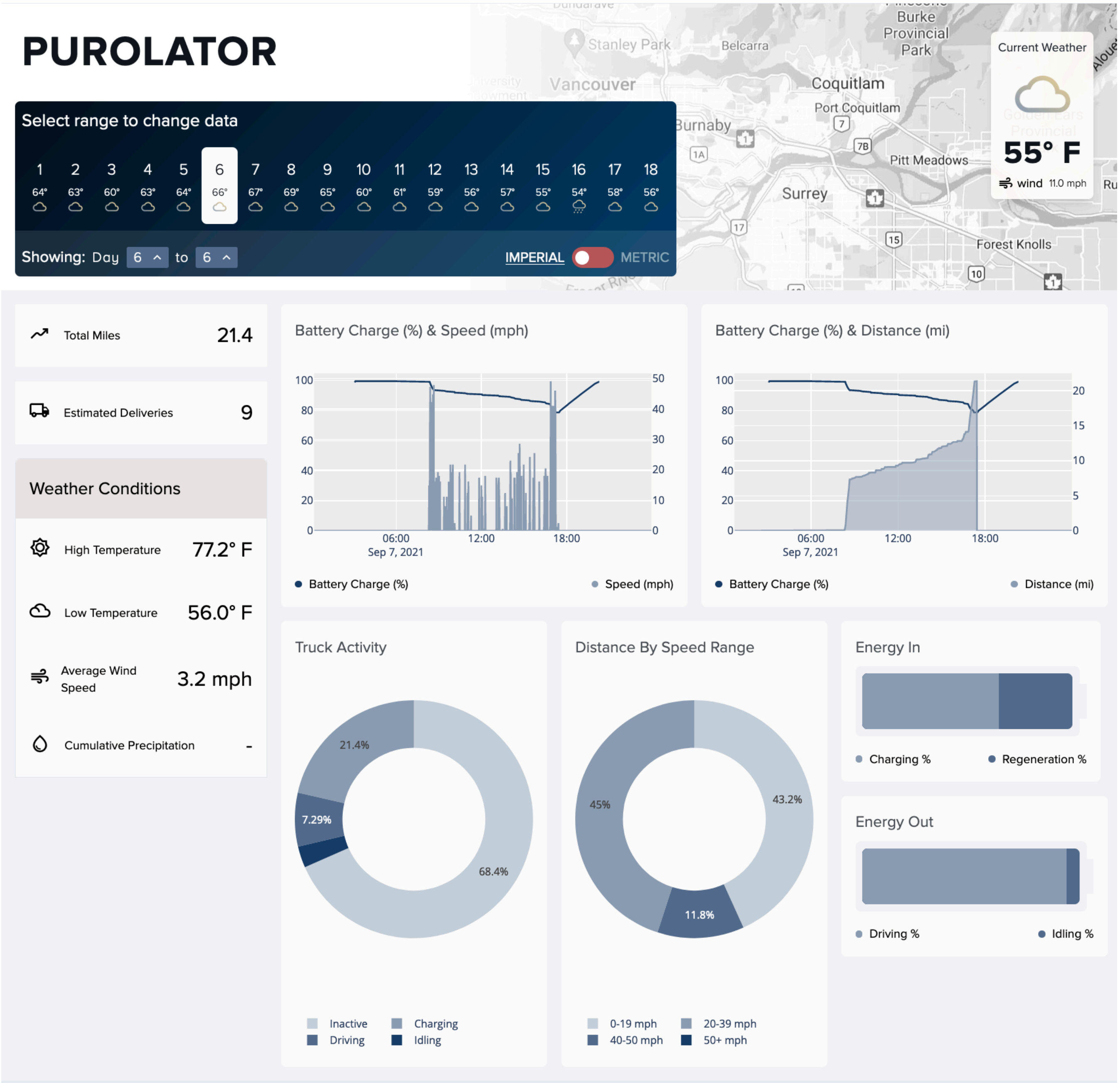
The metrics measured included the following:

METHODOLOGY

This report's conclusions were generated through the data collection and calculations from Run on Less – Electric. Of the 13 vehicles in the Run, 12 were instrumented with a Geotab telematics device, and one had its data collected via the manufacturer's own telematics device. The vehicle operations were continuously digitally tracked, and their metrics updated daily via a public website with the ability to view results by day or over a span of days. Metrics such as daily range, speed profiles, state of charge, charging events, amount of regenerative braking energy recovery, weather and number of deliveries were shown in near real time. Information on weather conditions was also obtained.

FIGURE ES3

EXAMPLE OF RUN ON LESS – ELECTRIC METRICS (CLICK HERE FOR A LARGER VIEW)



State of charge: State of charge (SOC) is similar to a diesel fuel gauge. Instruments in a diesel fuel tank measure the level of fuel remaining and report that to the fuel gauge in the dashboard and on the CAN data bus of the vehicle. Battery SOC for RoL-E was measured by continuously monitoring voltage, amperage, and amp hours remaining after fully charging — essentially counting the amp-hours expended over time and subtracting that from the full charge state. [6]

Daily range: NACFE determined distance driven using GPS position because some of the vehicles did not give access to the odometer data. Total miles for the day were tabulated and reported as a number, then distances were graphed versus time along with battery SOC.

Speed profiles: NACFE used GPS position to determine speeds. First, speeds along with SOC were graphed versus time, and then speed was categorized as percent distance in speed bands. [66]

Regenerative braking energy recovery: CBEVs can recover energy by using the drive motors to slow the vehicles. This is called regenerative braking; essentially the motors — rather than using energy — are acting as generators and putting energy back into the batteries. The amount of regenerative braking energy recovery is reported by the vehicle on the data bus.

Number of deliveries: There are no vehicle-based systems that specifically highlight a delivery instance — the act of stopping the vehicle and unloading (or loading). Deliveries also have different parameters when looking at a terminal tractor versus a box truck due to the differences in what constitutes a delivery. NACFE developed two different algorithms depending on truck type to identify a delivery event from telemetry data.

Charging rate: NACFE describes the charging rate as how fast and at what power level the vehicle is charging. Charging rate was determined from vehicle data bus signals using SOC over time when plugged into the charger. The vehicle data bus continuously reports voltage and amperage, and can integrate that over time to provide SOC. The fundamental measure is the power level (kW) over time, which equals the energy level (kWh). A 100-kWh battery pack depleted to 50% SOC during the work shift requires 50 kWh of energy to return to 100% SOC. Charging that battery can be done slowly, for example at 5 kW over 10 hours equating to 50 kWh. Or it can be done quickly, for example 50 kW in one hour again equating to 50 kWh.

Energy consumption: Consumption is the inverse of efficiency. In battery electric vehicles, the fuel efficiency metric often reported is kilowatt hours expended per mile (kWh/mi). This is not efficiency but rather consumption. NACFE did not directly report consumption through the RoL-E metrics dashboard, but it was feasible to estimate it from the data that was provided based on the specifications of the vehicles, the miles traveled per day, and the SOC data. NACFE found that there are multiple ways to measure consumption — daily charge method, net charge method, daily consumed method, and net consumed method — and they may differ in values.

Trucking activity: NACFE also tracked various types of activity for each vehicle in the Run.

- **Inactive** — Inactive time is when the vehicle is not using any significant power, the key is off, and the CBEV is not charging
- **Idling** — NACFE concluded that a CBEV was idling if the vehicle was not charging, not moving, and was expending any significant power for accessory loads like air conditioning.
- **Charging** — Charging time is when the vehicle is plugged into the charger and not moving and may or may not have accessories operating. To put this in a diesel perspective, having accessories operating during charging activity would be equivalent to idling at a fuel stop while pumping fuel into the tank — a procedure that is not advised with liquid fueling.
- **Driving** — Driving time is when the vehicle has velocity greater than zero. It also includes non-moving time at traffic stops shorter than 180 seconds.

Energy-in per day: The battery on an electric vehicle is continuously changing its SOC value based on the amount of energy that is going out and the amount of energy coming in. This can occur at the same time. Geotab engineers arrived at a method for estimating how much energy was recovered through regeneration versus how much was supplied through charging over the course of a day's operation.

Energy-out per day: Similar to energy-in, there is complexity in estimating where the energy is allocated during a day of operation

Weather: Vehicle performance always is in context of the operational environment. For RoL-E, NACFE pursued regions with diverse weather conditions. The three-week nature of the RoL-E demonstration limited the ability to observe a broad range of weather conditions, but the RoL-E fleets use these vehicles year-round. The local weather data for each day and fleet location was obtained via an Application Programming Interface from OpenWeather. For simplicity, since most trucks didn't go that far, NACFE collected weather information for the base location, not the truck's rolling location. [64]

"Three or four years ago people were saying 'we'll never electrify trucks.' Run on Less – Electric has shown that today there are some parts of that market that are ready {for electric trucks]. We've only had the theory, now Run on Less – Electric is showing the reality."

– Michael Berube, Deputy Assistant Secretary for Sustainable Transportation, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Other Factors

NACFE also looked at the role of the driver, regional factors in CBEV deployment, maintenance and utilities.

Drivers: The RoL-E drivers were a diverse group with a variety of experience levels, ethnicities, ages and genders. See ES4. The fleets selected their own drivers, but those drivers had to agree to the added complexity of being interviewed, photographed and videoed, and having their every working minute tracked for three weeks.

Drivers universally stated the electric vehicles provided better driving experiences versus diesels. A number of factors contributed to this conclusion including lower interior noise levels, low exterior noise levels, better acceleration, simplicity, easier charging vs fueling, no idle emissions, depot charging, no diesel smell, less fatigue, novelty factor, and positive brand image.

Regional Factors: RoL-E fleets in Minnesota, Montreal, Cincinnati, Kentucky, New York City, and the Southern California region face extremes in temperatures over the course of a year. Fleets in some of these instances like in Minnesota and New York City had been operating CBEVs through the winters and saw no performance issues that impacted their duty cycles. Other fleets had not yet gone a full year with their CBEVs so did not have first-hand experience, but all expected the vehicles to be capable of getting their specific duty cycles completed in

FIGURE ES4

THE 13 DRIVERS WHO PARTICIPATED IN RUN ON LESS – ELECTRIC

"Electric trucks are not the technology of the future. They are technology for now. Manufacturers are going into production starting now and over the next several years."

– Tim Farney, vice president, global sales, Dana Inc., Commercial Vehicle Division

their climates. The Southern California and Modesto area sites saw extreme heat during the summer on-site visits by the NACFE RoL-E teams with temperatures exceeding 100°F. Drivers and fleet managers reported no duty cycle limitations during these visits.

Maintenance: The three-week RoL-E demonstration was far too short to get any useful measured detail on maintenance. There is long-term reliability data on electric automobiles and buses showing that once vehicles are in production, their maintenance costs and failure rates trend downward versus internal combustion vehicles. This was the expectation of all the fleets in RoL-E. A few fleets that had operated their vehicles prior to RoL-E reported very high uptime and reliability. Maintenance cycles were expected to lengthen for wear items like brake systems where regenerative braking reduced the use of the wear items. Oil changes were largely no longer relevant. The significant failure modes tied to emission systems are not relevant to CBEVs. [73] [74]

Utilities: NACFE set out to engage with the utilities providing power to the RoL-E fleets. NACFE research and site visits to the RoL-E fleets showed that in some high visibility California markets utilities are actively engaged with customers to facilitate CBEV adoption. However, in other regions, the utilities are less engaged. In some cases, the fleets indicated that their utilities showed no interest in their work with CBEVs. [75] [76] [77] [78]

Clearly the utilities play a significant role in fleet electrification, but in many cases, they are not yet engaged with fleets. This is an industry challenge. Engaging a receptive utility opens up a number of alternatives for negotiating electricity pricing models. [7]

Total Cost of Ownership

Being confident in any of the cost elements in a total cost of ownership (TCO) calculation of CBEVs was not possible in the scope of the three-week RoL-E demonstration. Fleets and OEMs were reluctant to discuss much in terms of actual expenses and financial benefits. Many of the vehicles have not yet listed the manufacturer's suggested retail prices for specific models. Interviews with fleets and manufacturers surfaced their operational experiences and expectations in generic terms.

Prior to the Run, many of the fleets had not operated the vehicles for a sufficient period of time to accurately assess costs. The expectations were that the CBEVs would have lower operating expenses based on lower maintenance, less damage from moving parts, lower energy costs per mile, and many soft factors such as driver retention cost reduction, reduced environmental compliance costs, etc.

Findings

RoL-E demonstrated that for four market segments — vans and step vans, medium-duty box trucks, terminal tractors, and heavy-duty regional haul tractors — the technology is mature enough for fleets to be making investments in production CBEVs. Continuous improvement is expected to be rapid as these technologies gain market share. The environmental benefit of reduced CO_2 and particulate emissions is significant for replacing traditional diesel and gasoline-based vehicles.

Other findings include:

- Early adopters of CBEVs are validating an acceptable total cost of ownership in urban medium-duty vans and trucks, terminal tractors and short heavy-duty regional haul applications.
- CBEV adoption is occurring throughout North America, but use of longer haul heavy-duty electric semi-trucks use has been somewhat limited to California.
- There are benefits to CBEVs (quiet operation and reliability) as well as challenges (infrastructure and range).
- CBEV truck ecosystem inertia is in its early stages with many solutions emerging that will support adoption in the next several years.
- The industry needs to develop standards in the areas of charging, repair, maintenance and training.
- There is a huge demand for real-world information on electric vehicles in commercial applications and on charging infrastructure.
- The mix of startups, traditional truck OEMs, and component manufacturers is expediting the development of creative and practical solutions.

"Collaboration in the industry between energy suppliers, energy users, fleets, OEMs, government agencies and policymakers, as well as industry organizations, is crucial for developing and implementing solutions."

– Selda Gunsel, president, Shell Global Solutions and vice president, Global Lubricants and Fuels

- More thought is needed on the best way to gather and manage the necessary data for fleets and manufacturers to measure and monitor their CBEVs.
- Early adopters of CBEVs are having an influence on improving trucks and infrastructure.
- CBEVs present operational challenges, for example longer charging times than fueling, which these fleets are working to mitigate.

At the conclusion of the event, NACFE's Executive Director, Mike Roeth, said, "It's clear from the data collected during the Run that it is time for fleets to go electric in certain market segments, including the van and step van, medium-duty box truck, terminal tractor and heavy-duty regional haul tractor delivery segments." [86]

As a result of the Run, NACFE estimates that electrifying all US and Canadian medium- and heavy-duty trucks in the market segments studied in the Run would prevent about 100 million metric tons (or 1 megatonne) of CO_2 from entering the atmosphere as shown in Figure ES5. [89] [90]

FIGURE ES5

ESTIMATED NET SAVINGS FOR RUN ON LESS – ELECTRIC MARKET SEGMENTS

If all North American trucks in the four represented market segments were electric, the industry would save over a megatonne of carbon emissions each year and require approximately 169 gigawatt-hours of electricity to charge them.

MARKET SEGMENTS	POPULATION US & CANADA	CARBON AVOIDED ANNUALLY (MT CO_2e)	ELECTRICITY TO CHARGE ANNUALLY (gWh)
Class 3, 4, 5 Vans & Step Vans	4,143,406	43,476,632	89,342
Class 6 Box Trucks	385,687	7,681,707	12,475
Class 8 Terminal Tractors	25,242	929,687	726
Class 8 Regional Haul Tractors	656,294	47,940,877	66,040
Total	5,210,629	100,028,904	168,582

Figures don't add up exactly to totals due to rounding

In addition to the big overarching findings of the Run on Less – Electric demonstration which allowed us to gain better insight into battery electric vehicles in the four market segments — vans and step vans, medium-duty box trucks, terminal tractors and regional haul heavy-duty tractors — we also learned some little things.

These lessons learned were about CBEVs and their charging needs, the importance of understanding what you measure and how you measure it, the need for standards surrounding vehicle-charger interfaces and terminology, operational factors fleets need to consider in order to make the deployment of CBEVs go smoothly, and the complexity of working with utilities.

We expect all those helping to advance the use of electric vehicles in commercial applications — fleets, OEMs, suppliers, utilities, governmental agencies, legislators — will be able to leverage these lessons learned as they begin to deploy CBEVs in their operations. Figure ES6 includes these learnings categorized as charging, measurements, standards, operations and utilities.

FIGURE ES6

LESSONS LEARNED DURING RUN ON LESS – ELECTRIC (CLICK HERE FOR A LARGER VIEW)

Next Steps

Early in the second quarter of 2022, NACFE will publish market segment specific analyses of the RoL-E data. The four reports will cover vans and step vans, medium-duty box trucks, Class 8 terminal tractors, and heavy-duty regional haul tractors. A final report will take a deep dive into the data collected during RoL-E and subsequent data collected after the event.

Visit www.NACFE.org to download this and other reports

1 Introduction

The North American Council for Freight Efficiency (NACFE) was established in 2009 as a 501c3 non-profit to provide unbiased information to all stakeholders interested in improving the efficiency of moving freight. This is accomplished through a combination of creating in-depth reports on technologies for improving efficiency, through industry outreach, workshops and conferences, and demonstrations.

Run on Less is a biennial demonstration highlighting significant technologies available to the trucking industry. Three demonstrations have been conducted so far as illustrated in Figure 1. The 2017 Run on Less demonstrated that current production Class 8 diesel semi tractors pulling 53' van trailers and driven by experienced drivers could average 10.1 MPG in real-world long haul fleet operations. The 2019 Run on Less Regional (RoLR) demonstrated that current production Class 8 diesel semi tractors could average 8.7 MPG in real-world regional operations. That Run also included a natural gas tractor making the overall demonstration average 8.3 MPG. The 2021 Run selected battery electric trucks (BEVs) as the technology to demonstrate, including terminal tractors, vans, medium-duty box trucks and heavy-duty regional haul tractors. NACFE felt the industry was transitioning from prototypes to production level trucks, and that at this point in time fleets needed to know how those vehicles performed in the real-world and learn from those fleets already making investments in electrification.

Figure 1. Run on Less Demonstrations

2 Scope

The purpose of this report is to document the year-long effort to bring Run on Less – Electric to fruition and to provide an analysis of the findings and lessons learned from the demonstration.

3 NACFE'S MISSION

NACFE's overriding principle in reporting on technologies is to provide an unbiased perspective. NACFE recognizes that it also has vested interests and an agenda. NACFE's mission is simply to improve the efficiency of North American goods movement which in parallel reduces the environmental impact of freight hauling. NACFE pursues this goal in three ways: a) through publishing in-depth studies on the technologies, b) by conducting information sharing events including workshops, panels and conferences, and c) through demonstrations.

4 WHAT IS RUN ON LESS – ELECTRIC?

Run on Less – Electric (RoL-E) is a three-week demonstration of production level electric commercial vehicles in real-world operations at 13 fleets in regions across North America operating in market segments identified as high potential for employing battery electric trucks. Four segments were included: terminal tractors, vans and step vans, medium-duty box trucks and heavy-duty regional haul tractors.

4.1 WHY BATTERY ELECTRIC VEHICLES NOW?

Battery electric trucks have existed for more than 100 years. The technology made only small inroads in freight such as forklifts and carts and saw limited use in delivery vehicles and special purpose vehicles, due to limitations in lead-acid battery capability. Development of much higher energy dense lithium ion batteries in parallel with advances in electric motors, software and digital control systems made production battery electric passenger cars viable starting in 2009 to 2012 with the Tesla roadster (2009) and Model S (2012), the Nissan Leaf (2010), Chevy Volt hybrid (2010) and Chevy Bolt (2012). The long running success of the Toyota Prius Hybrid with nickel metal hydride batteries introduced in 2000 has also contributed to acceptance of battery powered vehicles.

In 2010, commercial battery electric vehicles (CBEVs) had early entrants including the Smith-Newton used by Frito-Lay starting in 2010 and the Navistar eStar with FedEx as shown in Figure 2 [1][2][3][4][5]. Electric and hybrid electric buses also were being introduced in that time frame from companies like Proterra and New Flyer.

Figure 2. Smith Newton and Navistar eStar

After 2010, as electric vehicle components began evolving into commodities, several small manufacturers saw opportunities in taking production chassis deliveries from Ford, GM, Isuzu, Fuso and others and upfitting them with electric drivetrains to fill niche market demands. New brands like Lightning eMotors, SEA Electric, Motiv, Workhorse, Phoenix Motorcars and others started low volume vehicle introductions.

The established large OEMs were largely silent in public on battery electric medium- and heavy-duty trucks, except for the occasional technology demonstration prototypes. Then in October 2017, Tesla's Elon Musk introduced a long-range battery electric Class 8 semi-tractor in a major press event and discussed production starting in 2019. The established truck manufacturers all started discussing electric trucks in public. Many began introducing prototypes, grant vehicles and laying out plans for production. Tesla's plans slipped out and the competitors kept pushing forward.

Spurring fleet and manufacturer interest in BEVs was the growing focus on sustainability by companies, investors, the public and regulators. The movement toward zero emission vehicles being required to combat emissions was gaining momentum at many levels and regulations and policies were starting to be put in place to enable a transition from fossil fuel powered vehicles to zero emission ones.

