NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

RUN ON LESS
ELECTRIC
REPORT

ELECTRIC TRUCKS HAVE ARRIVED:
The Use Case for TERMINAL TRACTORS

RUN ON LESS ELECTRIC REPORT

ABSTRACT This report contains information and findings on the three battery electric terminal tractors that took part in NACFE's Run on Less – Electric (RoL-E) commercial battery electric vehicle production vehicle demonstration. Collectively, the duty cycles for these terminal tractors were highly representative of the overall market segment.

The event included a total of 13 fleets and 13 vehicle models from 13 manufacturers located in eight states or provinces in the US and Canada. However, this report is only focusing on the battery electric terminal truck segment of the market — a market NACFE believes is 100% electrifiable.

If 100% of the terminal tractors in the US and Canada were electrified, it would require approximately 726 gWh of electricity for charging and result in the avoidance of 929,687 MT CO_2e annually. (e equals carbon dioxide equivalent.)

The Run took place from September 2 through September 19, 2021, with continuous tracking of vehicle parameters on two of the vehicles via a Geotab device and one via the manufacturer's own system.

"Originally when I was first introduced to the idea that I was going to be driving an electric vehicle, I was very hesitant about the technology. But it has been a game changer for me and I strongly recommend it."

— Conrad Hanson, Ruan Driver

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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

NACFE could use the assistance of fleets, manufacturers and other trucking industry stakeholders in improving freight efficiency. Become a part of this exciting opportunity.

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

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ELECTRIC TRUCKS HAVE ARRIVED: The Use Case for Terminal Tractors

This report documents the three terminal tractors that participated in 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 uses data from the Run, research and interviews with fleets, vehicle manufacturers and other industry experts about this market segment. The report shares key findings for electrifying terminal tractors — a market segment where electric vehicles are a good fit and one which fleets can use to gain a deeper understanding of the benefits and challenges of battery electric vehicles.

It includes some basic information about terminal tractors and the size and scope of the market. It looks at duty cycle and charging considerations and presents the benefits and challenges of battery electric vehicles. It includes information on the manufacturers and fleets that had terminal tractors in the Run and provides details on what metrics were measured. There also is a discussion of total cost of operation and return on investment.

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 long-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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WOMEN IN TRUCKING

Terminal Tractor Basics

The North American Council for Freight Efficiency's (NACFE) Run on Less – Electric (RoL-E) freight efficiency demonstration included three battery electric terminal tractors. A terminal tractor is defined as a kind of semi-tractor that is intended to move trailers within a cargo yard, warehouse facility, nearby warehouses, an intermodal facility, a large manufacturing facility or similar location. Terminal tractors have some unique features including a single-person cab, full height rear sliding door, short wheelbase, and more. See Figure ES 1. Terminal tractors in most applications travel very few miles in a day and their average speeds are very low. Mileages for the terminal tractors in RoL-E ranged from 14 to 29 miles. Frequently the maximum speed is limited to 15 to 25 mph. Some terminal tractors have a very high usage rate while others have substantially lower usage rates.

FIGURE ES1

TERMINAL TRACTORS HAVE SOME UNIQUE FEATURES INCLUDING A SINGLE-PERSON CAB, FULL HEIGHT REAR SLIDING DOOR, SHORT WHEELBASE, AND MORE

The size of the North American terminal tractor market is relatively small with the total population in North America estimated to be about 50,000. A 10-year average of production is about 2,500 per year with five manufacturers dominating the market.

"Terminal tractors are so much more maneuverable than a day cab truck that you might try to use. It is anywhere from three to five times faster to move a trailer with a terminal tractor."

— Dean Newton, Chief Engineer, Terminal Tractors, Distribution and EVs, Kalmar

Benefits of Electric Terminal Tractors

Battery electric terminal tractors offer many advantages in the marketplace. First, the electrical power for a battery electric vehicle (BEV) should be much less expensive than diesel fuel on an equivalent energy basis. Second, the maintenance cost for a BEV should be much less than that of the most recent terminal tractors. There are some obvious benefits to using battery electric terminal tractors as well as some less obvious ones.