In October 2020 NACFE gauged that the trucking industry seemed ready in 2021 for introducing production level CBEVs. NACFE had initiated reporting on electric vehicles in 2018 with a series of in-depth Guidance Reports and other reports:

1. *Electric Trucks – Where They Make* Sense (May 2018) [1]
2. *Medium-Duty Trucks – Total Cost of Ownership* (Oct. 2018) [6]
3. *Amping Up – Charging for Electric Trucks* (Mar. 2019) [7]
4. *Viable Class 7/8 Alternative Fuel Tractors* (Dec. 2019) [8]
5. *High-Potential Regions for Electric Truck Deployments* (Nov. 2020) [9]
6. *Making Sense of Hydrogen Fuel Cell Tractors* (Dec. 2020) [10]
7. *Battery Electric Powertrains for Class 8 Regional Haul Freight Based on NACFE's RoLR* (June 2020) [11]
8. *Defining Production* (Jan. 2020) [12]

Over the summer and fall of 2020, the NACFE team evaluated alternatives for the next Run on Less demonstration. Mike Roeth, executive director of NACFE, proposed and received approval from NACFE's Board of Directors to proceed with Run on Less – Electric in 2021 with the three-week demonstration period to be in September 2021.

5 The Run on Less – Electric Plan

The original goal was to engage 10 unique fleets in different regions of North America that were operating production level CBEVs from different manufacturers. They would agree to allow real-time data collection from their trucks over the period of the demonstration. Additionally, the participants would identify their own driver, route and loads as part of normal daily operations. The fleets, manufacturers and other stakeholders would be interviewed on-site at their respective operations during the three months prior to the demonstration for the purposes of interviewing participants and capturing video for NACFE. The data collection process also would be reviewed with each fleet.

Funding for the event would be pursued through sponsorships and in-kind contributions. Participating fleets would not be compensated outside of whatever publicity they might receive from participating in the demonstration and through their own social media and press releases.

A significant educational outreach effort would be conducted by NACFE in the five months prior to the demonstration through a series of webinars that became the Electric Truck Bootcamp.

Social media and the press would be engaged through a series of fleet profile videos prior to the demonstration and then daily CBEV topic videos would be released during the demonstration capturing comments and video from the participant site interviews and other interviews with subject matter experts.

The demonstration would kick-off at a major industry conference and conclude at another major industry event. Interim conferences also would be opportunities to discuss the demonstration. The COVID pandemic was a critical factor in planning from the initial work in the fall of 2020 all the way through October 2021 and the completion of the demonstration. The NACFE team committed to the NACFE Board of Directors to deal with challenges associated with COVID to accomplish the RoL-E demonstration objectives in the prescribed time frame.

The final version of the schedule provided to participants and organizers in May 2021 is shown in Figure 3. The Yogi Berra observation that “it ain’t over ‘til it’s over” highlights that the RoL-E plan went through further iterations as the real-world dealing with COVID unfolded.

Figure 3. The RoL-E timeline May 2021 (NACFE)

6 Industry Events

Announcements for RoL-E inviting participation began as early as December 2020 through social media and on January 13, 2021 a formal press conference was held [18][19]. An example of social media posting is shown in Figure 4. The plan was to make the official notice of teams at the annual American Trucking Associations (ATA) Technology & Maintenance Council (TMC) event, March 8 to 11, 2021 in Orlando. TMC organizers announced in late February that due to COVID precautions, the event was being rescheduled, first to April, and then finally to September [17].

The selection of fleets was announced March 31 in a press conference and on social media [20].

Figure 4. NACFE social media example

The original goal was to have 10 fleets representing products from 10 OEMs. Successfully deploying emerging technologies like CBEVs is a joint effort of both the OEMs and the fleets, so NACFE felt it important to include both in RoL-E as participant pairs. Ultimately after interviewing more than 30 prospective pairings, NACFE settled on 13 fleets and OEMs capable of supplying drivers, vehicles and routes for the September three-week demonstration. Vehicles would cross the spectrum from Class 3 to Class 8, including terminal tractors. A NACFE objective was to showcase not only where CBEVs were in use in California but in regions outside of California including Canada. The teams initially selected were:

- Alpha Baking Co. operating a Workhorse C1000 in Chicago.
- Anheuser-Busch using a BYD tractor in the Los Angeles area.
- Biagi Brothers operating a Peterbilt 579EV out of Sonoma, Calif.
- Cardenas Inc. using an Xos van in Ventura, Calif.
- NFI using a Volvo VNR Electric out of Chino, Calif.
- Penske operating a Freightliner eCascadia in Los Angeles
- PepsiCo's Frito-Lay Division using a Cummins box truck in Modesto, Calif.
- Purolator operating a Motiv-powered step van in Vancouver, British Columbia, Canada.
- Roush Fenway Racing using a ROUSH CleanTech truck out of Concord, N.C.
- Ruan using an Orange EV terminal tractor in Otsego, Minn.
- Ryder System Inc. using a Lonestar Specialty Vehicles terminal tractor in Georgetown, Ky.
- SAQ: Quebec Liquor board operating a LION8 truck in Montreal.
- TBD operating a Lightning eMotors truck in the New York City area.

The challenges of securing fleet and OEM participation for vehicles just entering production amid the pandemic caused NACFE to revise the RoL-E participants as the start of the demonstration drew near. NACFE replaced The Alpha Baking Co. operating a Workhorse C1000 in Chicago at the end of July with

Servall Electric Company operating the same BEV model in Cincinnati. In the same period, the SAQ: Quebec Liquor board operating a LION8 truck in Montreal was replaced by Day & Ross running a Lion Class 6 box truck in Montreal. The Lightning eMotors truck in the New York City area was finalized as the DHL fleet. The Biagi Brothers Peterbilt 579EV also was to be replaced with the latest version from Peterbilt/Meritor, but the charger and new vehicle were not in place in time to support the start of the demonstration.

All vehicles were to be equipped with Geotab tracking systems. In some cases, this was no challenge as vehicles already were equipped or were easily connected. In other cases, special adapter cables had to be designed, built and installed. NACFE and Geotab worked with the fleets and OEMs over the course of several months to provide data connectivity. Ultimately, one company was not connected via Geotab and a workaround using their own data system was implemented. In parallel, NACFE developed the data dashboard website with the software company YoJonesy [21].

NACFE was given the opportunity by the Department of Energy (DOE) to promote RoL-E as part of DOE Secretary Jennifer Granholm's formal announcement of the SuperTruck 3 program on April 15, 2021 at the U.S. Department of Energy Fireside Chat: Clean Trucks and Moving Freight on the Road to Decarbonization [22][23]. The video of this event is available on YouTube and the runonless.com video page as shown in Figure 5.

Figure 5. DOE Secretary Granholm SuperTruck III announcement

The official kickoff for RoL-E was scheduled for September 3. The ACT Expo industry event conveniently was scheduled for the week of August 30 through September 2. The organizers of ACT Expo 2021, Gladstein, Neandross & Associates, ultimately chose to hold a live, in-person event, but up until the event actually occurred, there was a risk of the event becoming a virtual event or being canceled. ACT Expo organizers agreed to NACFE holding a workshop on electric trucks and RoL-E as part of the first day of the event. Attendance at ACT Expo reportedly exceeded 5,000 attendees, more than double the number from prior pre-COVID events [14][15]. NACFE's workshop was extremely well attended, filling the room which seated in excess of 200 people as seen in Figure 6.

Figure 6. NACFE ACT Expo 2021 Workshop (Mihelic)

ACT Expo also invited Roeth to moderate the opening Battery Tech Workshop as shown in Figure 7. The opening remarks included discussion of Run on Less – Electric to a standing room only audience that exceeded 200 attendees [14][15].

Figure 7. Mike Roeth moderating ACT Expo 2021 Battery Tech Workshop (Mihelic)

NACFE's original goal was to host the Finale of the RoL-E demonstration at The North American Commercial Vehicle (NACV) industry show in Atlanta scheduled for September 28. Unfortunately, NACV decided to "postpone" its event to a later year with announcements to participants on May 4, 2021, shown in Figure 8 [13].

May 4, 2021
CHICAGO – Organizers of the North American Commercial Vehicle (NACV) Show announced today that they are postponing their 2021 event, originally scheduled for September 28-30 at Atlanta's Georgia World Congress Center.

Registered exhibitors were informed of the postponement earlier through a letter from the joint owners of the biennial event – Newcom Media and Hannover Fairs USA.

The decision was made after discussion with both manufacturers and fleets, who cited the lingering effects of COVID-19 on willingness to travel and attend large gatherings. Additionally, the growing number of events competing with one another in the fall of 2021 also factored into the decision.

"Each organization and individual attendee has made choices over the past months based on a variety of factors, health and safety being the most pressing. While many exhibitors demonstrate commitment to the show and vaccination rates continue to rise, our research shows that the trucking industry will not be ready to attend large events like they traditionally have this fall," said Ed Nichols, Vice President of Hannover Fairs USA.

"While we are disappointed that we cannot produce the NACV show this year, we are eager to start working on the future event, focusing on reconnecting the trucking industry and delivering value to our customers," stated Joe Glionna, President of Newcom Media Inc.
The NACV Show will be rescheduled. Organizers plan to share more information regarding future plans in July 2021.

Figure 8. NACV postponement notice

NACFE quickly pivoted the RoL-E finale from the NACV event to planning to conclude the RoL-E demonstration as part of Climate Week in New York City the week of September 20 to 26. The plan included using DHL's participant truck and driver, and potentially others from RoL-E along with Sir Richard Branson. This plan had to be revised when organizers went to a virtual format for Climate Week in response to rising COVID cases in New York City. NACFE held a virtual press conference September 22 and posted videos to social media in conjunction with RMI promotion of the finale event.

NACFE capitalized on multiple high profile industry events, some shown in Figure 9, to present information on RoL-E during and after the period of the RoL-E demonstration including:

- ACT Expo 2021, Long Beach, CA, Aug. 30 to Sept. 2
- ATA Technology & Maintenance Council (TMC) Fall 2021, Cleveland, Sept. 12 to 16
- SAE Commercial Vehicle Congress, Chicago, Sept. 14 to 16
- The Battery Show & Electric & Hybrid Vehicle Technology Expo, Novi, MI, Sept. 14 to 16
- NYC Climate Week, New York City, Sept. 20 to 26
- MOVE America, Austin, TX, Sept. 27 to 29
- NACFE Autonomous Truck Workshop, Indianapolis, Oct. 22
- ATA Management Conference & Exhibition (MCE), Nashville, Oct. 23 to 26
- VERGE 2021, Virtual, Oct. 25 to 28
- Global Drive Electric Advisory Group led by Climate Works (OP26,) Edinburgh, Oct. 29 to 30
- DOE SuperTruck 3 Award Announcement, New York, Nov. 1
- Women in Trucking Accelerate, Dallas, Nov. 7 to 9

Figure 9. Industry events discussing RoL-E (NACFE)

Ultimately only two of these events went virtual due to COVID mitigation, the NYC Climate Week NACFE Finale and Verge. All others were in-person events with NACFE RoL-E highlighted through either a trade show booth, panels, and/or presentations. Industry media and social media covered all these events providing a broad distribution about RoL-E. Assisting in promotion of RoL-E media events were Gladstein, Neandross and Associates and RMI along with ATA, SAE, The Battery Show and MOVE America.

NACFE's Run on Less demonstrations have seen relevance well beyond the duration of the actual events. The expectation of the NACFE Board of Directors is that the extensive RoL-E trove of panels, interviews, videos, data and experiences will continue to be add value into the future.

7 Selecting Fleets, OEMs, Vehicles & Duty Cycles

Run on Less demonstrations focus on technologies that are in production and that fleets currently can procure. In contrast, prototypes such as the DOE SuperTrucks and other technology demonstrators only intend to show what might be in production in the future. The first Run on Less demonstration in 2017 showed that production trucks could exceed 10 MPG in real-world operations. Those tractors and trailers incorporated technologies demonstrated in the DOE SuperTruck 1 vehicles built by major truck OEMs that were first seen in public between 2013 and 2016.

The emerging nature of CBEVs in the 2021 time frame provided challenges in finding production intent vehicles for RoL-E. In December 2020, NACFE identified more than 30 vehicle models to consider in planning the event. Figure 10 is an internal planning slide from December 2020. That list was prepared based on discussions with fleets, press announcements from companies, and projections from experts. However, reality has a way of inserting itself; product introductions get rescheduled, or more succinctly, stuff happens. The 2021 calendar year had its share of stuff, not the least of which was the impact from COVID mitigation strategies, a booming e-commerce segment, rising demand for vehicles in all segments, imbalances in supply and demand of materials, and shortages of critical components, especially computer chips.

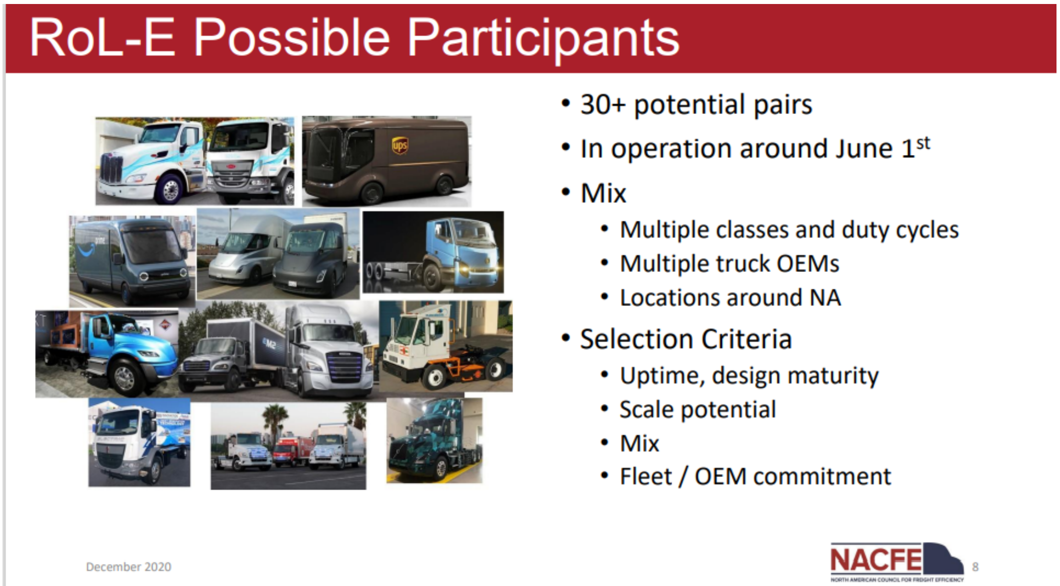


Figure 10. Initial thoughts on RoL-E participants

NACFE's mission to be unbiased requires that every effort be expended to include a broad mix of OEMs in Run on Less demonstrations.

The goal was to secure participation from 10 fleets with 10 different battery electric models from 10 different manufacturers looking at Class 3 through 8 freight-carrying vehicles. Emerging technologies typically start first as proof-of-concept OEM prototypes with significant manufacturer support, often stated as "an engineer in the glovebox." Early production units, on the other hand, are intended for fleets to fully evaluate operational use of production representative vehicles. The fleet and the OEMs are effectively a pairing in the success of the emerging technology deployment. NACFE required both the fleets and the OEMs to agree to be participants for each RoL-E entry. The vehicles had to be in operation at the fleets by June 1, 2021 to allow time before the September 1 start of RoL-E so the operators could work out any learning curve issues with the vehicles.

The June time frame also permitted NACFE to perform site visits, interviews and obtain video to use in an extensive planned NACFE media effort. The delta variant of COVID was just ramping up and travel was an ongoing logistical concern for NACFE staff.

California dominates the news when it comes to battery electric trucks. California is a leader in zero emission technology adoption. State and regional programs have supported fielding many CBEVs in different duty cycles. The environmental conditions also tend to be ideal for operations, with moderate temperatures and road grades in many regions.

NACFE wanted to demonstrate that CBEVs were being operated in all parts of North America, not just California. NACFE placed an emphasis on locating fleets and trucks in other regions of the US and Canada, ultimately securing participation in British Columbia, Quebec, New York, Ohio, Kentucky, North Carolina, Minnesota and California. (As shown in Figure 11.) Fleets in other regions including Texas, Florida, Colorado, Oregon, Washington and Alaska were contacted, however issues over vehicle type, timing, manufacturer or fleet company commitment, COVID travel protocols and other factors prevented participation by fleets in those areas.

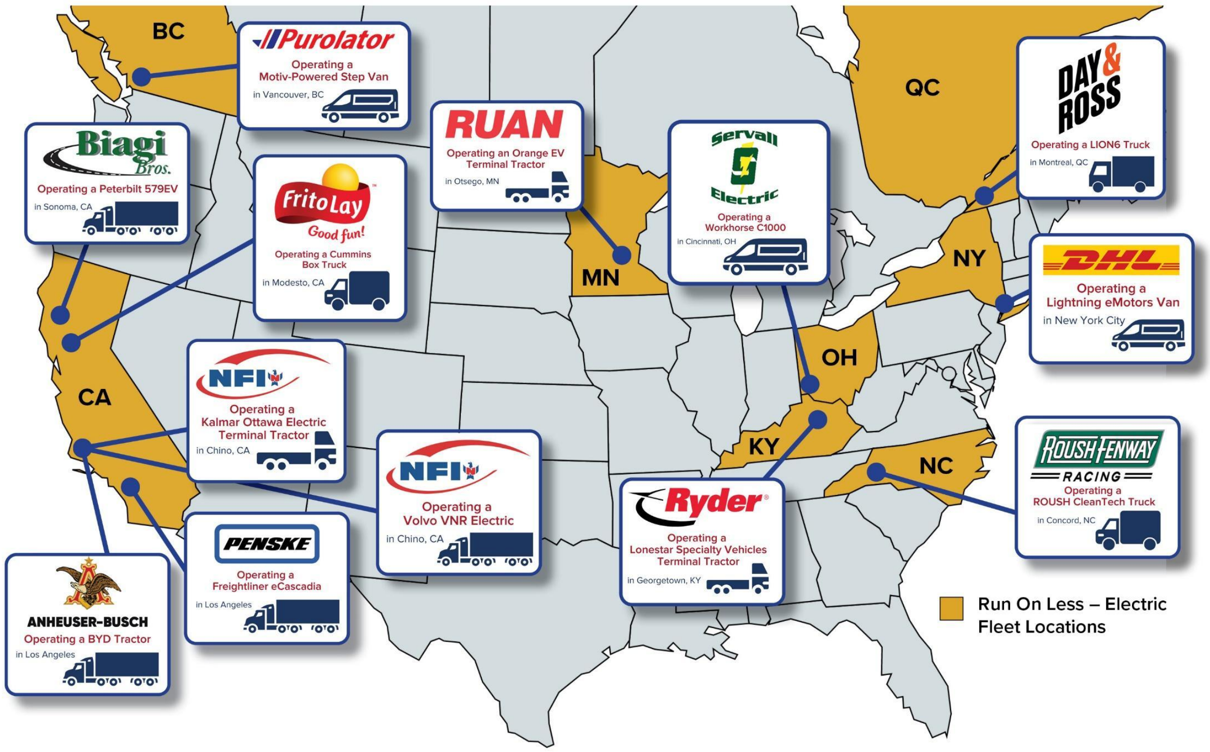


Figure 11. RoL-E participation

The probability of needing last minute fleet substitutions because of the dynamic conditions in 2021 was factored into planning. NACFE went from wanting 10 participants to ultimately opting for 13 candidate pairings of fleets and OEMs. As the spring and summer progressed, NACFE stayed with 13 participants even when complications with some fleets and vehicles arose. Alternatives were quickly found to replace them.

The 13 candidates also gave RoL-E an outstanding broad mix of vehicles in four market segments, ultimately with three vans and step vans, three terminal tractors, three medium-duty box trucks and four Class 8 tractors. This cross section of vehicle types and manufacturers gave NACFE an excellent snapshot of the state of the CBEV industry.

The June 1 date for having on-site operational vehicles at the fleets also was allowed to slip as OEMs and fleets wrestled with 2021 challenges. Site visits by NACFE went ahead as planned beginning in May and continuing through early August. In some instances, a fleet had earlier versions of the electric truck in operation for NACFE to film and interview around, with the expectation that the truck intended for RoL-E would arrive in time to support the start of the demonstration around September 1. In some cases, the fleets had just received the vehicle when NACFE arrived for interviews. In others, the fleets had been operating the vehicles for as many as nine months.

Fleets and OEMs permitted Geotab to instrument and monitor their vehicles in RoL-E. NACFE has worked extensively with Geotab in past Run on Less events and on other projects. Geotab provides telematics tracking technology. Connecting each vehicle to a Geotab device involved NACFE and Geotab resources working in concert over several months. In some cases, specially configured cables needed to be built. In some cases, new software had to be developed to interface correctly with the trucks. Ultimately 12 of the 13 vehicles were equipped with Geotab devices. Arrangements were made with one OEM to pull telematics data from that OEM's proprietary data system as it was not going to be possible to get a Geotab device installed on its RoL-E truck.

Vehicle types and duty cycles for RoL-E included four categories.

- Vans and Step Vans
- Medium-duty Box Trucks
- Terminal Tractors
- Heavy-duty Regional Haul Tractors

7.1.1 Vans and Step Vans

Urban delivery duty cycles using Class 3 to 6 vans and step vans is an ideal duty cycle for battery electric powertrains. These vehicles generally do not have issues with vehicle tare weight impacting freight weight. In those weight sensitive cases such as laundry pickup and delivery or paper products delivery, fleets have the option of moving up to the next available class vehicle. Non-CDL licensed drivers can drive these vehicles. Range also generally is not a concern with these duty cycles which tend to be below 100 miles a day, and often below 50 miles per day. The urban traffic and street driving also permit energy recovery through regenerative braking systems. Regenerative braking is an energy recovery mechanism that slows down a moving vehicle by converting its kinetic energy into a form that can be either used immediately or stored until needed. Charging times and electricity rates also are not that demanding as these vehicles operate in one-shift operations with long overnight dwell times making it possible to use low charging rates, more inexpensive chargers, and low-cost electricity. For a more in-depth look at this market segment, read the *Vans & Step Vans: Market Segment & Fleet Profile Fact Sheet*.

7.1.1.1 DHL and Lightning eMotors

DHL is a global logistics company and a leader in investing in new technologies to improve sustainability [24]. Their RoL-E participant was located in Manhattan, in the heart of New York City. The duty cycle for this vehicle was representative of package delivery in the downtown area of any large high-rise metropolis like Chicago, San Francisco, Miami, etc. DHL has been operating nine CBEVs in Manhattan since November 2020 and plans to expand with another 55. The vehicles see relatively short daily miles; as the fleet manager explained, time is spent delivering up in the buildings with the vehicle not moving. DHL's vehicle for RoL-E was the Lightning eMotors Transit 350HD. Lightning eMotors produces a variety of electric freight and transit vehicles [25]. The van was a Ford Transit van upfit with a battery electric drivetrain and electric accessories. Batteries were located under the vehicle so there was no compromise to cargo capacity volume. The vehicle was equipped with a 43-kWh battery with a dynamometer tested range of 61 miles. DHL's duty cycle in Manhattan easily fit in this daily range, where often the vehicles travel less than 15 miles per day. The DHL fleet manager remarked that they actually could use a smaller battery [26]. An overview of the DHL Lightning eMotors RoL-E vehicle is shown in Figure 12.

Truck

Truck Class	Class 3
Type	Cargo Van
OEM	Lightning eMotors
Model	Transit 350HD
Production Level	In Series Production
Battery Capacity	43 kWh
Estimated Range	61 miles

Figure 12. DHL and Lightning eMotors

7.1.1.2 Purolator and Motiv

Purolator is Canada's leading integrated freight, package and logistics provider [27]. The Vancouver, British Columbia operation is employing five Motiv step vans. Purolator, according to Paul Merrick, general manager Western Canada, is the first national company to deploy electric trucks, including deployments in Toronto and Montreal, and has a goal of becoming the greenest courier company in Canada. They have a history of investing in new technologies including operating more than 200 hybrid electric vehicles in 2005. Purolator plans to have more than 1,800 CBEVs on the road in the next decade. The city of Vancouver and province of British Columbia are leaders in supporting zero emission vehicles. Motiv makes both cargo and transit vehicles [28] and has been developing electric vehicles since 2009. Range anxiety is not an issue with these vehicles as they are equipped with the industry standard J1772 charging port and in the rare event of an unplanned charging need, the driver can use web applications to easily find a public charging station used by cars. The Purolator RoL-E participant was a Class 6 Motiv Epic F-59 step van with a Morgan van body and chassis adapted from a Ford F-59 chassis [29]. An overview of the Purolator Motiv RoL-E vehicle is shown in Figure 13.

Truck

Truck Class	**Class 6**
Type	**Step Van**
OEM	**Motiv**
Production Level	**In Production**
Battery Capacity	**127 kWh**
Estimated Range	**105 miles**

Figure 13. Purolator and Motiv

7.1.1.3 Servall Electric and Workhorse

Servall Electric is a third-generation electrical construction business providing residential, commercial, and industrial electrical services in the Cincinnati, Ohio region [30]. Servall Electric is a company that is hired to install BEV chargers. In supporting that line of business, according to Julie Ann Lake, vice president of operations, they felt they should have firsthand experience with their own CBEVs. This is their first electric vehicle. Workhorse is a technology company focused on providing sustainable and cost-effective solutions to the commercial transportation sector. They build Class 2 through 6 vehicles [31]. Servall Electric's RoL-E participant was a Workhorse C1000 delivery step van with ~13,000 lbs. GVWR and 1000 cubic feet of cargo space. Workhorse was able to lower the floor of the vehicle 10" improving ingress and egress due to the electric drivetrain being a more efficient package. Range and weight have been no issue for Servall Electric [32]. An overview of the Servall Electric Workhorse RoL-E vehicle is shown in Figure 14.

Truck

Truck Class	**Class 5**
Type	**Step Van**
OEM	**Workhorse**
Model	**C1000**
Production Level	**In Series Production**
Battery Capacity	**102 kWh**
Estimated Range	**150 miles**

Figure 14. Servall Electric and Workhorse

7.1.2 Medium-duty Box Trucks

Urban delivery duty cycles using Class 6 box trucks also are ideal duty cycles for battery electric powertrains. These vehicles are more likely to have payload weight concerns for those denser payloads. Class 6 vehicles can be driven by non-CDL licensed drivers, where moving up to Class 7 to carry additional payload would require a CDL licensed driver and all that entails. However, many loads carried by these vehicles tend to cube out, i.e., fill up the volume of the vehicle freight compartment, not weigh out, i.e., use the entire allowance of legal gross vehicle weight. Range also is generally not a concern with these duty cycles which tend to be below 100 miles a day, and often below 80 miles per day. Drivers of box trucks tend to participate in loading and unloading vehicles which also can entail multiple stops. The urban traffic and street driving also permit energy recovery through regenerative braking systems. Charging times and electricity rates also are not that demanding as these vehicles generally operate in one-shift operations with long overnight dwell times making it possible to use low charging rates, more inexpensive chargers, and low-cost electricity. For a more in-depth look at this market segment, read the *MD Box Trucks: Market Segment & Fleet Profile Fact Sheet.*

7.1.2.1 Day & Ross and Lion

Day & Ross is one of the largest transportation companies in Canada. According to Billy Rae Rattray, environmental specialist, Day & Ross is adding electric trucks to support its broader sustainability efforts which have included aerodynamic improvements to tractors and trailers, route optimization software and telematics, for example. This early adopter is gaining firsthand experience with the technologies to better evaluate long-term strategies for emissions reduction [36]. The Day & Ross RoL-E participant was a Lion Electric Lion6 box truck operating in Montreal, Canada. Lion is a Canada-based electric vehicle manufacturer that produces a range of transit and commercial vehicles across a range of vehicle classes up to Class 8. Lion is expanding manufacturing to include a factory in the US in Illinois [37]. Day & Ross was just beginning operations with two CBEVs at the Montreal facility. The duty cycle targeted for these were lanes with less than 125 miles (200 km) where return-to-base charging could be utilized, and loads cubed out rather than weighed out. The Montreal operations see winter snow conditions and Day & Ross and Lion feel these trucks are specified properly to address the harsher climate conditions [38]. An overview of the Day & Ross Lion RoL-E vehicle is shown in Figure 15.

Truck

Truck Class	Class 6
Type	Single Axle Straight truck with 3300lb tuckaway liftgate
OEM	Lion
Model	Lion6
Production Level	Full production
Battery Capacity	252 kWh
Estimated Range	250-290km
Components	SAST with direct drive electric motor, 252kWH battery pack, 26 foot box and 3300lb tuckaway liftgate.

Figure 15. Day & Ross and Lion

7.1.2.2 Frito-Lay and Cummins

PepsiCo has set aggressive corporate goals for reducing the environmental impact of its operations. Its Frito-Lay facility in Modesto, California is a site-wide effort toward becoming a net zero emission facility. As a significant part of the project, Frito-Lay is replacing all existing diesel-powered freight equipment with zero and near zero emission technologies [33]. Its new fleet consists of battery electric delivery box trucks, battery electric terminal trucks, and two types of Class 8 tractors powered by either renewable natural gas or batteries. Frito-Lay's RoL-E participant was a Cummins New Power battery electric Class 6 box truck. The cab and chassis for this truck were from a Peterbilt Model 220EV. Cummins New Power is not a vehicle manufacturer, but a provider of low-carbon production powertrain systems [34]. The Frito-Lay vehicle was a production intent demonstration vehicle based on the Cummins drive system. The duty cycle for this vehicle was delivering Frito-Lay snacks to stock local grocery stores. The driver starts the shift around 4 a.m. The driver parks his personal transportation, swapping positions with the box truck at the assigned factory site charging station. The driver loads the truck with carts full of product at a nearby location at the factory site, then makes deliveries to multiple stops where he unloads the truck and stocks the grocery store. The driver's shift ends around noon. Returning to the charging station, the driver swaps positions with his personal car and then backs the truck into the charging station, connects the charger, and drives his personal vehicle home. This is repeated five days per week [35]. Range and payload weight are not a challenge for this duty cycle. An overview of the Frito-Lay Cummins RoL-E vehicle is shown in Figure 16.

Truck

Truck Class	Class 6
Type	Medium-Duty Box Truck
OEM	Cummins
Model	Peterbilt 220EV
Production Level	Pre-Production
Battery Capacity	155 kWh
Estimated Range	100 miles
Components	Central Drive Unit

Figure 16. Frito-Lay and Cummins

7.1.2.3 Roush Fenway Racing and Roush CleanTech

Roush Fenway Racing (RFR) is one of the most successful teams in NASCAR in its 33rd season [39]. According to Ian Prince, heading Real Estate & Sustainability, RFR in a cooperative project with Castrol, became the first certified carbon neutral racing team in the US. It is offsetting emissions on the track with carbon reductions in its off-track operations. The RFR RoL-E participant vehicle was a Roush CleanTech F-650 based on a Ford F-650 chassis. Roush CleanTech is a Division of Roush Enterprises and is a Ford Qualified Vehicle Modifier [40]. Roush CleanTech developed and integrated the electric drive system into the vehicle. RFR uses the vehicle to distribute parts and racing components within a 35-mile radius of its facility in Charlotte, North Carolina [41]. Range and payload weight are not an issue. An overview of the RFR Roush CleanTech vehicle is shown in Figure 17.

Truck

Truck Class	Class 6
Type	Medium-Duty Box Truck
OEM	Roush CleanTech/Ford
Model	F-650
Production Level	Prototype
Battery Capacity	138 kWh
Estimated Range	100 miles
Components	Dana TM4 e-motor & Soundon New Energy batteries

Figure 17. Roush Fenway Racing and Roush CleanTech

7.1.3 Terminal Tractors

Terminal tractors, also known as yard trucks, yard hostlers, and other names, are purpose-built vehicles for moving trailers around warehouses, distribution centers and other terminals. These vehicles sometimes have to operate inside buildings. Most terminal tractor operations are inside the fence, but occasionally they are used to move trailers on public streets or even highways between two nearby facilities. The terminal operations tend to be demanding with short dwell times when drivers take breaks and often slip seating for multi-shift operations. Slip seating refers to when a driver isn't assigned a specific truck, but rather gets into one once another driver returns from their route. The vehicles accumulate a surprising number of daily miles considering they rarely if ever leave their facilities. Terminal tractors can number in the single digits to more than 100 vehicles depending on the facility.

Several factors in the operation of terminal tractors make CBEVs a logical fit. The vehicles are always at the depot, so are always near charging facilities. Weight is generally not an issue since the vehicles are usually 4x2 configurations with very spartan, lightweight one-person cabs. Terminal driving is very stop and go, which is appealing to the acceleration and regenerative braking advantages of the electric drivetrain. Safety also is enhanced due to the quiet operation of the electric powertrain. Drivers can be more aware of their surroundings, traffic, and pedestrians. The zero emission nature and quiet operation also permits use of these vehicles inside warehouses where other powertrains would require building ventilation systems. Range and payload are not issues as long as the drivers make use of opportunity charging. One other factor is that terminal tractors can make use of available chargers when delivery vehicles are out in the field, increasing utilization of those assets. For a more in-depth look at this market segment, read the *[Terminal Tractors: Market Segment & Fleet Profile Fact Sheet](#)*.

7.1.3.1 NFI Terminal and Kalmar

NFI is a privately held North American supply chain solutions provider. It owns facilities globally and operates approximately 60 million sq. ft. of warehouse and distribution space. Its dedicated fleet consists of more than 4,500 tractors and 12,500 trailers operated by 3,900 company drivers and 500 owner-operators. NFI has a significant drayage presence at nearly every major US port, leveraging the services of an additional 1,200 owner-operators. The company's business lines include dedicated transportation, distribution, brokerage, transportation management, port drayage, intermodal, global logistics, and real estate [42]. NFI employs a significant number of terminal tractors in its operations. NFI's RoL-E participant vehicle was a Kalmar Ottawa T2E operating in Chino, California. Kalmar is a major producer of terminal tractors with a 60-year history [43]. According to Gina Lopez, vice president terminal tractors, it has about 100 battery electric terminal tractors in the field as of RoL-E. These early production units are gaining field experience with customers and providing feedback for product enhancements. The terminal tractor moves trailers around between multiple warehouses at the NFI Chino campus, occasionally driving on public streets. Weather conditions in Chino are hot during the summer months when it is common for temperatures to exceed 100°F. The NFI operations are considered more demanding of range and pick-up and drop activity, according to Kalmar. The vehicles operate on a 24/7 basis supporting warehouse operations and opportunity charge whenever possible. According to NFI's Bill Bliem, senior vice president of fleet services, they have never had a low battery out of service vehicle [44]. Range and payload weight are not an issue. An overview of the NFI Terminal Kalmar vehicle is shown in Figure 18.

Truck

Truck Class	Class 8
Type	Terminal Tractor
OEM	Kalmar
Model	Ottawa T2E
Production Level	In Series Production
Battery Capacity	220 kWh

Figure 18. NFI Terminal and Kalmar

7.1.3.2 Ruan and Orange EV

Ruan is a family-owned transportation management company. Founded in 1932, it provides dedicated contract transportation, managed transportation, and value-added warehousing. With more than 89 years of transportation experience, Ruan is one of the top 10 privately owned transportation service companies in the country. The company operates in 48 states, has more than 300 locations nationwide, and employs 5,600 people. The company owns or operates 4,000 power units and 10,000 trailers. Ruan says it continues to research and develop innovations in technology, equipment, and safety [48]. Ruan's Paul Jensen, senior vice president, supply chain solutions, said they see opportunities to use technologies in various parts of the organization to improve sustainability and improve the work environment, including running electric forklifts and other electric pieces of equipment in the warehouses in addition to the electric terminal tractors. The Ruan RoL-E participant vehicle was the Orange EV T-Series operating in Otsego, Minnesota. Orange EV has been producing electric terminal tractors since 2015. The company has accumulated in excess of 1.1 million operational hours and more than 3.7 million miles in its products, in 24/7 duty cycles in a range of US and Canadian regions [49]. The Minnesota operations expose the vehicles to harsh winter conditions. Ruan has had the Orange EV vehicle make use of opportunity charging to maintain battery state of charge. Ruan's Brad Gehring, vice president fleet services, feels that based on their use to date, these vehicles will see a 10-year life, three more than their diesels [50]. Range and payload weight are not an issue. An overview of the Ruan Orange EV vehicle is shown in Figure 19.

Truck

Truck Class	Class 8
Type	Terminal tractor
OEM	Orange EV
Model	T Series
Production Level	Production
Battery Capacity	160 Kwh

Figure 19. Ruan and Orange EV

7.1.3.3 Ryder Systems and Lonestar SV

Ryder System, Inc. is a leading logistics and transportation company providing supply chain, dedicated transportation, and commercial fleet management solutions, including full-service leasing, rental, maintenance, used vehicle sales, professional drivers, transportation services, freight brokerage, warehousing and distribution, e-commerce fulfillment, and last mile delivery services. Ryder provides services throughout the United States, Mexico, Canada, and the United Kingdom. It manages more than 250,000 commercial vehicles and operates more than 300 warehouses encompassing approximately 55 million square feet [45]. The Ryder Systems RoL-E participant vehicle was a Lonestar SV Reman electric terminal tractor operating in support of a major automotive manufacturer in Georgetown, Kentucky. Lonestar Specialty Vehicle is a Texas-based manufacturer of terminal tractors. The Reman line of electric terminal tractors was introduced in 2019 [46]. According to Ryder's Joe Champa, asset manager, the customer dictates their sustainability requirements, and Ryder's objectives are to meet those expectations which in this case includes a goal of a 20% carbon footprint reduction over the next four years. The Lonestar vehicle is assisting the company in meeting that goal. This also is a learning opportunity for Ryder, according to Ryan Salvail, director advanced vehicle technology, to gain experience with chargers and CBEV operations. The terminal tractor duty cycle is high idle and high hourly run rate. The truck can run for more than 22 hours before needing charging, according to Chas Meas, EV fleet sales at Lonestar. Opportunity charging makes it feasible for 24/7 operations [47]. Range and payload weight are not an issue. An overview of the Ryder Lonestar vehicle is shown in Figure 20.

Truck

Truck Class	Class 8
Type	Terminal Tractor
OEM	Lonestar SV
Model	S22
Production Level	Production
Battery Capacity	224 kWhr
Estimated Range	Not applicable
Components	Dana powertrain (batteries, motor and controllers)

Figure 20. Ryder and Lonestar SV

7.1.4 Heavy-duty Regional Haul Tractors

Heavy-duty day cab regional haul is a more challenging duty cycle for CBEVs because duty cycles are more sensitive to range and payload weight needs. The discussion on range splits into distinct topics of individual trip range, the driver's one-shift day range, and the truck's one-day range. Vehicles may be able to easily do some number of round trips before recharging, but they may not be able to do all the multiple round trips over one driver's entire shift. In the case of slip-seat operations, the vehicle may need to do two or three driver shifts per day with little dwell time at the depot available for charging. However, where the trip distance is short, and/or operations have lengthy delivery dwell times, CBEVs can adequately handle the entirety of one-shift operations. Payload weight also factors into capability to accomplish a day's work for the truck. Lighter payloads place lower demands on power, but even heavy beverage loads may be fine if the net daily mileage is not very demanding of the batteries. For a more in-depth look at this market segment, read the *HD Regional Haul Tractors: Market Segment & Fleet Profile Fact Sheet*.

7.1.4.1 Anheuser-Busch and BYD

Anheuser-Busch (AB) is a global beverage producer and distributor. The corporation is committed to carbon emissions reduction detailed in its 2025 Sustainability Goals [51]. It sets a target to reduce carbon emissions across its value chain by 25% by 2025. Contributing to that goal, AB estimates that converting its fleet to zero emission technology will reduce its transportation carbon footprint 18% by 2025. AB is investigating a variety of technologies toward reaching this goal. AB announced in 2019 it was purchasing 21 BYD battery electric tractors for use in southern California [52]. BYD is a leading commercial electric truck manufacturer headquartered in Los Angeles [53]. BYD has produced more than 60,000 electric buses and 13,000 electric trucks and is on its third-generation design, according to George Miller, senior sales manager. The AB RoL-E participant vehicle was a BYD 8TT heavy-duty tractor operating in the Inland Empire in Southern California. The vehicles have been operating since April 2020. The duty cycle uses end-loader beverage trailers to deliver to chain stores with multiple stops and trips per day. AB runs eight electric trucks at this facility on its shorter routes, according to AB's Kassidy Kiesel, senior delivery manager [54]. AB has been able to use these vehicles without any compromise compared to diesel tractors. Vehicles cover an entire day's delivery needs with no issues with weight, range or charge times. An overview of the AB BYD CBEV is shown in Figure 21.

Truck

Truck Class	**Class 8**
Type	**Heavy-Duty Tractor**
OEM	**BYD**
Model	**8TT Tandem Axle**
Production Level	**In Series Production**
Battery Capacity	**435 kWh**
Estimated Range	**150 - 200 Miles**
Components	**Cabover**

Figure 21. Anheuser-Busch and BYD

7.1.4.2 Biagi Brothers and Peterbilt/Meritor

Biagi Brothers is a full-service logistics company providing businesses and organizations with 3PL and supply chain solutions. Founded in 1978, the company still operates as a family-owned and operated supply chain management enterprise. It has distribution centers, warehouses and truck terminals strategically located throughout the US. With a work force of 600 plus employees, the company owns more than 270 tractors, 750 trailers, operates 3.5 million square-feet of food-grade warehouse space and has 20 distribution centers [58]. The Biagi Brothers RoL-E participant vehicle was a Peterbilt 579EV Class 8 tractor with a Meritor electric drivetrain operating between Napa, CA and Sonoma, CA transporting wine to temperature-controlled storage facilities. Peterbilt has been deploying pre-production CBEVs with fleets to assess their strengths and weaknesses to provide input for production vehicle designs [59]. Meritor is Peterbilt's and Kenworth's non-exclusive supplier for electrification as the initial launch partner and primary supplier for the integration of functional battery-electric systems [60]. The duty cycle for this vehicle is a short 13-mile distance between Napa and Sonoma with some rural highway and urban traffic and grade changes. Biagi Brothers has been operating a first generation Peterbilt/Meritor pre-production prototype and received a second-generation production intent vehicle at the start of RoL-E. Data reported by RoL-E was for the first-generation pre-production prototype [61]. Individual round trips of 26 miles even with maximum payload weights are not an issue. However, multiple trips in the same shift can exceed the battery pack net range requiring a second truck to complete the shift. An overview of the Biagi Brothers Peterbilt/Meritor CBEV vehicle is shown in
Figure 22.