Obvious benefits include quiet operation, performance advantages, stay near home base to facilitate charging, use less energy during idling, have a smaller emissions footprint, and have no odors when operating.

Less obvious benefits of electric terminal tractors include possible avoidance of licensing fees, and potential for in-warehouse operation.

Challenges of Electric Terminal Tractors

Offsetting the benefits of battery electric terminal tractors, of course, is their purchase price. The cost of a battery electric terminal tractor is significantly higher and charging infrastructure to supply electricity for the vehicle is required. Incentives can be difficult to apply for and the process of procuring infrastructure can be long. There also is a need for training of drivers, technicians, first responders, and other fleet personnel.

Terminal Tractors in RoL-E

Three of the 13 vehicles in RoL-E were battery electric terminal tractors. Three fleet-OEM pairs in RoL-E operated terminal tractors: NFI with a Kalmar Ottawa T2E, Ruan with an Orange EV T Series and Ryder with a Lonestar SV S22. See Figure ES2. Each of the terminal tractors that participated in RoL-E are in production (although volumes are limited at this time) and can be ordered from the various manufacturers. Each tractor was equipped with a telematics device that reported the tractor activity throughout each day.

There was significant variation between the three locations. The Ruan Minnesota location only requires

METHODOLOGY

This report's conclusions were generated through the data collection and calculations from the three terminal tractors that participated in Run on Less – Electric, interviews conducted with representatives from the participating fleets and tractor builders and input from other industry experts. Of these three vehicles, two 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 also was observed.

FIGURE ES2

ELECTRIC TERMINAL TRACTORS FROM KALMAR, LONESTAR SV AND ORANGE EV.

one terminal tractor, an electric one, moving only a few trailers around each day, operating one only shift a day. Near the other end of the spectrum is the Ryder tractor in Kentucky, which is one of more than 40 operating at this large manufacturing complex. Finally, NFI operates about eight terminal tractors across its Chino warehouse complex. Mileage per day on the three terminal tractors varied from a high of 29 to a low of 14 throughout the Run. A variety of factors were measured including 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 as well as weather conditions.

Market Segment Performance

Based on the duty cycle and frequency of intermittent charging, fleets may be able to reduce the battery pack size, which will lower the overall cost of the vehicle without sacrificing performance.

If 100% of the terminal tractors in the US and Canada were electrified, it would require approximately 726 gWh of electricity for charging and result in the avoidance of 929,687 MT CO_2e annually. (e equals carbon dioxide equivalent.) See Figure ES3.

FIGURE ES3

ESTIMATED NET EMISSIONS 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

TCO and ROI

It is important to track the costs and benefits of battery electric terminal tractors versus the baseline diesel unit to determine ROI. From a purchase price standpoint, a diesel-powered terminal tractor will cost somewhere between $100,000 and $120,000, depending on configuration, options, etc. OEMs have stated that a new battery electric terminal tractor can cost between $275,000 and $350,000 depending on configuration, options, etc.

If only considering purchase price, the fuel savings and maintenance cost savings for a typical battery electric

"I am optimistic that the electric terminal tractor is going to save on maintenance costs and increase uptime at the end of the day."

– Joe Champa, Director of Customer Logistics, Ryder

terminal tractor application, the payback can be eight years or more. In reality though, the many other benefits of electric versus diesel offer other real cost benefits. See Figure ES4. Therefore, in these situations, most businesses would require other factors like incentives, the need for learning about operating and maintaining electrified vehicles, driver acceptance, and other advantages to help tip the scales of the business decision. Potential incentives that might be available to offset the front-end costs of purchasing and implementing a battery electric terminal tractor also need to be factored in.