Truck

Truck Class	**Class 8**
Type	**Heavy-Duty Tractor**
OEM	**Peterbilt**
Model	**579EV**
Production Level	**In Series Production**
Battery Capacity	**396 kWh**
Estimated Range	**150 miles**

Figure 22. Biagi Bros. and Peterbilt/Meritor

7.1.4.3 NFI Freight and Volvo

NFI is a leading supply chain solutions provider operating more than 4,500 tractors and more than 12,500 trailers across the US and with drayage operations at many US ports. NFI is an industry leader in investing in zero emission alternatives with operations in Southern California in partnership with state and regional agencies and manufacturers [42]. NFI's RoL-E participant vehicle was the Volvo VNR electric hauling shipping containers between the ports of Los Angeles/Long Beach and NFI's Inland Valley facilities. The duty cycle for this truck includes some urban street, yard, and interstate driving with round trips on the order of 110 miles and a localized 6% grade crossing a steep bridge at the ports. Volvo through its Volvo Lights project has been fielding battery electric tractors for fleet use and is in production with the VNR from its factory in Virginia [62]. The standard shipping containers are either 20' or 40' long. Weights for the containers tend to be in the 35,000 lbs. to 40,000 lbs. range. NFI estimates the maximum gross vehicle weight leaving the ports is 72,000 lbs. and the average is less than that. The payload weight and the single round trip of 110 miles are not an issue for the electric trucks. However, multiple trips in the same shift are challenging and require a second vehicle. An overview of the NFI Volvo CBEV vehicle is shown in Figure 23.

Truck

Truck Class	**Class 8**
Type	**Heavy-Duty Tractor**
OEM	**Volvo**
Model	**VNR Electric**
Production Level	**Pre-Production**
Battery Capacity	**396 kWh**
Estimated Range	**175 miles**

Figure 23. NFI Freight and Volvo

7.1.4.4 Penske and Daimler

Penske Transportation Solutions is the umbrella brand for Penske Truck Leasing, Penske Logistics, Epes Transport Systems, Penske Vehicle Services, and related businesses. Penske's businesses provide innovative transportation, supply chain and technology solutions. Penske Logistics provides supply chain management and logistics services to leading companies around the world, delivering value through its design, planning and execution in transportation, warehousing and freight management, and dry-van truckload carrier services. The company has decades of experience in a range of industries. Penske's focus on sustainability includes participation in US and Canada SmartWay programs. It used an independent third-party consulting firm to inventory its carbon footprint to target reduction efforts [55]. Penske's RoL-E participant vehicle was a Daimler Truck North America (DTNA) eCascadia operating in the Los Angeles region between Temecula, CA and San Diego on Interstate 15, approximately 60 miles each direction. DTNA has been actively deploying pre-production Class 8 heavy-duty electric vehicles and is actively consulting with fleets to understand how the vehicles are used and where improvements are needed [56]. The duty cycle for this truck involves urban and on-highway miles pulling refrigerated trailers with deliveries to eight to 15 customers starting at 4 p.m. Penske's Paul Rosa, senior vice president, procurement and fleet planning, and DTNA's Alex Voets, manager emobility product marketing, are both using these vehicles to assess strengths and weaknesses and the capabilities of the technology to gain firsthand real-world operational experience [56]. Individual round trips with opportunity charging have no issues, however, multiple trips in a day may exceed the capacity of the batteries. An overview of the Penske DTNA CBEV is shown in Figure 24.

Truck

Truck Class	Class 8
Type	Heavy-Duty Tractor
OEM	Freightliner
Model	eCascadia
Production Level	Pre-Production
Battery Capacity	440 kW
Estimated Range	175 miles

Figure 24. Penske and Daimler

8 What was Measured?

The RoL-E website dashboard was developed to capture and present data on CBEV operations for a variety of end users' interests. All data originates from the vehicles themselves through the Geotab integration on 12 of the 13 vehicles, and through the proprietary data system on the final vehicle. The metrics captured for each participant are shown in Figure 25.

Daily Environment	Continuous Truck	Derived Daily Vehicle
• High Temperature • Low Temperature • Average Wind Speed • Cumulative Precipitation	• Miles Driven • Speed • Battery State of Charge • Energy Recovery	• Deliveries per Day • Charging Rate • Consumption • Truck Activity • Energy In per Day • Energy Out per Day

Figure 25. Vehicle parameters reported

Due to the variety of charging systems encountered in RoL-E, no performance data was collected from the chargers themselves. NACFE also investigated charger efficiencies but had limited on-site data. Getting power from the grid and transferring it to the vehicle via the charger introduces some losses due to heating and other inefficiencies. Efficiency losses are very dependent on material choices, individual charger designs, and other factors. Charging system designs tend to follow the adage "you get what you pay for" meaning that the more expensive the charging system, the better the efficiency and the lower the losses of energy in going from the grid to the vehicle. NACFE found that efficiencies were in the range of 80% to 95% for the variety of charging systems encountered in RoL-E. For example, an 80% efficient 20 kW charger then only delivers 16 kW to the vehicle. A 90% efficient 125 kW charger only delivers 112.5 kW to the vehicle.

RUN ON LESS ELECTRIC

Lesson Learned

The energy draw from the grid to the charger is going to be more than what the vehicle is receiving. Charger efficiency is important in estimating total energy demand.

Charging values reported by the vehicle also require understanding where on the vehicle the measurements actually are being taken. The point of measurement can vary between manufacturers and between models. There are losses between the point of connection to the charger and the location in the vehicle where the charging value is being monitored. NACFE found that Geotab is aware of this and can estimate a value for the losses between the plug and the point of measurement in the vehicle when reporting the charging level. For RoL-E, only the measured values were used.

RUN ON LESS ELECTRIC

Lesson Learned

Validate what is actual measured data and where in the vehicle it is measured. Identify where derived data is being reported and clarify what assumptions are built into those derivations.

The sampling rate of data is important in analyzing vehicle performance. In 2019's Run on Less Regional, NACFE partnered with both Geotab and the Department of Energy (DOE) National Renewable Energy Laboratory (NREL) to collect data on the 10 vehicles. NREL installed data loggers on each vehicle to record performance, summarizing for NACFE the data every second — what is termed 1 Hz data. What this means is that the performance of every monitored metric is recorded nearly continuously and recorded along with the position of the vehicle through GPS data. In Run on Less Regional, that created more than 7.2 million seconds of data, or well in excess of 1,800,000,000 data points! Geotab's system tries to minimize that data where possible so the cost and complexity of handling that data is reduced. For example, if a vehicle is traveling at a constant speed over a defined flat stretch of highway, every second of data may not be all that important. Sampling the data less frequently does not significantly introduce errors for most data users. Reducing the sampling rate allows for smaller data storage and less demanding data transfer between the vehicle and the database. That also reduces the costs of collecting and analyzing the data.

The challenge with working with third party data aggregators like Geotab is that the way all that data collection is done, simplified and reported is part of the proprietary knowledge of the company — in essence, the secret sauce. End users of the data may not be able to discern easily what is truly measured directly from the vehicle data bus or what has been derived from that data and what assumptions and simplifications have been built into the consolidated data they receive. For the majority of fleet data users, these details are not significant, and companies like Geotab have made significant investments to assure the accuracy of the data they are reporting. However, engineers and scientists may find this level of data insufficient to properly analyze duty cycles. For those instances, 1 Hz or better data loggers are required. Truck developers and even some fleets often use data loggers like those NACFE and NREL employed in Run on Less Regional. However, for RoL-E, data loggers were not an option due to the immature nature of battery electric trucks and the unwillingness of OEMs to share that level of detail with NACFE for these early production designs.

RUN ON LESS ELECTRIC

Lesson Learned

Determine what sampling rate you can afford and determine if it is sufficiently accurate for your purposes.

For RoL-E, NACFE determined that Geotab data was sufficiently accurate for the objectives of the demonstration.

8.1 Weather Data

Vehicle performance always is in context of the operational environment. For RoL-E NACFE pursued regions with diverse weather conditions. The three-week nature of the RoL-E demonstration limits the ability to observe a broad range of weather conditions, but the RoL-E fleets are using these vehicles year-round. NACFE conducted site visits and interviewed 91 people as part of RoL-E and discussed seasonal experience and expectations. A summary of these fleet's thoughts on weather sensitivity can be found in the RoL-E Stories from the Road video [Temperature](#) [64].

The local weather data for each day and fleet location were obtained via an Application Programming Interface (API) from OpenWeather [69]. For simplicity, since most trucks didn't go that far, NACFE collected weather information for the base location, not the truck's rolling location.

An example of the weather data reported for one day of a RoL-E vehicle is shown in Figure 26.

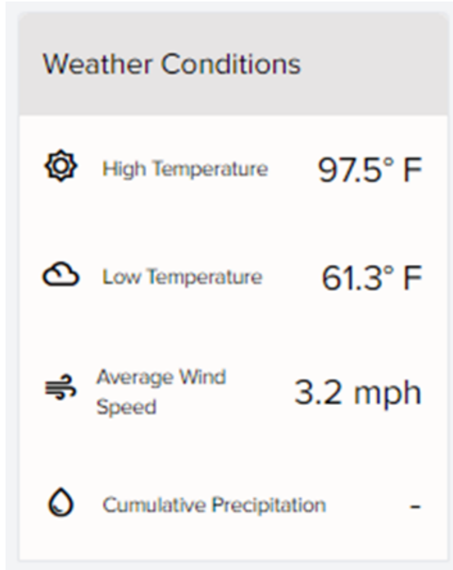


Figure 26. Weather data example

Lesson Learned

Weather conditions at the vehicle at all times requires higher resolution sensors and equipment not installed on today's vehicles. While external temperatures may be available on vehicle data buses, wind, rain, ice, fog, etc. conditions are not captured by the vehicle and can only be inferred from more regional data.

8.2 Continuous Truck Data

The RoL-E vehicles produce a large amount of data. The protocols for CBEVs are evolving. To some extent, each manufacturer is adapting new protocols from its experience with diesels, but standardization still is some way off in the future. NACFE and Geotab engineers worked with each of the manufacturers to interface with their vehicles to obtain the continuous data needed for RoL-E. The Geotab system connects via a single harness to the vehicle's data buses and samples the data as determined by Geotab using the Geotab device.

8.2.1 Geotab GO Device

The gateway between the vehicle and the database is the Geotab GO device shown in Figure 27 [65]. For diesels, this unit normally plugs into the standard diagnostic port located in the vehicle dash. For CBEVs, a custom cable also may be needed to connect to the appropriate data bus on the vehicle. The GO device includes GPS telemetry tracking for the vehicle.

8.2.2 GPS Position Data

NACFE in consultation with the RoL-E fleets chose not to publish GPS tracking data of the vehicles in their operations to protect their proprietary business information. Delivery routes, specific customers, and delivery times would have been found easily through the GPS data. While NACFE did not publish the GPS information, it was continuously collected by Geotab along with the other operational data. Geotab has extensive background information on how its systems work. The accuracy of the GPS data with respect to location and speed is discussed in some detail on its website [66][67][68].

Figure 27. Geotab GO Device (Geotab)

RUN ON LESS ELECTRIC

Lesson Learned

The trucking industry could benefit from standardizing CBEV data buses and interfaces.

8.2.3 Miles Driven

Distance driven can be determined from either the vehicle odometer data or through continuously evaluating GPS position. Geotab recommended using GPS position to determine miles traveled for RoL-E because some of the vehicles in RoL-E did not provide access to the odometer data.

NACFE reported distance traveled on the RoL-E metrics dashboard. First, total miles for the day were tabulated and reported as a number, then distances were graphed versus time along with battery state of charge (SOC). See an example in Figure 28. Distance is the right-hand axis of the graph. The staircase nature of the SOC graph illustrates different rates of energy use, with steeper parts of the curve representing higher rates of expending energy.

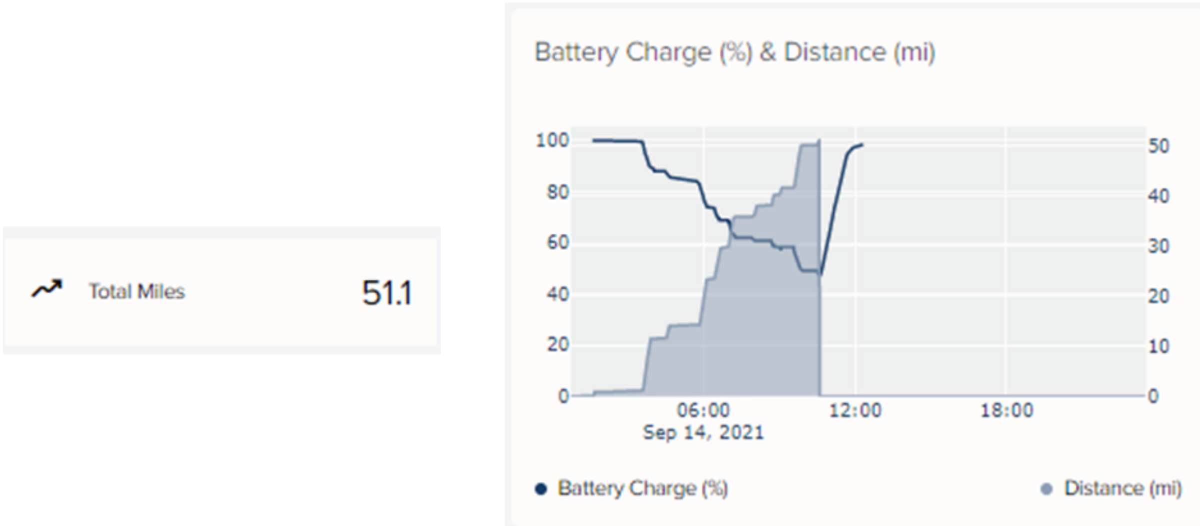


Figure 28. Distance and SOC data example

8.2.4 Speed

Speed values can come from either the vehicle speedometer data or through evaluating GPS position. Geotab recommended using GPS position to determine speeds for RoL-E. Geotab discusses speed accuracy via its GPS data analysis: "With a clear view of the sky, GPS speed has shown to be more accurate than most vehicle speedometers."

"GPS isn't perfect, but it's a lot more accurate than a vehicle speedometer," said Richard Langley, professor of geodesy and precision navigation at the University of New Brunswick, in an article for the *Canadian Globe and Mail*. "GPS accuracy, however, may vary slightly as the vehicle travels from regions with a good view of the sky to those without. Heavily tree-lined streets and urban canyons are the biggest culprits when it comes to GPS inaccuracy, in addition to tunnels and covered parking lots [66]."

NACFE reported speeds on the RoL-E metrics dashboard. First, speeds along with SOC were graphed versus time, and then speed was categorized as percent distance in speed bands. See the example in Figure 29. Speed is the right-hand axis of the graph, and the multiple spikes represent the truck reaching speed and then stopping.

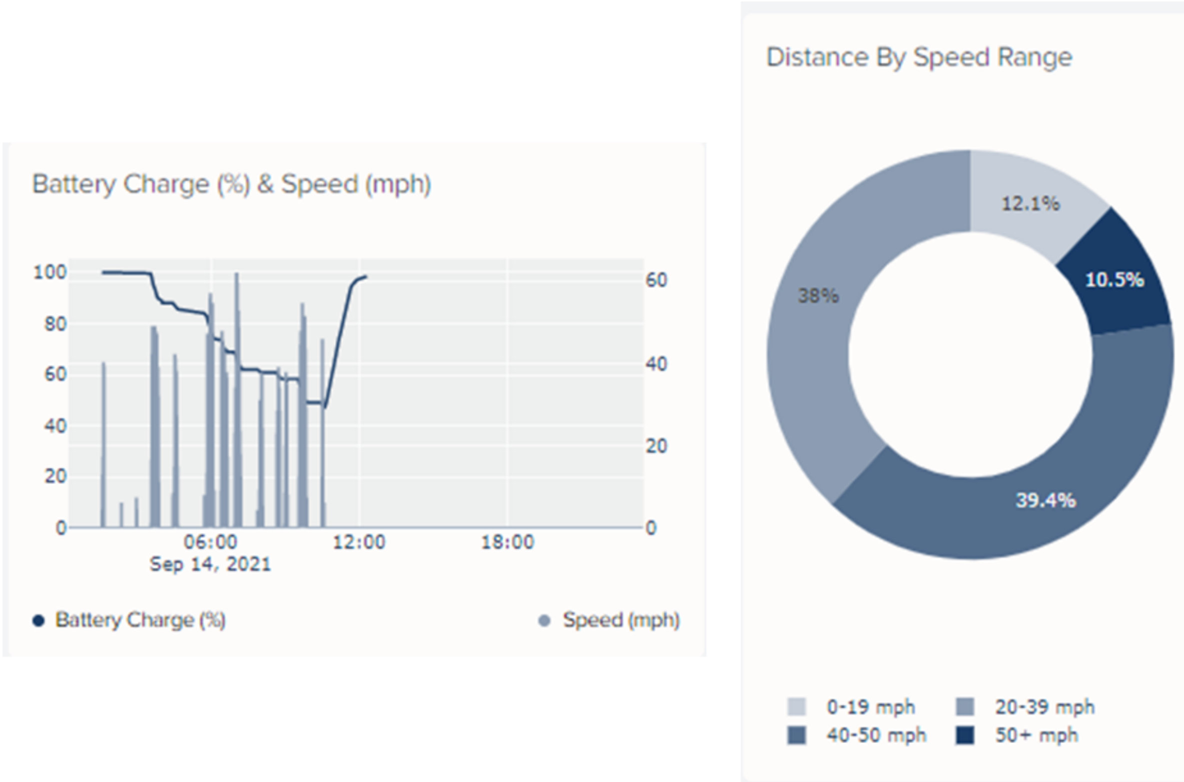


Figure 29. Speed data example

8.2.5 Battery State of Charge (SOC)

A diesel vehicle has a fuel tank. Instruments in the tank measure the level of fuel remaining and report that to the fuel gauge in the dashboard and on the CAN data bus of the vehicle. Those instruments have precision and accuracy tolerances, and even the way the vehicle is sitting on the road can change the level of the fuel in a tank if it is not on a perfectly flat surface. Also, drivers don't really know what is meant by "Full" and "Empty" on the gauges because each manufacturer has built in margins at both ends of the scale. For example, when the gauge is pointing at E, the vehicle still has some amount of fuel left, and when the gauge needle is pointing at F, drivers often notice they can drive some distance before the needle moves.

SOC is like the diesel fuel gauge. It is just as problematic and challenging. Battery SOC for RoL-E is a measurement made by the vehicle by continuously monitoring voltage, amperage, and amp hours remaining after fully charging — essentially counting the amp-hours expended over time and subtracting it from the full charge state. These values can have variability due to instrument precision and accuracy, and the way 100% charged is defined for the specific battery system. Current and voltage may be measured at the battery or at the inverter, and those numbers also may differ. For consistency, Geotab data for RoL-E estimated SOC at the vehicle manufacturer's point of measurement and reported on the CAN data bus monitoring voltage and current.

Each manufacturer may interpret SOC differently. The batteries have an absolute capacity value at the time they are charged. This value may change over the life of the battery with repeated charging events.

The manufacturer also may choose to make portions of the battery inaccessible to the vehicle operator to protect the battery from harsh conditions that might alter the product life. For example, manufacturers may not allow use of the battery pack below 15% or 20% to prevent "deep cycling" from damaging the life of the battery. Similarly, they may not permit use of the battery beyond 90% of the maximum capacity to prevent overheating during charging from damaging the battery pack life. NACFE detailed the reasons for the differences between absolute capacity and operational capacity in its *Guidance Report: Medium-Duty Electric Trucks Cost of Ownership* [6].

One of the RoL-E fleet managers noted that it would help if all the SOC gauges were standardized and reported only the amount of battery accessible by the driver. Essentially "Full" and "Empty" mean different things in every different vehicle model. The fleet manager felt that drivers need to be able to get into different vehicles and not be confused by different SOC gauge values.

Lesson Learned

SOC readings should be standardized across the industry so that any driver can get into any truck and know the gauge reading means the same thing.

RoL-E showed battery SOC versus time in two graphs, one an overlay with speed and the other an overlay with distance as shown in Figure 30.

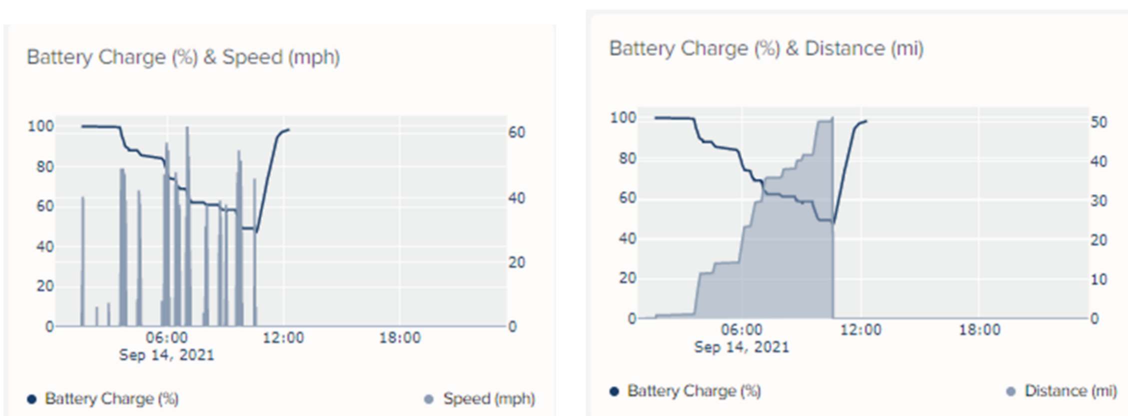


Figure 30. Battery SOC vs. Time example

Lesson Learned

Early adopters of CBEVs may choose duty cycles that reduce risks from range anxiety, keeping battery use above 50% SOC each shift. As drivers and fleet managers gain confidence in CBEV technology, more demanding duty cycles will evolve.

Opportunity charging, charging midway during a work shift in between driving, for example over lunch breaks, can extend the daily range of a battery electric truck. RoL-E saw opportunity charging successfully used by terminal tractors and one of the Class 8 regional fleets used it to extend range in one experiment during RoL-E.

Lesson Learned

Regenerative braking can reduce demands for grid energy or conversely help in range extension depending on the duty cycle.

8.2.6 Energy Recovery

Battery electric vehicles generally can recover energy by using the drive motors to slow the vehicles. This is called regenerative braking; essentially the motors rather than using energy are acting as generators and putting energy back into the batteries. The amount of regenerative braking energy recovery is reported by the vehicle on the data bus. OEMs and fleets may have the ability through software to adjust or tune the level of regenerative braking experienced by each driver and vehicle as they gain experience and confidence in operating with regenerative braking. An example of the daily energy split between charging and regenerative energy recovery with respect to total energy into the battery is shown in Figure 31where regeneration accounted for about 22% of the battery total energy in.

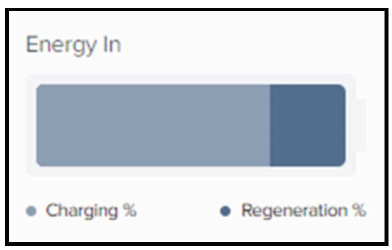


Figure 31. Regeneration vs. Charging example

Lesson Learned

Regenerative braking can reduce demands for grid energy or conversely help in range extension depending on the duty cycle.

8.3 Derived Daily Vehicle Data

RoL-E provided both measured data and derived data. Derived data makes use of measured data in combination with some level of interpretation to arrive at an estimate for a new metric.

8.3.1 Deliveries per Day

Deliveries, the act of stopping the vehicle and unloading (or loading), are metrics NACFE wanted to capture for RoL-E. There are no vehicle-based systems that specifically highlight a delivery instance. Deliveries also have different parameters when looking at a terminal tractor versus a box truck due to the differences in what constitutes a delivery.

NACFE developed two different algorithms depending on truck type to identify a delivery event from telemetry data.

For non-terminal tractors, deliveries were when there was a key-off event at least 2 miles (straight line distance) from the home terminal and the truck hadn't had a key-off event in the previous 0.2 miles. The 2-mile range was to permit on-site operations such as loading to occur since some of the facilities have large sites and vehicles travel inside the fence. The 0.2 miles is because occasionally the truck would stop in the parking lot of a delivery site before going to the dock to unload. The 0.2-mile range avoided double counting a delivery at a site.

For terminal tractors, NACFE looked for quick (within 90 seconds) back and forth movements that indicated a trailer drop or hook followed by another similar back and forth at least 60 seconds after the previous one. Two of those movements were counted as a delivery (i.e., one hook and one drop).

Deliveries were then summarized per day and posted to the RoL-E metrics dashboard.

RUN ON LESS ELECTRIC

Lesson Learned

Vehicle telemetry data does not describe why a vehicle performed a maneuver. Adding in forward looking video to record events could help audit and confirm delivery events.

8.3.2 Charging Rate

For RoL-E, NACFE describes the charging rate as how fast and at what power level. Charging rate was determined from vehicle data bus signals using SOC over time when plugged into the charger. The vehicle data bus continuously reports voltage, amperage, and can integrate that over time to provide SOC.

The fundamental measure is the power level (kW) over time which equals the energy level (kWh). A 100-kWh battery pack depleted to 50% SOC during the work shift requires 50 kWh of energy to return to 100% SOC. Charging that battery can be done slowly, for example at 5 kW over 10 hours equating to 50 kWh. Or it can be done quickly, for example 50 kW in one hour again equating to 50 kWh. Faster charging depends on the design of the vehicle as to how quickly the batteries can physically charge—limitations on the harnesses, connectors, batteries and other components may constrain the maximum power that can be applied to the vehicle.

RUN ON LESS ELECTRIC

Lesson Learned

A vehicle designed for a maximum power of 150 kW cannot charge at 350 kW level without risking damage. Extreme fast charging at 1 MW requires not only a charger capable of that power level, but also the vehicle must have been designed to accept that power level.

The nature of charging is that batteries absorb energy at different rates depending on how fully charged they are. The SOC of the battery typically changes more slowly the closer it is to being fully charged. Manufacturers often discuss charge times to 80% of full charge because charging speeds are typically fastest up to that SOC level, then the chemistry and materials of the battery start to slow the rate of charge as more electricity becomes heat rather than battery charge. In some batteries, the last 10% to 20% charging can take as long as the first 80% to 90%.

Lesson Learned

Standards for reporting EV vehicle specifications need to be established to provide uniformity in reporting charge times, battery SOC levels, consumption kWh/mi baseline conditions, etc.

Geotab provided the battery SOC over time. This was then graphed per day of data collection as shown in the example in Figure 32. The battery SOC is the left-hand axis of the graph. The SOC charge is seen to start decreasing after about 4 a.m. as the driver takes the vehicle out on deliveries. SOC falls to about 50% around 11 a.m. when the driver returns to the depot and plugs the charger into the vehicle. The battery then charges fairly quickly in this example reaching full charge in about an hour. In this example, the truck has a 155-kWh battery pack, so 50% SOC equates to approximately 77 kWh. Recharging this in one hour equates to a charge rate of 77 kW per hour. Also note that the curve at the very end of the charging period showing that the speed of restoring the battery to full SOC slows down near the end of the charging cycle.

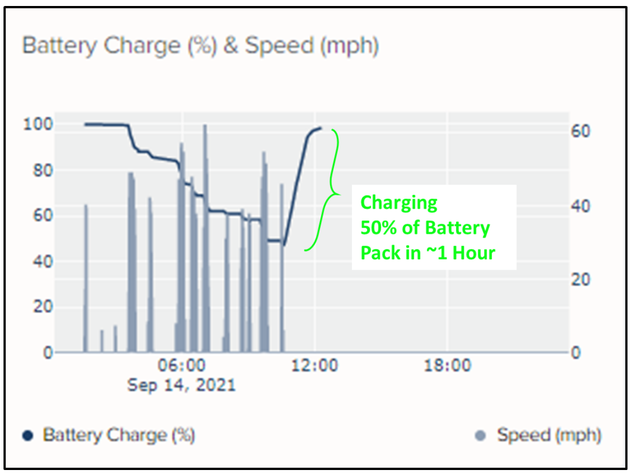


Figure 32. Charging rate example

8.3.3 Consumption

Consumption is the inverse of efficiency. Diesel-powered vehicles report fuel efficiency as miles traveled per gallon of fuel expended. Consumption for them is then gallons of fuel expended per mile traveled. In battery electric vehicles, the metric often reported is kilowatt hours expended per mile or kWh/mi. This is not efficiency but rather consumption.

NACFE did not directly report consumption through the RoL-E metrics dashboard, but it was feasible to estimate it from the data that was provided based on the specifications of the vehicles, the miles traveled per day and the SOC data. NACFE found that there are multiple ways to measure consumption and they may differ in values. An example of a daily data tabulation for one vehicle is shown in Figure 33.

Day	Distance (mi)	Charge (kWh)	Moving Power Consumed (kWh)	Regen Power (kWh)	Idling Power Consumed (kWh)	Net Power Consumed (kWh)	Net Power Consumed Consumption (kWh/mi)
1	47.9	68.1	84.9	18.7	7.3	73.5	1.5
2	48.1	68.7	84.5	17.9	3.3	69.9	1.5
3	35.5	46.9	58.8	12.9	4.4	50.3	1.4
●	●	●	●	●	●	●	●
●	●	●	●	●	●	●	●
●	●	●	●	●	●	●	●
●	●	●	●	●	●	●	●
25	51.5	63.2	88.7	21.4	4.7	72.05	1.4
Net	750.1	1021.2	1290.6	294.7	102.5	1098.4	
Charging Consumption (kWh/mi)	1.4					Average Consumed Consumption (kWh/mi)	1.5

Figure 33. Example RoL-E CBEV daily data tabulation

The Excel spreadsheet in Figure 33 has very few calculations. The Net Power Consumed column is a calculation adding the Moving Power Consumed to the Idling Power Consumed and subtracting the power recovered by Regen. Charging Consumption is the Net Charge divided by the Net Miles for the whole period. Average Consumed Consumption is just averaging each of the daily consumption values from the energy consumed. Note that NACFE had the opportunity to capture 25 days of data, a week beyond the end of the official RoL-E demonstration.

The four methods NACFE identified for evaluating consumption are described below:

- **Daily Charge Method** – This method counts how many kWh are charged each day then divides that by the numbers of miles traveled that day. These daily kWh/mi values can then be averaged over a period of time.
- **Net Charge Method** – This method counts the total kWh charged over multiple days then divides by the sum of all the miles driven over those days.
- **Daily Consumed Method** – This method subtracts the kWh expended driving and idling from the daily measure of charging then divides by the miles driven for that day. Multiple days of consumption metrics can then be averaged.
- **Net Consumed Method** – This method totals all the reported daily driving and idling kWh and subtracts it from the total of daily charging kWh, then divides that by the total sum of driving miles for the period of interest.

NACFE expects that third parties are very likely to estimate the consumption values from the RoL-E data. NACFE chooses to provide estimated consumption for the RoL-E vehicles to preclude errors by third party analysts. NACFE believes that fleets, OEMs and others will benefit from this snapshot in time of consumption for these RoL-E early production vehicles. The values are tabulated and averaged for each market segment in RoL-E in Figure 34 using two methods, the Net Charging method and the Net Consumed method.

Segment	Consumption Average of Net Charging (kWh/mi)	Consumption Average of Net Consumed (kWh/mi)
Class 6 Box	1.34	1.32
Class 8 Tractor	2.67	2.56
Class 3-6 Van	1.10	1.06
Class 8 Terminal tractor	1.90	2.88

Figure 34. RoL-E consumption estimate by market segment

RUN ON LESS ELECTRIC

Lesson Learned

Consumption and efficiency can be confusing metrics. Care should be taken to clarify how they are estimated.

8.3.4 Truck Activity

Truck activity was categorized into four parts

- Inactive
- Idling
- Charging
- Driving

A RoL-E example of Truck Activity is shown in Figure 35.

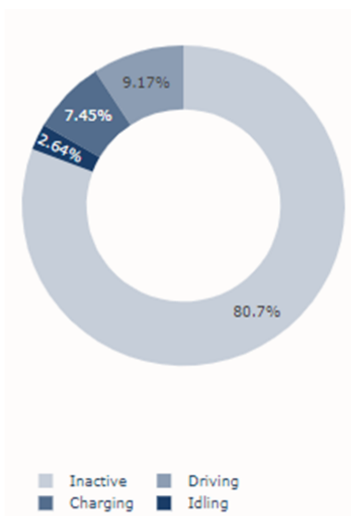


Figure 35. Truck activity example

8.3.4.1 Inactive Time

Inactive time is when the vehicle is not using any significant power, the key is off, and the CBEV is not charging. An example is shown in Figure 35 where Inactive is shown as 80.7% of the day.

8.3.4.2 Idling Time

The definition “idling” applied to a diesel-powered vehicle is fairly clear. The diesel engine is running but the vehicle is not moving. Idling with respect to a CBEV is somewhat more challenging. Idling for a diesel means creating emissions, and idling is necessary to power many accessories like the HVAC systems. However, accessories like lights and radios often run directly off batteries in diesels and are not considered idling when used with the engine off. With a CBEV, idling does not have emissions and HVAC systems run from batteries just like radios and lights.

RUN ON LESS ELECTRIC

Lesson Learned

Terminology like idling used for diesels may not directly apply to CBEVs. Care should be taken to clarify terms between diesels and CBEVs.

NACFE concluded that a CBEV was idling if the vehicle was not charging, not moving and there was any significant power being expended for accessory loads like air conditioning.

Idling is determined from the Geotab data bus along with the other truck activity parameters. “Not moving” also needs a time span. If the truck was not moving at a traffic light, it was not considered to be idling. Stops greater than 180 seconds were interpreted as idling. Figure 35 illustrates partitioning a day of truck activity for one example RoL-E vehicle, where Idling is shown as 2.64% of day.

8.3.4.3 Charging Time

Charging time is when the vehicle is plugged into the charger, not moving and may or may not have accessories operating. To put this in a diesel perspective, that third state would be idling at a fuel stop while pumping fuel into the tank, a procedure that is not advised with liquid fueling. An example of CBEV charge time is shown in Figure 35 where Charging is shown as 7.45% of day.

8.3.4.4 Driving Time

Driving time is when the vehicle has velocity greater than zero. It also includes non-moving time at traffic stops shorter than 180 seconds. An example is shown in Figure 35 where Driving is shown as 9.17% of day.

8.3.5 Energy-In per Day

The battery on an electric vehicle is continuously changing its SOC value based on the amount of energy that is going out and the amount of energy coming in. This can be occurring at the same time, for example, a CBEV exiting from an Interstate engages regenerative braking by removing pressure on the accelerator pedal to slow the vehicle. The vehicle has its required exterior lights turned on and the driver is using the HVAC system. At that moment the batteries are seeing electricity being supplied by the motors in regeneration mode and also seeing loads from the accessories. The management of energy on board the vehicle is having to monitor a range of interacting factors over the course of the day. The only sure values known are the SOC at the start of the day before the vehicle is in use and the SOC at the end of the shift before the vehicle is plugged into the charger. Everything in between involves some level of estimation.

The diesel truck corollary to this complexity would be if you could add extra fuel from a spare fuel can to the fuel tanks while driving down the road. It gets more complicated in that regenerative braking only works well at certain deceleration rates and not at others. Slamming on brakes in an emergency stop situation likely will not recover any energy. Additionally, if the batteries are near capacity, like at the start of a shift, regenerative braking has nowhere to put the recovered energy, so the friction brakes turn it to heat which dissipates to the environment.

Geotab engineers arrived at a method for estimating how much energy was recovered through regeneration versus how much was supplied through charging over the course of a day's operation. The graphic in Figure 36 illustrates an example of this split in energy sources.

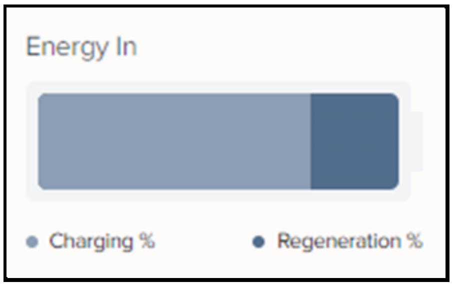


Figure 36. Energy-In example

8.3.6 Energy-Out per Day

Similar to Energy-In, there is complexity in estimating where the energy is allocated during a day of operation. The graphic in Figure 37 shows an example of the split between driving and idling.

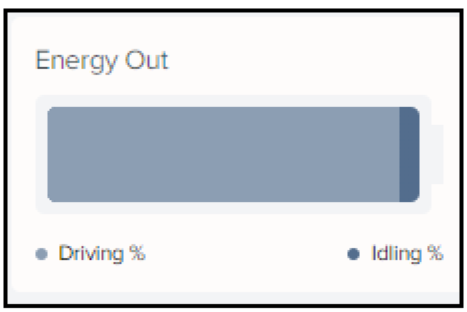


Figure 37. Energy Out example

9 The Drivers

NACFE Run on Less demonstrations to date have relied extensively on the willing participation of drivers. During three RoL demonstrations, NACFE has engaged with 31 real-world drivers performing their duties. Their insights and firsthand experiences have been crucial to documenting the effectiveness of the technologies being demonstrated. These drivers volunteer for the added complexity of being interviewed, photographed, filmed and their every working minute tracked for three weeks. Some of these drivers go on to have roles as industry influencers through social media, are invited to speak on panels, are interviewed by industry media, and are invited to other events. In November 2021, the Department of Energy asked NACFE to recommend a driver to participate in an announcement at John F. Kennedy Airport in New York. The announcement concerned the DOE's SuperTruck 3 contract awards. In attendance were Vice President Kamala Harris and DOE Secretary Jennifer Granholm. Biagi Brothers RoL-E driver Pat Brandon accepted the invitation and made national news [70][71]. Pictures from the DOE announcement event are shown in Figure 38.

Figure 38. Biagi Brothers RoL-E driver Pat Brandon at DOE SuperTruck 3 Announcement

Fleets chose their own routes and drivers for RoL-E. NACFE required that the drivers be available for the duration of the demonstration, available ahead of time for interviews, photographs and filming, and potentially available for the RoL-E finale event. NACFE decided early in the planning that having all the vehicles and drivers at a finale event would not be feasible after consulting with the fleets, in part due to travel restrictions such as the closed border with Canada and unknowns regarding evolving corporate policies with respect to COVID.

The RoL-E drivers are a diverse group with a variety of experience levels, ethnicities, ages and genders as shown in Figure 39. Along with the drivers, NACFE interviewed fleet managers, sustainability managers, operations managers, and executives from the fleets. Additionally, NACFE invited the local utilities, regulators, charging system providers, and other groups to be interviewed during site visits to all 13 locations. In total, 91 interviews were conducted contributing segments to more than 30 production videos released by NACFE over the course of demonstration.

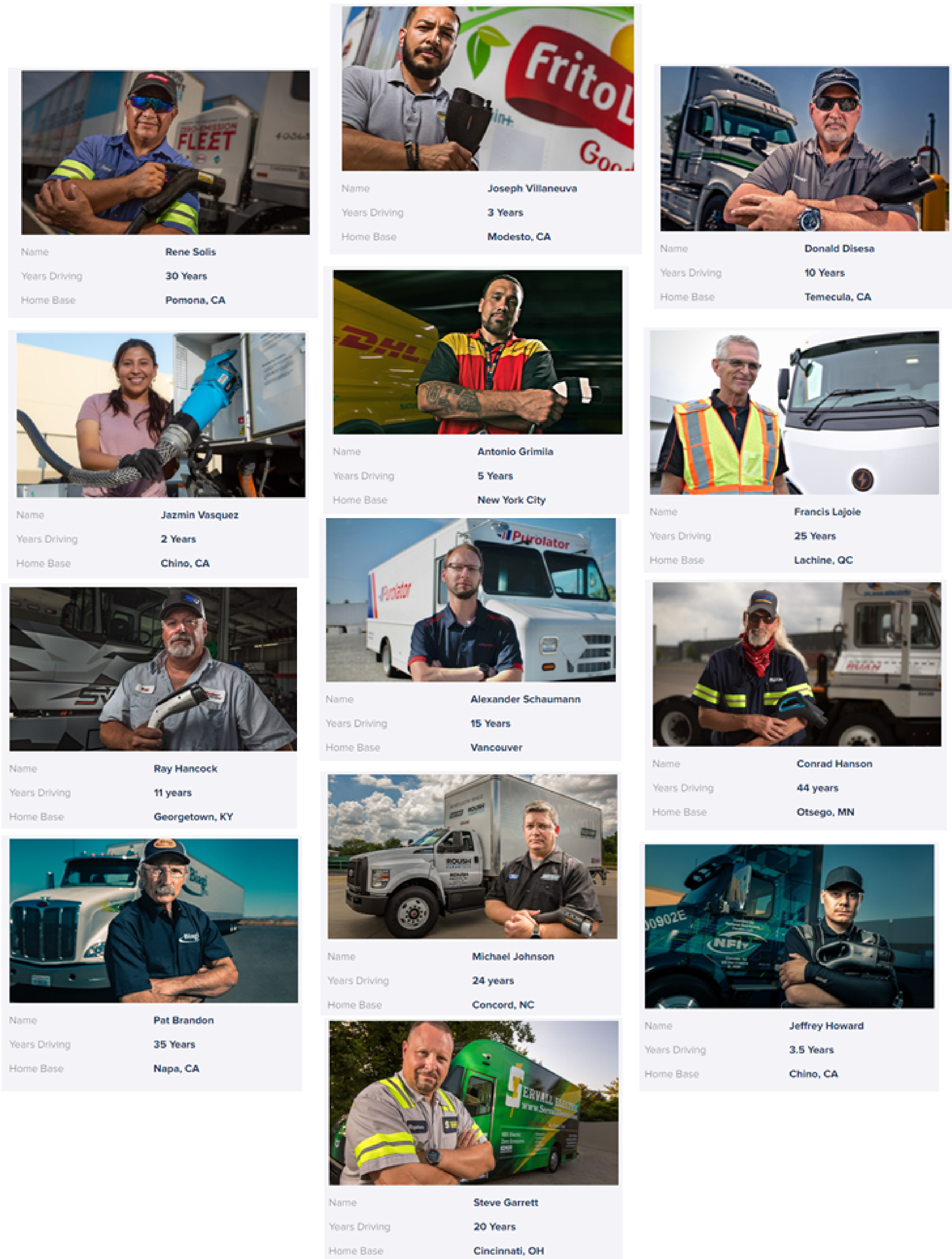


Figure 39. RoL-E drivers

Drivers universally stated the electric vehicles were better driving experiences versus diesels. There were several factors contributing to this conclusion.

- **Low Interior Noise Levels** — Every driver commented on how quiet the electric vehicles were versus diesels. One indicator of this was that drivers could hear the in-cab radio at low volume levels. One experienced driver commented that many experienced drivers have poor hearing in their left ears because of the noise from cab mounted vertical exhausts.
- **Low Exterior Noise Levels** — Drivers commented that they were more aware of surrounding noises when driving the electric truck and they felt this contributed to better safety. They could better hear other vehicles, warning signals, sirens, traffic noises, etc. One driver also commented that the public noticed and appreciated how quiet his Class 8 vehicle was while driving through small towns with open air restaurants and busy pedestrian traffic. Drivers making early morning deliveries remarked that many have delivery windows timed so as not to annoy surrounding residential neighborhoods. The CBEVs are so quiet that these fleets might be able to make deliveries earlier in the day.
- **Better Acceleration** — Drivers with on-road duty cycles noted that the acceleration of the CBEVs was much better than the diesels allowing them to keep up with cars when traffic lights change. They felt the diesels tend to obstruct traffic starting out from traffic lights due to their slower acceleration which can anger other drivers. The terminal tractor drivers also felt the acceleration helped them with moving trailers more efficiently.
- **Simplicity** — Drivers felt the CBEVs were fundamentally simpler to operate. The one-pedal driving is a factor several discussed. Driving without worrying about shifting also was mentioned. While some CBEVs do have transmissions, they may have only a couple gears and the driver is oblivious to their operation. Charging is very simple with software monitoring and controlling "fueling" the vehicle and in many cases, notifying drivers about the charging via smart phone application. In one case, both the driver and the fleet manager could monitor the charging status of the truck via smart phones and would be notified if the vehicle was parked at a charger and not charging when it needed to be. Diesel trucks typically do not warn their fleet managers when they are low on fuel.
- **Easier Charging vs. Fueling** — Drivers did not have to deal with fluids like fuels, oils, or DEF. The drivers just get in the CBEV and drive. For most drivers, at the end of the shift, they quickly plug the vehicle into a charger and go home. There is no driver time spent fueling the CBEVs. With diesels, fueling typically requires driving to a fuel station, waiting in line, then fueling at either the start or end of a shift. One fleet in New York estimated this took at least 60 minutes for fueling a diesel truck, where with the CBEV, the driver just plugged in at night spending less than a minute of time plugging and unplugging the vehicle.
- **No Idling Emissions** — Drivers commented that the CBEVs did not have emissions when idling. No idle rules and five-minute idle shutdowns are not a factor for a CBEV. Drivers can run accessories like HVAC systems without dealing with emission regulations.
- **Depot Charging** — All 13 drivers charged their vehicles at their fleet's depots. None of the drivers had to go out of route to find commercial fueling stations. Those side trips eat into revenue miles.
- **No Smells** — Several drivers remarked the CBEVs did not have fumes or odors that permeate the cab or their clothing. There is no fuel spilling on clothes and boots.

- **Less Fatigue** — Nearly every RoL-E driver commented that they were less fatigued at the end of their shifts from driving the CBEV. Physically this is due to less effort driving, particularly braking. The lower ambient cab noise environment also contributes to less fatigue.
- **Novelty** — At least two of the older drivers commented that the CBEVs were so appealing a technology change that they might postpone retirement. Several of the younger drivers found many positives from driving more environmentally responsible vehicles, to being leading edge technology operators versus their peers, to self-worth from family and friends positive opinions about them driving CBEVs.
- **Positive Brand Image** — On a company level, the drivers felt operating CBEVs was a positive boost for their company's brand image, demonstrating a commitment to improved technologies, a commitment to improving the work environment of employees and a commitment to improving the environment.

RUN ON LESS ELECTRIC

Lesson Learned

Given the ease of operation, drivers of CBEVs want the technology to succeed.

10 Charging Cycles

Charging for the RoL-E vans and step vans, box trucks and regional haul heavy-duty trucks was based on one-shift operations with return-to-base (RTB) operational duty cycles where the vehicles would charge while parked at their base facilities, usually overnight. These vehicles have long dwell times with 8 to 14 hours between shifts during which they can recharge from the prior shift. Figure 40 shows SOC over a three-day period for one of the Class 8 RoL-E trucks. In this example, the truck actually operated two days without a charging event and ran the battery all the way to zero SOC traveling 150 miles before fully recharging overnight.

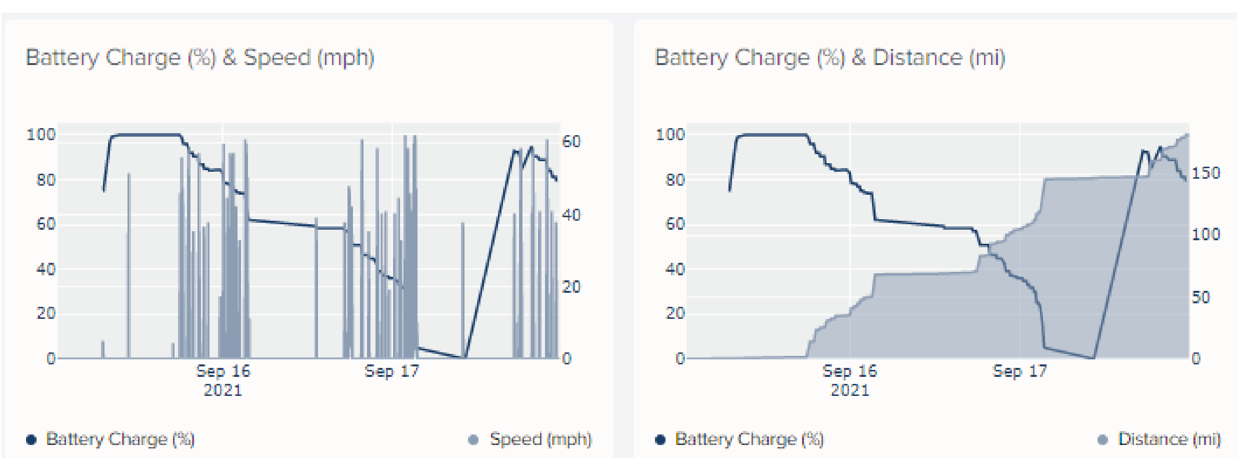


Figure 40. Example Class 8 RoL-E SOC history over three-day period

Terminal tractors have different duty cycle demands, often needing to operate for multiple shifts in a day and may use opportunity charging to supplement overnight charging. Opportunity charging is simply making use of short stops such as lunch breaks to "top off" the battery by connecting it to the charger for as long as the break and charging at higher levels during those stops. Figure 41 illustrates the SOC of one of the terminal tractors over a two-day period. The battery charging appears as a saw tooth in the graph with multiple short charging events. The steepness of the charging events indicates higher rate charging power levels.

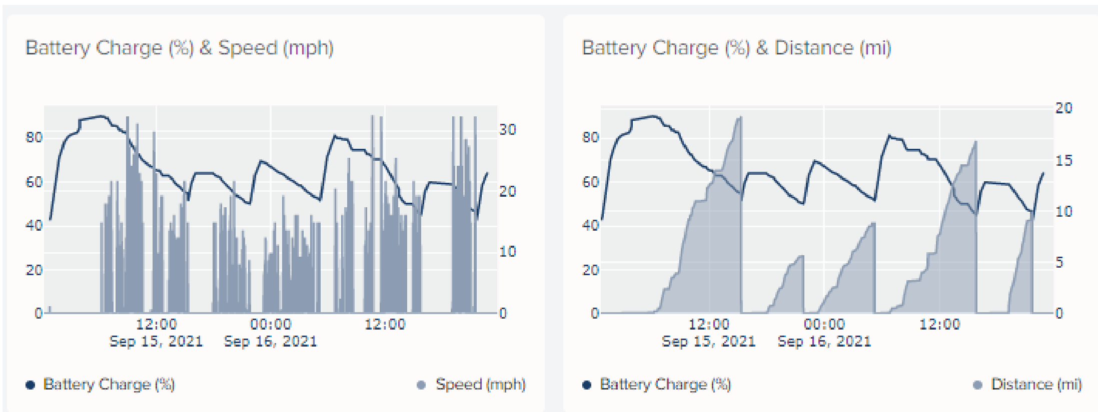


Figure 41. Example terminal tractor SOC over two-day period

RUN ON LESS ELECTRIC

Lesson Learned

Explicitly know your duty cycles, range requirements, dwell time, etc.

The depth of discharge during a shift determines how much charge is needed for the next day's operations for RTB charging. What this means is that charging events restore the battery to whatever the manufacturer defines as 100% SOC. For example, on day 1 the vehicle is driven such that the SOC is 60% at the end of the shift. This means the charger only has to recharge 40% overnight. The RoL-E trucks rarely fell below 50% SOC, meaning that overnight charging could be done at fairly low power levels. Low power levels also mean low-cost electricity rates are possible, and smaller capacity chargers are more than sufficient. Managing charging to use the lowest possible power levels is the key to minimizing electricity pricing.

NACFE has reported that the rated capacity of the battery packs may not be the physical maximum or minimum of the battery pack. Each OEM determines what "Full" and "Empty" means for its own vehicle design, if we adapt terms familiar to anyone using a traditional fuel gauge. The definitions are not standardized. The manufacturers build in safety factors to avoid damaging the battery packs at both ends of the SOC. The goal is to maintain the battery life expectancy by avoiding extremes of depletion or overheating. Those margins occur at both ends of the scale, so 'Full" and "Empty" means different things to different vehicles.

The vehicles in RoL-E were fairly new, varying from a few months old to at most a year old. Another battery SOC factor is that batteries lose capacity as they go through their life. The RoL-E trucks have not yet seen any significant degradation in battery capacity. NACFE has found that OEMs plan to offer warranties of 5, 8 or 10 years for batteries depending on the type of battery and vehicle. This generally translates into a goal that the battery capacity will not diminish below 80% over that period.

For a deeper dive into these safety factors, see NACFE's two reports, *Electric Trucks – Where They Make Sense* and *Medium-Duty Electric Trucks Cost of Ownership* [1][6].

Feedback from some of the RoL-E drivers and fleet managers was the desire to standardize the SOC definitions and only show the battery capacity the driver has access to during operations. Stated more simply, "Empty" means when the battery SOC stops being accessible to the driver, and "Full" means the maximum SOC the driver has available.

A key NACFE finding in RoL-E is that the 13 fleet vehicles could charge at fairly low charging rates. An example highlights why. The Peterbilt Model 220 electric box truck is shown on the Peterbilt website as having a 141-kWh energy storage equating to a range estimate of 100 miles. There is a second option for a 282-kWh energy storage equating to an estimated 200-mile range [16]. If this 141-kWh truck drove until it had 60% SOC left, then it would be at 85 kWh SOC, needing to recharge 56 kWh overnight. If the truck has 12 hours in which to recharge, then 56/12 = 4.7 kW per hour. One of the RoL-E fleets was operating a small fleet of eight of these trucks. Their managed charging system was observed at one point to be charging each of these vehicles at between 5 to 6 kW per hour. The chargers were rated to 125 kW.

RUN ON LESS ELECTRIC

Lesson Learned

Choose battery capacity and charging based on those duty cycles with some safety factor to account for aging of the batteries.

A reason for the 125-kW charger was that it was used for both the box truck and electric terminal tractors at the facility. NACFE observed an electric terminal tractor charging at 105 kW when at 94% SOC. NACFE found that the facility had negotiated with the utility for electricity rates based on keeping all vehicle charging below a net cap value. The fleet of eight box trucks charging at a slow ~6 kW still permitted a terminal tractor to opportunity charge at ~105 kW and stay under the negotiated cap to avoid time-of-use premium charges for the electricity.

RUN ON LESS ELECTRIC

Lesson Learned

Use managed charging to minimize electricity demand and cost.

Another reason for installing the 125 kW chargers was to future proof the installation, knowing that the future might bring other uses and other vehicle demands on the charging system.

Lesson Learned

Have a system perspective on electrifying a facility. More than one type of electric vehicle can use the same charger and they may have completely different needs.

11 Regional Factors

Run on Less demonstrations have been timed to occur every two years in September. They are a snapshot over a three-week period of real-world operations by real-world fleets and drivers equipped with production vehicles. Weather during the 2017 RoL included two hurricanes, and everything tied to them over the southern and eastern states. RoL Regional in 2019 had very mild weather as did RoL-E.

Weather can have significant impacts on a diesel-powered vehicle's fuel economy. The difference between summer and winter driving for a diesel truck can exceed 1 MPG. There are many contributing factors for that including changes to the fuel for winter, increased use of idling to keep both driver and vehicle in good condition, worse performance of systems such as the emissions systems due to idling, etc.

CBEVs similarly tend to use more energy in high heat or extreme cold weather for similar reasons. The numbers vary by vehicle, duty cycle, climate and situation, but a 30% to 40% reduction in range during extreme winter conditions has been recorded in electric automobiles. Similarly, with heat waves exceeding 100°F, drivers have to use air conditioning, which uses battery energy. Some electric buses have gone so far as to equip the HVAC systems with small diesel-powered systems for those extreme weather conditions.

Mountains and road grades also demand more energy from the batteries, just as diesels use more fuel climbing hills. What is advantageous, is that CBEVs can recover energy on the downhill segments. Drayage operations out of the Ports of Los Angeles and Long Beach start or end their trips by crossing a 6% grade bridge, the Gerald Desmond Bridge [72]. See Figure 42. While the rest of the duty cycles are fairly flat terrain, the grade is significant enough that the prototype CBEVs operating there have been specifically designed for crossing the bridge. Recently the bridge was replaced with a parallel bridge with a slightly less demanding 5% grade.

Figure 42. Gerald Desmond Bridge (Port of Long Beach)

RoL-E fleets in Minnesota, Montreal, Cincinnati, Kentucky, New York City and the Southern California region told NACFE staff members that they all face extremes in temperatures over the course of an entire year. Fleets in some of these instances like in Minnesota and New York City had been operating CBEVs through the winters and saw no performance issues that impacted their duty cycles. Other fleets had not yet gone a full year with their CBEVs so did not have firsthand experience, but all universally expected the vehicles to be capable of getting their specific duty cycles completed in their climates. The Southern California and Modesto area sites saw extreme heat during the NACFE team's summer on-site visits with temperatures exceeding 100°F. Drivers and fleet managers reported no duty cycle limitations during these visits.

RUN ON LESS ELECTRIC

Lesson Learned

Fleets and OEMs need to specify CBEVs for four season operations and road grades and account for extremes, not just nominal conditions, in sizing battery packs. Both the drivers and the trucks need to be protected from extreme conditions and that places greater loads on the kWh needed.

12 Maintenance & Downtime

The three-week RoL-E demonstration was far too short to get any useful measured detail on maintenance. Site visits included talking with fleets about their experiences to date and their expectations. The RoL-E Stories from the Road video Maintenance & Uptime captures their comments [73].

There is long-term reliability data on electric automobiles and buses showing that once vehicles are in production, their maintenance costs and failure rates trend downward versus internal combustion vehicles. This universally was the expectation of fleets in RoL-E. A few fleets that had operated their vehicles prior to the RoL-E demonstration reported very high uptime and reliability. Fleets understand that this technology is new and there is some learning curve to be expected.

Maintenance cycles were expected to lengthen for wear items like brake systems where regenerative braking reduced the use of the wear items. Oil changes were largely no longer relevant. The significant failure modes tied to emission systems are not relevant to CBEVs.

The high voltage systems on these early production CBEVs must be serviced by experts typically from the leasing agencies or the OEM's service network. This meant that fleets did not require their own high voltage service expertise in house.

Over air software updates also appear very promising for reducing shop visits to correct software-related issues across a fleet.

NACFE's Roeth describes CBEVs as elegant solutions due to the significant reduction in friction producing moving parts versus a traditional diesel vehicle. Failure rate data on CBEVs is just starting to be collected, and nothing was available for NACFE to review for RoL-E.

TMC working with FleetNet America tracks and reports on the frequency of roadside repairs for Class 8 diesel-powered vehicles across three groups — Less-Than-Truckload (LTL), Tank, and Truckload (TL) Dry Van. Their first quarter 2021 report states, "Truckload carriers averaged 21,856 miles between breakdowns, a 13.1% decrease in miles from the previous quarter. The time between breakdowns for LTL carriers dropped 18.7% to 44,380 miles in the first quarter from 54,556 in the final quarter of 2020. The tank truck sector saw a slight improvement, running 17,420 miles in the first quarter, down from 19,905 in the previous quarter [74]."

The RoL-E vehicles over the 25 days that NACFE recorded data saw the lowest mileage in one delivery van in New York City totaling ~250 miles while a drayage Class 8 tractor in Southern California had ~2,300 miles. The probability of a roadside failure during RoL-E was small.

RUN ON LESS ELECTRIC

Lesson Learned

Measuring maintenance and downtime require a long-term project, on the scale of months or perhaps years to capture seasonal effects as well as sufficient mileage. Participation in programs like that from TMC and FleetNet America would benefit fleets tracking maintenance.

There were issues at the very start of RoL-E with some vehicles not connecting correctly to chargers or the Geotab devices, one vehicle had to be replaced at the last minute because it could not connect to a new type of charger that was just installed, and starting the demonstration on a holiday weekend was not well thought out as some drivers had planned vacation time. NACFE had tried to maintain a requirement for fleets and OEMs that all vehicles and chargers be operational by August 1, but had to decide between excluding a valuable participant, or working with them to get their vehicle into the program. In light of all the challenges that COVID and supply chain issues had thrown at the trucking industry, NACFE opted to work to the last possible minute with every fleet.

However, once those RoL-E data teething pains were quickly resolved, all 13 RoL-E vehicles operated on their duty cycles with no lost downtime and no maintenance activity.

13 Power & Utilities

NACFE set out to engage with the utilities providing power to the RoL-E fleets. Utilities were included in the RoL-E Bootcamp panels. NACFE research and site visits to the RoL-E fleets showed that in some high visibility California markets, utilities like Southern California Edison (SCE), Pacific Gas & Electric (PG&E), Modesto Irrigation District (MID), San Diego Gas & Electric (SDG&E), etc. are actively engaged with customers to facilitate CBEV adoption [75][76][77][78]. However, in other regions, the utilities are less engaged. In some cases, the fleets indicated that their utilities had showed no interest to date in their work with CBEVs.

NACFE's report *Amping Up: Charging Infrastructure for Electric Trucks* outlines how communication between all the vested parties is critical to successful deployment and operation. Figure 43 shows that the fleet's journey toward electrification starts with engaging the utility [7].

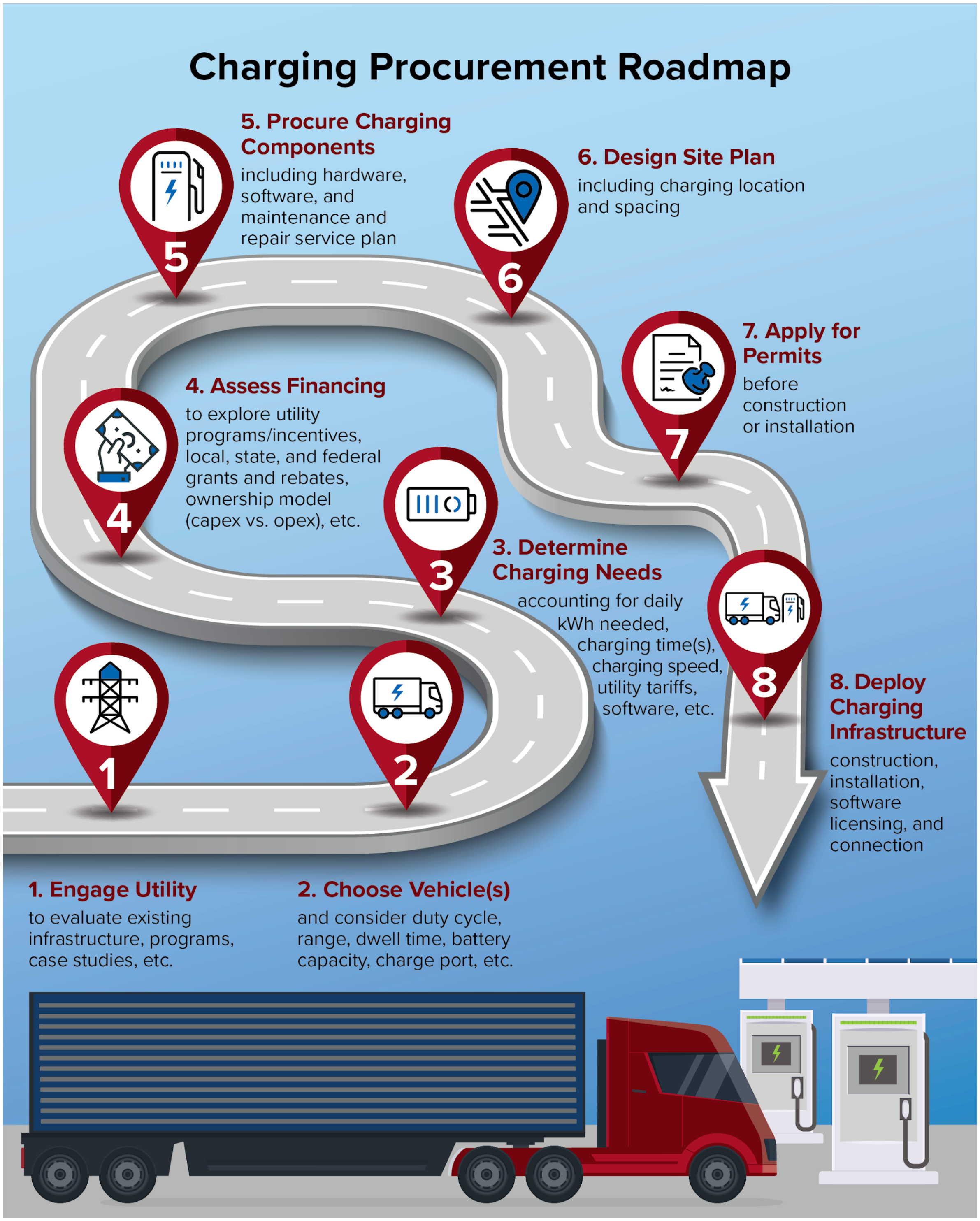


Figure 43. Path toward fleet electrification (NACFE)

A 2019 Smart Electric Power Alliance (SEPA) report identified only 38 US utility run managed-charging pilot and demonstration projects, where 26 were actively available to customers [79]. This is in a US market that has in excess of 3,300 electric utilities [7][80]. The NACFE/RMI report *High-Potential Regions for Electric Truck Deployments* highlights where the greatest opportunities are for the adoption of CBEVs

[81]. Factors contributing to higher priority are described in the Venn diagram in Figure 44. The high potential regions are shown in Figure 45.

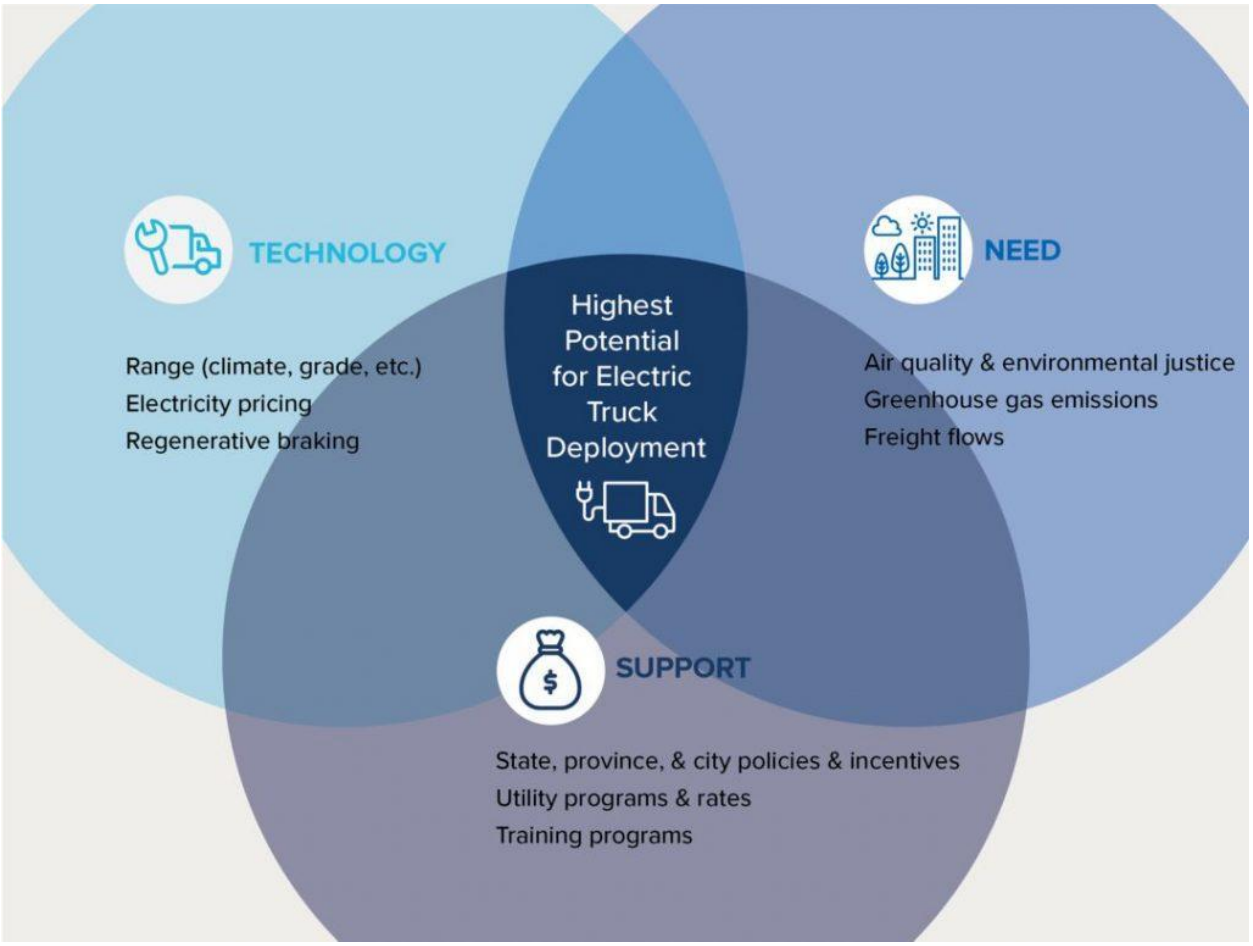


Figure 44. Factors evaluated for highest potential for electric truck deployment (NACFE/RMI) [81]

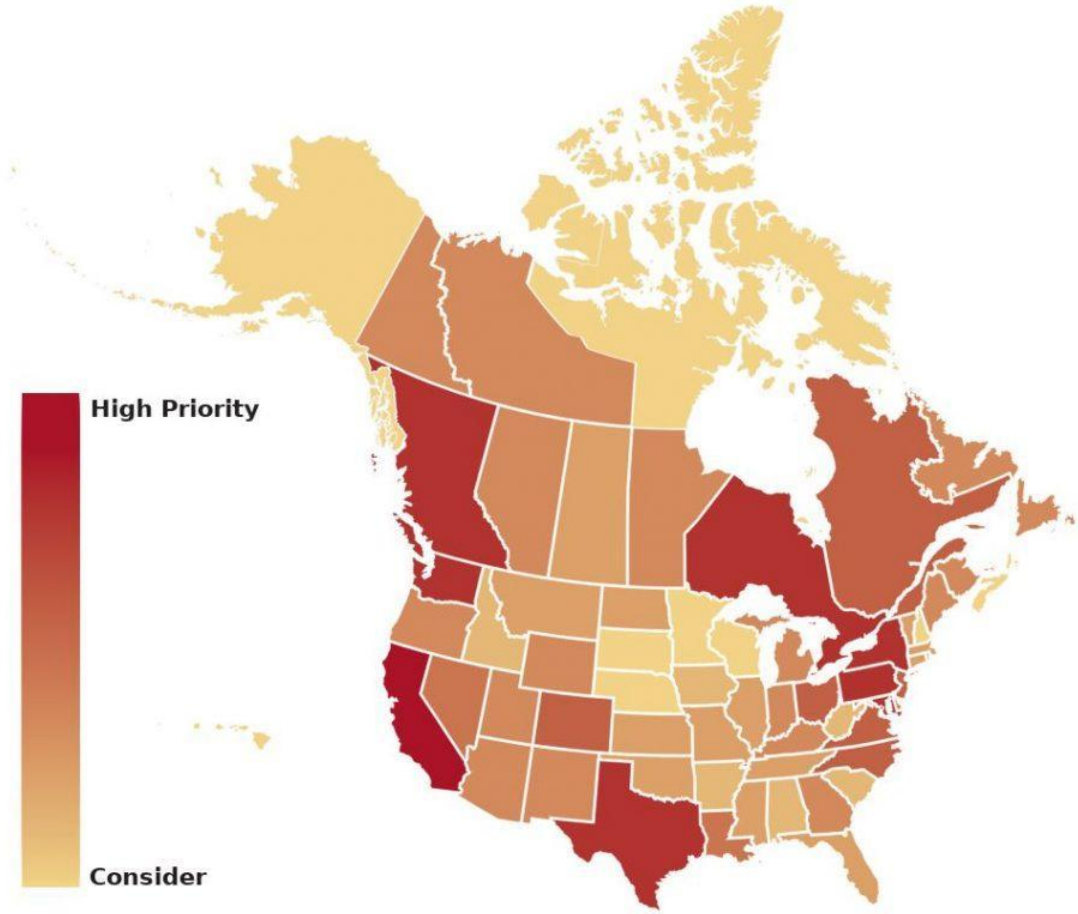


Figure 45. Electric truck deployment highest potential regions (NACFE/RMI) [81]

Clearly the utilities play a significant role in fleet electrification, but in many cases, they are not yet engaged with fleets. This is an industry challenge. The Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding (MOU) signed by 15 states and the District of Columbia in 2020 outlines a path to zero emission vehicles including facilitating utility engagement [82]. The enactment of Advanced Clean Truck rules in California and Oregon are the embodiment in regulation of the MOU [83][84]. This is in parallel with federal goals through the White House of increasing the adoption of zero emission light-, medium- and heavy-duty vehicles with targets for requiring manufacturers to produce growing percentages of zero emission vehicles over time [85].

Lesson Learned

Fleets may not always have a receptive contact at utilities with respect to electrifying their fleets. Sometimes they have to start the process without utility support.

Engaging a receptive utility opens up a number of alternatives for negotiating electricity pricing models. This is particularly true when taking a holistic view of all the facility's electricity needs, not just focusing on the CBEVs. Fleets also need to leverage the fact that their facilities represent value to the utilities as well. In one example, a utility providing power to a RoL-E fleet said that the utility has to ensure they have a margin for emergencies. This is very similar to the requirement that banks have some amount of cash on hand to deal with fluctuating demands. Facilities that have their own on-site power storage and generation also may represent power margin for utilities. Another example is that a fleet facility viewed as part of the utility system may represent an opportunity to manage loads for the utility. Fleets may be able to negotiate electricity price breaks in exchange for volunteering to be first on the list to have their power turned down or off in an emergency. In another example, a utility that has too much generation at certain parts of the day, may negotiate electricity price breaks to promote a fleet site using power at that time of day to help shed load. In parallel with this, there are Low Carbon Fuel Standard (LCFS) credits that essentially represent positive cash flow after purchasing an electric vehicle, and other types of incentives and funding opportunities to consider. There are a number of possible areas for negotiation on electricity pricing.

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Lesson Learned

There are a number of opportunities in the fleet-utility relationship to negotiate on net electricity pricing models.

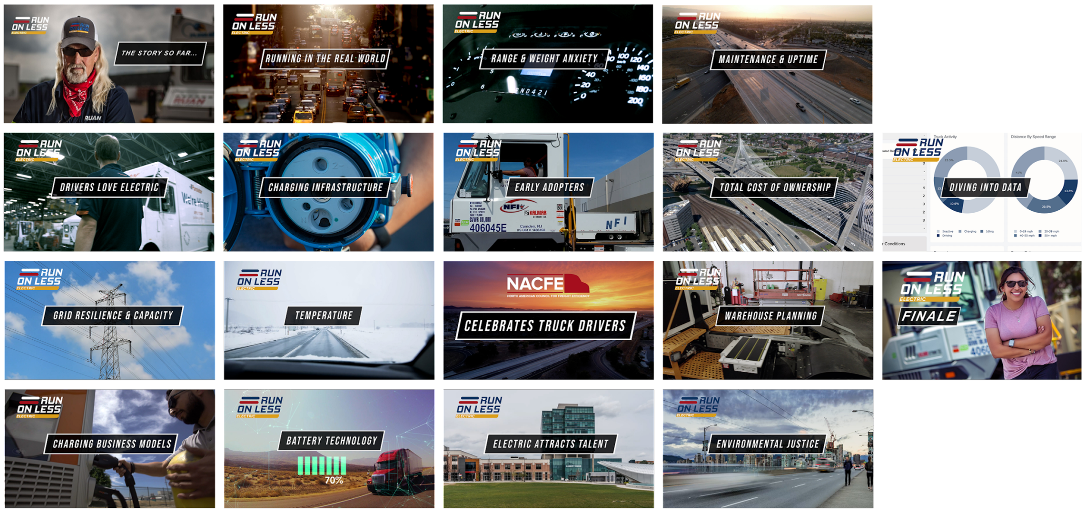
14 Videos – Stories from the Road

Communicating about RoL-E required using several different methods. A planned component of this communication effort was the creation of short topic-specific videos that could be issued daily via social media during the course of the RoL-E demonstration. These are described as “Stories from the Road.” Other videos also were needed to help in pre-demonstration promotion and post demonstration reporting. Some of these were fleet profile videos, others covered specific topics like the kickoff and the finale events. In total, more than 30 videos were created during RoL-E.

A rough outline of Stories from the Road content episodes was developed prior to starting the site visits. The actual content from interviews would not be fully known until all the interviews were completed and the mountain of recordings sifted through. In total, 91 people were interviewed. Each site visit consisted of one to two days of recording interviews and filming operations. A conservative estimate exceeds 100 hours of video collected by professional film crews assigned to each site visit. Overall direction of the filming was done through James Brown Media [88].

Each of the Stories from the Road episodes was loosely scripted over the month of August based on feedback from the site interview teams and the sequential release of fleet profile videos. The week before the official kickoff of the Run, a focused team began creating, reviewing, and editing the episodes. When RoL-E kicked off on September 2, there were three episodes complete. Over the next three weeks, the team kept ahead of the daily releases, producing essentially one new video per day, scouring the raw film footage and interweaving new tables or label graphics where needed. See Figure 46.

The primary objective of each video was to share first-hand comments on the key topics facing electric trucks. The sequence of the shows was prioritized based on NACFE's experience in preparing Guidance Reports on electrification.



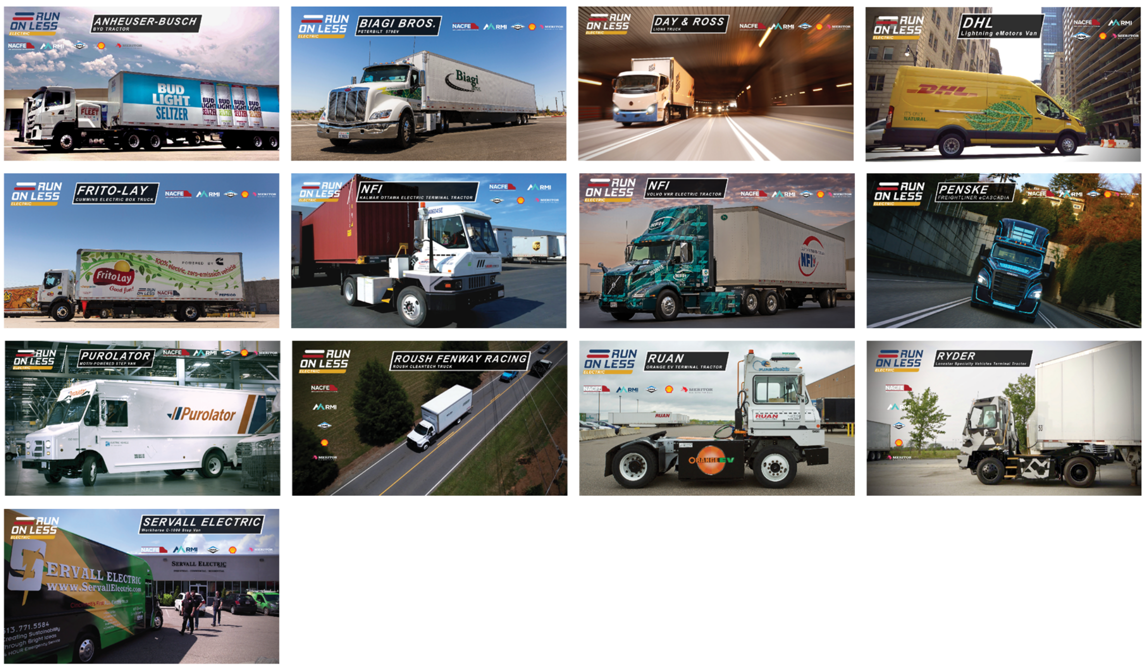
Episode	Title and link
1	The Story So Far….
2	Running in the Real-World
3	Range & Weight Anxiety
4	Maintenance & Uptime
5	Drivers Love Electric
6	Charging Infrastructure
7	Early Adopters
8	Total Cost of Ownership
9	Grid Capacity & Readiness
10	Temperature
11	Truck Driver Appreciation Week 2021
12	Warehouse Planning
13	Charging Business Models
14	Battery Technology
15	Electric Brings Talent
16	Environmental Justice
17	Diving into Data
18	Finale

Figure 46. Stories from the Road RoL-E videos

These videos in total provide a little more 70 minutes of content with each episode running about four minutes. The content is intended to be reused and repurposed as the topics are not specific to RoL-E, but applicable to the ongoing discussion on the electrification of the commercial trucking industry.

15 Videos – Fleet Profiles

The RoL-E site visits to the 13 fleet locations recorded raw interviews and b-roll video for use in topic-specific videos. Fleet profiles were planned for the RoL-E website to be accompanied by videos. The goal was to release fleet profile videos individually during the run-up promotion for the RoL-E demonstration during the month of August. These videos could be used by participating fleets and sponsors in their own social media promotion. The 13 fleet videos and their links are listed in Figure 47.



Fleet and OEM Profile Video Links
Anheuser-Busch and BYD
Biagi Bros. and Peterbilt/Meritor
Day & Ross and Lion
DHL and Lightning eMotors
Frito-Lay and Cummins
NFI Freight and Volvo
NFI Terminal and Kalmar
Penske and Daimler
Purolator and Motiv
Roush Fenway Racing and Roush CleanTech
Ruan and Orange EV
Ryder Systems and Lonestar SV
Servall Electric and Workhorse

Figure 47. RoL-E Fleet Profile Videos

16 Electric Truck Bootcamp

The RoL-E Electric Truck Bootcamp was conceived to both educate on the electrification of commercial vehicles and to build interest in the RoL-E demonstration. The Bootcamp included 10 panels spread out biweekly from April to August leading up to the kickoff of RoL-E. ACT News was engaged to assist in promoting and hosting the panels.

The panels brought together a diverse group of expertise, typically four or five panelists per topic. The complete list of Bootcamp panelists is shown in Appendix 1. The summary of the 10 Bootcamps with links to the videos is shown in Figure 48.

ACT News Link	Date	Title
Bootcamp 1	April 20	What's Driving Electric Trucks?
Bootcamp 2	May 4	Charging 101 – Planning & Buildout
Bootcamp 3	May 18	Charging 201 – Power Management & Resilience
Bootcamp 4	June 1	Working with Your Utility
Bootcamp 5	June 15	Incentives for Electrification
Bootcamp 6	June 29	Maintenance, Training, & Safety
Bootcamp 7	July 13	Financing the Transition & Innovative Business Models
Bootcamp 8	July 27	Sustainable Supply Chains & End of Life
Bootcamp 9	August 10	Global Perspectives
Bootcamp 10	August 24	Drivers and Electric Trucks

Figure 48. Bootcamp RoL-E panels

Attendance at the Bootcamps was very strong, as tabulated in Figure 49, with some sessions exceeding 400 attendees. Post-session viewing of the recordings are not included in these numbers.

Session	Date	Registered		Attended	
		Total	Unique	Total	Unique
1: What's Driving Electric Trucks	4/20/21	945	945	492	492
2: Charging 101: Planning and Buildout	5/4/21	1094	335	483	190
3: Charging 201: Power Managemnet and Resilience	5/18/21	1214	343	422	111
4: Working with your Utility	6/1/21	1178	200	375	70
5: Incentives for Electirifcation	6/15/21	1299	187	351	59
6: Maintenance, Training and Safety	6/29/21	1256	145	276	43
7: Financing the Transition & Innovative Business Models	7/13/21	1342	133	294	61
8: Sustainable Supply Chains & End of Life	7/27/21	1351	102	282	36
9: Global Perspectives	8/10/21	1389	94	275	36
10: Drivers and Electric Trucks	8/24/21	1482	103	272	39
	Totals	12550	2587	3522	1137

Figure 49. Electric Truck Bootcamp attendance

The Bootcamp included the ability to test oneself on key things learned in each session by taking a post session quiz. Completing all 10 quizzes successfully qualified a person as an Electric Truck Bootcamp Expert with a prize RoL-E hat sent to those Experts. Twenty-two attendees successfully completed all 10 quizzes. To continue promotion of the Bootcamp recordings, cards were printed and handed out at many industry events. The card's front and back are shown in Figure 50.

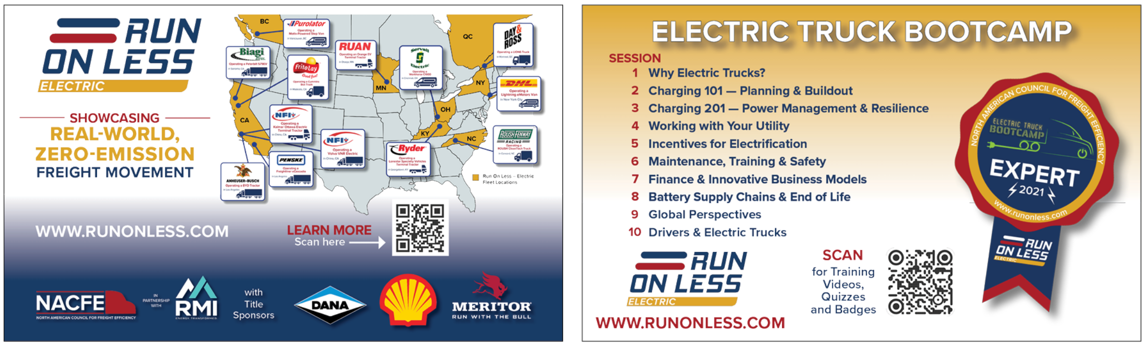


Figure 50. RoL-E and Electric Truck Bootcamp handout 3x5 card

Recordings of these Bootcamp sessions can be found on both the ACT News website and the RoL-E website. These sessions are expected to have a long shelf life with value added relevancy for the next few years providing educational content during the growth in the electrification of commercial trucking.

Lesson Learned

Partnering with a well-established and capable group to promote and run virtual panels allowed NACFE to focus on content and increase the success of the Bootcamp.

17 TCO Ramifications

Putting hard numbers to total cost of ownership (TCO) of CBEVs was not possible in the scope of the three-week RoL-E demonstration. Fleets and OEMs were reluctant to discuss much in terms of actual expenses and financial benefits. Many of the vehicles have not yet listed the manufacturer's suggested retail prices (MSRP) for specific models. Interviews with fleets and manufacturers did surface their operational experiences and expectations in generic terms. Many are captured in the Stories from the Road video Total Cost of Ownership. Many of the fleets had not operated the vehicles for a sufficient period of time to accurately assess costs. The expectations were that the CBEVs would have lower operating expenses based on lower maintenance work, less damage from moving parts, lower energy costs per mile, and many soft factors such as driver retention cost reduction, reduced environmental compliance costs, etc.

One of the primary reasons these first movers were getting first-hand experience with CBEVs was that they want to more accurately determine the TCO in their specific operations. NACFE will continue to report total cost of ownership in our ongoing guidance reports.

18 Initial Findings – Pre-Run

The RoL-E demonstration kickoff press conference was held August 30 as part of the ACT Expo event in Long Beach. NACFE's Roeth detailed the findings up to that point based on the months of preparation for the event, the RoL-E participant site visits, the Electric Truck Bootcamp, and dry-runs of data collection with Geotab.

1. Early adopters of CBEVs are validating an acceptable total cost of ownership in urban medium-duty vans and trucks, terminal tractors and short regional haul applications.
2. CBEV adoption is occurring throughout North America, but longer haul heavy-duty semi-truck use has been somewhat limited to California.
3. There are benefits to CBEVs (quiet operation and reliability) as well as challenges (infrastructure and range).
4. CBEV truck ecosystem inertia is in its early stages with many solutions emerging that will support adoption in the next several years.
5. The industry needs to develop standards in the areas of charging, repair, maintenance and training.
6. There is a huge demand for real-world information on electric vehicles in commercial applications and on charging infrastructure.
7. The mix of startups and traditional truck OEMs and component manufacturers is expediting the development of creative and practical solutions.
8. More thought is needed on the best way to gather and manage the necessary data for fleets and manufacturers to measure and monitor their CBEVs.
9. Early adopters of CBEVs are having an influence on improving trucks and infrastructure.
10. CBEVs present operational challenges, for example longer charging times than fueling, which these fleets are working to mitigate.

19 Run on Less – Electric Findings

The RoL-E Finale event was a virtual press conference held September 22 during Climate Week in New York City. The press release for the event starts by quoting Roeth [86]:

"It's clear from the data collected during the Run that it is time for fleets to go electric in certain market segments, including the van/step van, medium-duty box truck, terminal tractor and short heavy tractor regional delivery segments."

The infographic in Figure 51 was presented during the event and it captures the findings from RoL-E. Sections 1, 2 and 3 of the infographic discuss the significant role of transportation in generating CO_2 greenhouse gas emissions. Section 4 is the primary results observed in RoL-E projected for the entire RoL-E market segments.

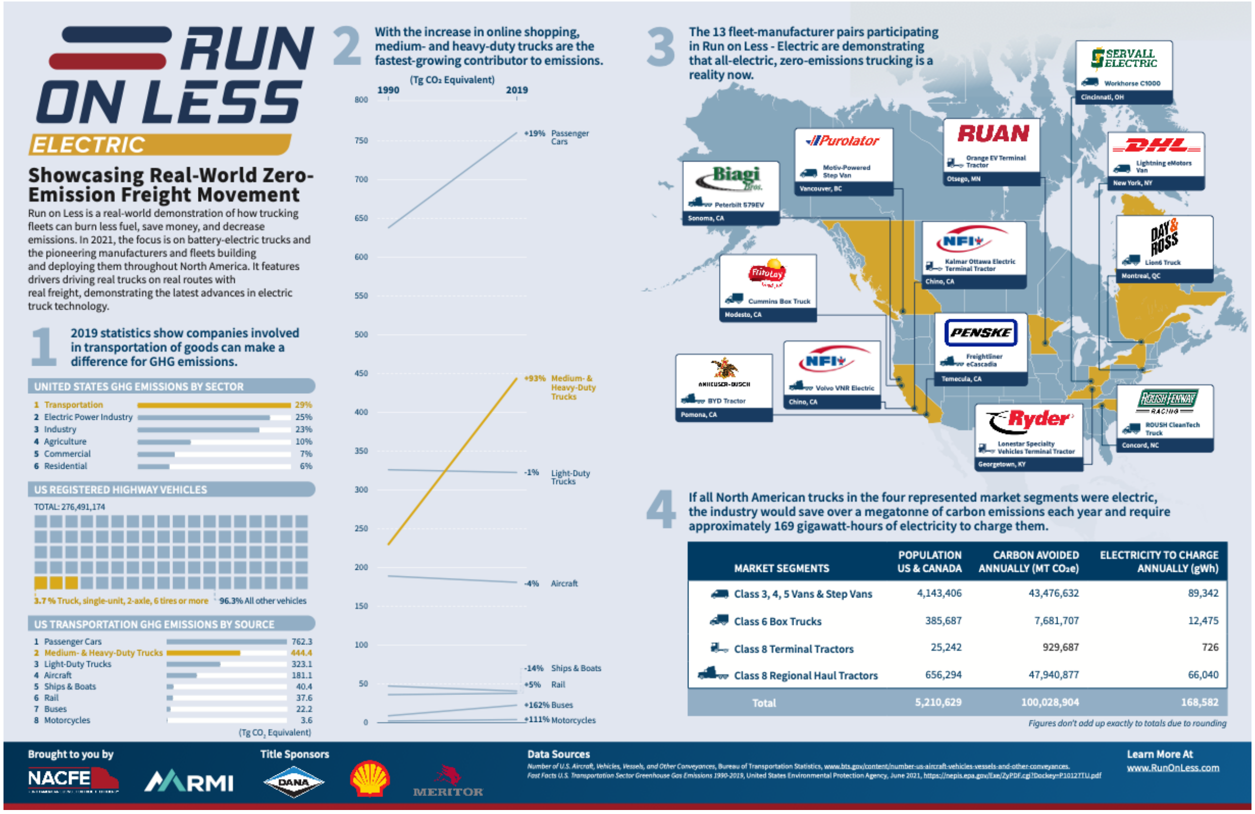


Figure 51. RoL-E findings (Click here to see a larger image)

NACFE estimates that the four segments featured in the Run encompass 5.2 million vehicles as detailed in Figure 51 part 4, enlarged in Figure 52.

4 If all North American trucks in the four represented market segments were electric, the industry would save over a megatonne of carbon emissions each year and require approximately 169 gigawatt-hours of electricity to charge them.

MARKET SEGMENTS	POPULATION US & CANADA	CARBON AVOIDED ANNUALLY (MT CO_2e)	ELECTRICITY TO CHARGE ANNUALLY (gWh)
Class 3, 4, 5 Vans & Step Vans	4,143,406	43,476,632	89,342
Class 6 Box Trucks	385,687	7,681,707	12,475
Class 8 Terminal Tractors	25,242	929,687	726
Class 8 Regional Haul Tractors	656,294	47,940,877	66,040
Total	5,210,629	100,028,904	168,582

Figures don't add up exactly to totals due to rounding

Figure 52. RoL-E Market segment estimation

Market segment volumes were estimated from published sources including FTR, ACT Research and others [89][90]. Carbon avoided annually was based on the estimated fuel economy (MPG) of each of these classes in specific duty cycles combined with the estimated annual vehicle miles traveled in those duty cycles to arrive at annual fuel consumed. The carbon content of fuel consumed was estimated using published US EPA conversion factors for gallons of diesel and gasoline [87]. Electricity to charge was estimated from energy consumption values (kWh/mi) from multiple public sources combined with those observed in RoL-E.

The four market segments for RoL-E are subsets of the entire population of freight hauling vehicles and their associated vehicle miles traveled. They are segments where production level vehicles are becoming available from factories. As fleets and manufacturers gain experience with these vehicles and evolve the designs over subsequent model years, the expectation is that there will be opportunities for CBEVs in other segments.

The primary goal of all Run on Less events is to demonstrate the capabilities of production technologies in real-world operations with real fleet drivers and loads. RoL-E is a snapshot in September 2021 of electrification in four vehicle market segments that make sense for fleets. CBEVs are not yet capable of replacing diesel and gasoline powered vehicles in all market segments, but RoL-E has shown the technology is currently capable of replacing those internal combustion vehicles in four segments — terminal tractors, vans and step vans, medium-duty box trucks and heavy-duty short regional haul trucks — representing more than 5 million Class 3 through 8 freight vehicles. This represents many years of production based on historical market demand for these vehicle classes.

20 Next Steps

NACFE's goal is to publish market segment specific analyses of the RoL-E data in the first quarter of 2022. The four reports will cover vans and step vans, medium-duty box trucks, Class 8 terminal tractors, and heavy-duty regional haul tractors. A final report, will take a deep dive into the data collected during RoL-E and subsequent data collected after the event.

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22 Appendix A – Electric Truck Bootcamp Sessions

The panelists and topics of the 10 RoL-E Electric Truck Bootcamp sessions are shown here with links to the recorded videos.

Bootcamp 1: April 20 | What's Driving Electric Trucks?

Matt Wetta
National Account Manager – Alternative Powertrain
Peterbilt

Kathy Kinsey
Senior Policy Advisor
NESCAUM

Steve Slesinski
Director, Global Product Planning
Dana Incorporated

Kelly Schmandt Ferguson
Director, Market Transformation
LA Cleantech Incubator

T.J. Reed
Vice President, Global Electrification
Meritor

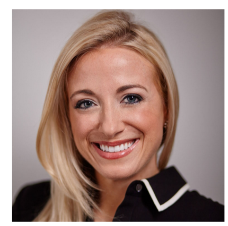
Bootcamp 2: May 4 | Charging 101 – Planning & Buildout

Paul Stith
Director, Global Transportation Initiatives
Black & Veatch

Peter Thomas
Commercial Business Development Manager
Electrify Commercial

Steve Bloch
Western Regional Vice President, EV Charging Infrastructure
ABB

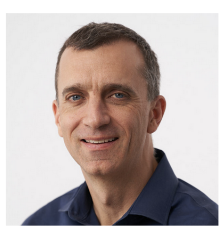
Joe Colett
Technical Manager of Charging Services
Portland General Electric



Alycia Gilde
Senior Director Initiative Lead, Clean Fuels and Infrastructure
CALSTART

Bootcamp 3: May 18 | Charging 201 – Power Management & Resilience

Levi Lomeland
Sr. Account Executive in charge of West Coast Business Development
Electriphi



Scott Fisher
Vice President of Fleets & OEMs
Greenlots

Namit Singh, Ph.D.
Chief Strategy Officer & CoFounder
Microgrid Labs

Pam MacDougall
Senior Manager of Grid Modernization
Environmental Defense Fund (EDF)

Christy Lewis
Director of Analysis
WattTime

Bootcamp 4: June 1 | Working with Your Utility

Brian Sloboda
Director, Consumer Solutions
National Rural Electric Cooperative Association (NRECA)

Andrew Papson
eMobility Advisor
Southern California Edison (SCE)

Ryan Wheeler
Fleet Electrification Product Owner
National Grid

David Visneau
Executive Vice President, Strategy & Operations
MP2 Energy

Bootcamp 5: June 15 | Incentives for Electrification

Victoria Carey
Senior Project Officer
New Jersey Economic Development Authority

Kyle Winslow
Federal Policy Director
CALSTART

Jess Dawe
Policy Analyst, Clean Fuels Branch
Natural Resources Canada (NRCAN)

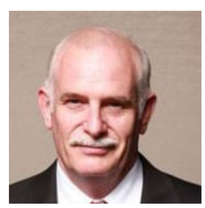
Joel Donham
Lead Engineering Consultant
Center for Transportation and the Environment (CTE)

Bootcamp 6: June 29 | Maintenance, Training, & Safety

Gary Lalonde
Vice-President of North American Truck Sales
The Lion Electric Co.

Kevin Otto
Chair, TMC Electrified Vehicle Task Force and Technical Advisor, NACFE
NACFE

Gregory Bowen
eMobility Trainer/Developer
Daimler Trucks North America



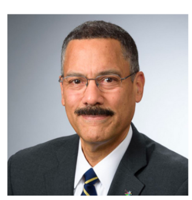
John Frala
Professor, Alternative Fuels/Electric & Fuel Cell Vehicles
Rio Hondo College

Mike Steiner
Customer Engineering Support
Michelin North America

Bootcamp 7: July 13 | Financing the Transition & Innovative Business Models

Chris Nordh
VP – Commercial Development
Workhorse

Brett Hauser
Operating Partner
Partners Group



Bert Hunter
EVP & Chief Investment Officer
Connecticut Green Bank

Steven Moelk
Project Implementation Manager, Customer Fulfilment
Connecticut Green Bank

Steve Clevett
Consultant
eTransEnergy

Simon Lonsdale
Co-Founder and Head of Sales & Strategy
AMPLY Power

Bootcamp 8: July 27 | Sustainable Supply Chains & End of Life

Jimmy O'Dea
Senior Vehicles Analyst
Union of Concerned Scientists

Kunal Phalpher
Chief Commercial Officer
Li-Cycle

Jeff Spangenberger
Materials Recycling Group Lead, Applied Materials Division
Argonne National Laboratory

Derek Matthews
Global Partnership Manager, Power & Propulsion Solutions
BAE Systems Inc.

Bootcamp 9: August 10 | Global Perspectives

Oscar Delgado
Manager, Zero-emission Fleets Center
The International Council on Clean Transportation (ICCT)

Dave Mullaney
Principal, Carbon-Free Mobility
RMI

Cristiano Façanha
Global Director
CALSTART

Samhita Shiledar
Manager, India Program
RMI

Bootcamp 10: August 24 | Drivers and Electric Trucks

Jim Castelaz
CTO & Founder
Motiv Power Systems

Ken Marko
Senior National Fleet Sustainability Manager
PepsiCo/Frito-Lay

Julie Johnson
Enterprise Business Development
Lightning eMotors

23 Appendix B – Lessons Learned

24 Appendix C – Market Segment Fact Sheets


VANS & STEP VANS

Jennifer Wheeler, Senior Program Manager, NACFE

Market Segment & Fleet Profile Fact Sheet

Operational Characteristics

Duty Cycle	Return to Base
Use Case	Urban delivery / Last mile
Average Range	50 miles
Routes	Fixed
Fueling	Overnight
Miles per Gallon	7.4
Replacement Cycle	10 years
Average Age	8.4 years
Axle Configuration	4x2

Definition

Market Summary

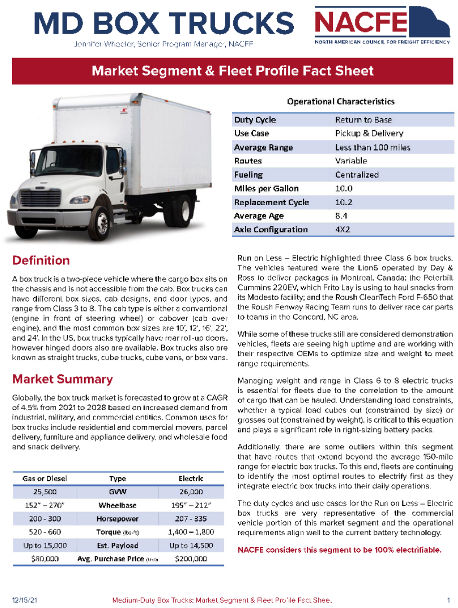
Cargo Vans Diesel vs. Electric Comparison

Gas	Fuel Type	Electric
10,001 – 14,000	GVW	10,360 – 11,000
148"	Wheelbase	148"
235"	Overall Length	235"
275 - 310	Horsepower	215
260	Torque	733
4,200	Est. Payload	5,000
358	Cargo Volume	358
$35,000	Avg. Purchase Price	$79,900 - $99,000

Step Vans Diesel vs. Electric Comparison

Gas	Fuel Type	Electric
16,001 – 19,500	GVW	12,500
190"	Wheelbase	190"
27.75'	Overall Length	27'
350	Horsepower	425 BHP
468	Torque	7500 Nm
10,080	Est. Payload	6,000
948	Cargo Volume	1,000
$71,000	Avg. Purchase Price	$100,000 - $169,000

[Vans & Step Vans: Market Segment & Fleet Profile Fact Sheet]


MD BOX TRUCKS

Market Segment & Fleet Profile Fact Sheet

Operational Characteristics

Duty Cycle	Return to Base
Use Case	Pickup & Delivery
Average Range	Less than 100 miles
Routes	Variable
Fueling	Centralized
Miles per Gallon	10.0
Replacement Cycle	10.2
Average Age	8.1
Axle Configuration	4X2

Definition

Market Summary

Gas or Diesel	Type	Electric
25,500	GVW	26,000
152" – 270"	Wheelbase	195" – 212"
200 - 300	Horsepower	207 - 335
520 - 660	Torque	1,400 – 1,800
Up to 15,000	Est. Payload	Up to 14,500
$80,000	Avg. Purchase Price	$200,000

NACFE considers this segment to be 100% electrifiable.

[MD Box Trucks: Market Segment & Fleet Profile Fact Sheet]


TERMINAL TRACTORS

Jennifer Wheeler, Senior Program Manager, NACFE

Market Segment & Fleet Profile Fact Sheet

Operational Characteristics

Duty Cycle	Single to multiple shifts
Operation	High idle and high run rate
Daily Range – On Road	Less than 150 miles
Daily Range – Off Road	Less than 100 miles
Routes	Fixed
Fueling	Between shifts
Fuel Consumption	2.5 gallons/hour
Replacement Cycle	10 -12 years
Average Age	6 years
Axle Configuration	4x2 (most common) & 6x2

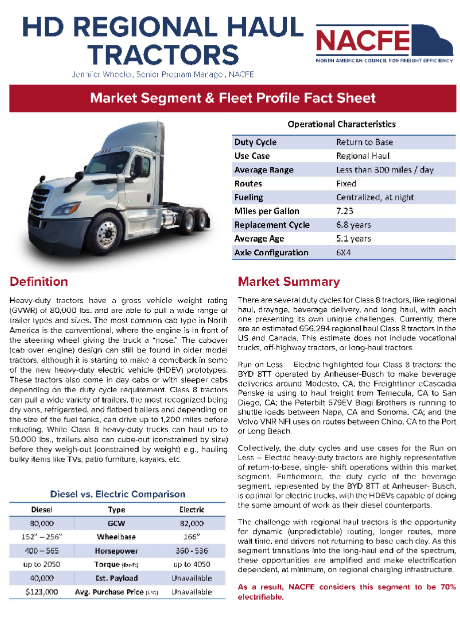
Definition

Market Summary

Diesel vs. Electric Comparison

Kalmar T2	Vehicle	Kalmar T2e
Diesel	Fuel Type	Electric
81,000	GCWR	81,000
14,500	Approx. Weight	20,000
126"	Height	126"
97"	Width	97"
116"	Wheelbase	126"
191"	Overall Length	201"
200 - 240	Horsepower	215
540	Torque	500
25 mph	Max Speed	45 mph
$100,000 – $117,000	Purchase Price	$272,000 - $349,000

[Terminal Tractors: Market Segment & Fleet Profile Fact Sheet]


HD REGIONAL HAUL TRACTORS

Market Segment & Fleet Profile Fact Sheet

Operational Characteristics

Duty Cycle	Return to Base
Use Case	Regional Haul
Average Range	Less than 300 miles / day
Routes	Fixed
Fueling	Centralized, at night
Miles per Gallon	7.23
Replacement Cycle	6.8 years
Average Age	5.1 years
Axle Configuration	6X4

Definition

Market Summary

Diesel vs. Electric Comparison

Diesel	Type	Electric
80,000	GCW	82,000
152" – 256"	Wheelbase	166"
400 – 565	Horsepower	360 - 536
up to 2050	Torque	up to 4050
40,000	Est. Payload	Unavailable
$123,000	Avg. Purchase Price	Unavailable

As a result, NACFE considers this segment to be 70% electrifiable.

[HD Regional Haul Tractors: Market Segment & Fleet Profile Fact Sheet]