One other key measure that is an input to the ROI model is the cost of electricity at a given location. For early adopters of battery electric terminal tractors, the relatively modest power requirements of a small number of vehicles are unlikely to make a large difference in the electrical rates that most locations are paying. When the number of battery electric vehicles gets larger or when the charging demands force large peaks in the electrical consumption, these factors become more and more important.

Note on TCO and ROI: This section uses the data from the three terminal tractors that operated in Run on Less – Electric and these comments are an example of one such use case's TCO; they are not meant to present a definitive TCO for every fleet. Each fleet should do its own calculations based on its business model and vehicle duty cycles. The less obvious benefits should be factored in as well as fleets go after incentives to help with early electric vehicle deployments.

FIGURE ES4

COMPARISON BETWEEN AN ELECTRIC TERMINAL TRACTOR VS. A DIESEL TERMINAL TRACTOR

Comparison

Diesel vs Electric

Using Kalmar specs as a representative sample for terminal tractors

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** (lbs-ft)	500
25 mph	**Max Speed**	45 mph
$100,000 – $117,000	**Purchase Price** (USD)	$272,000 - $349,000

Terminal Tractor Report Findings

The study team has six key findings based on the three battery electric terminal tractors that participated in RoL-E.

1. NACFE considers terminal tractors one of the best, if not THE best, paths for a heavy-duty tractor fleet to learn about and implement a BEV in a fleet operation.
   - Choosing to purchase a battery electric terminal tractor will help mobilize the fleet to understand the many aspects of what will be required in future larger purchases of BEVs. This would include evaluating the areas of purchasing, TCO considerations, facilities, vehicle parking, operations changes, selecting and installing electric charging infrastructure, driver training and reactions, maintenance, etc.
   - The battery electric terminal tractor is limited to a small area around the facility, so it is always close to home. This allows for opportunity charging.
   - Electric units are available to be a direct replacement of virtually all diesel-powered terminal tractor use cases with very few operational adjustments.
   - Most terminal tractor duty cycles can get by with low power level (and thus less expensive) charging stations.
2. The drivers in Run on Less – Electric all rave about their quieter operation and improved performance. All the drivers mentioned that they liked the responsiveness of the battery electric terminal tractor, and they also liked the regenerative braking feature once they got used to it. In fact, Ryder driver Ray Hancock, said, "For me the difference between an electric and a diesel tractor is response. When you drive an electric truck, when you press the accelerator, you get an immediate response." Drivers all mentioned the quiet operation, and some mentioned that this made hearing dispatch orders much easier. Also, one driver mentioned that it was great not having to deal with diesel fuel odors and spills.
3. The maintenance cost of a battery electric terminal tractor compared to the most recent diesel-powered terminal tractors (2017 and later with diesel particulate filters and selective catalytic reduction aftertreatment systems) is dramatically reduced (approximately 60% to 75%). Multiple fleet leaders mention that newer diesel terminal tractors have created significant maintenance headaches and costs. Even with very little early experience with the battery electric terminal tractors, fleets are clear that these are a big improvement.
4. Battery electric terminal tractors have a positive environmental impact and will contribute to overall business sustainability goals.
5. Payback times for a battery electric terminal tractor compared to diesel-powered units are currently long for most applications (eight or more years) without incentives and other factors to help the TCO calculation. Initial cost of a battery electric terminal tractor is currently $275,000 to $350,000 compared to $100,000 to $125,000 for a diesel-powered unit.
   - In most cases, electricity will be much less expensive than the diesel fuel that would be consumed by a conventional terminal tractor. In addition, there are significant maintenance cost benefits to the battery electric terminal tractor.
   - In many areas of the country there are incentives available to offset some of the purchase price of the electric equipment as well as incentives to help substantially with the costs of installing charging equipment. In addition, in some areas, Low Carbon Fuel Standard credits are available to offset some of the ongoing electricity costs of charging the vehicles.
   - Many additional less obvious benefits should be monetized specific to each fleet's circumstances.

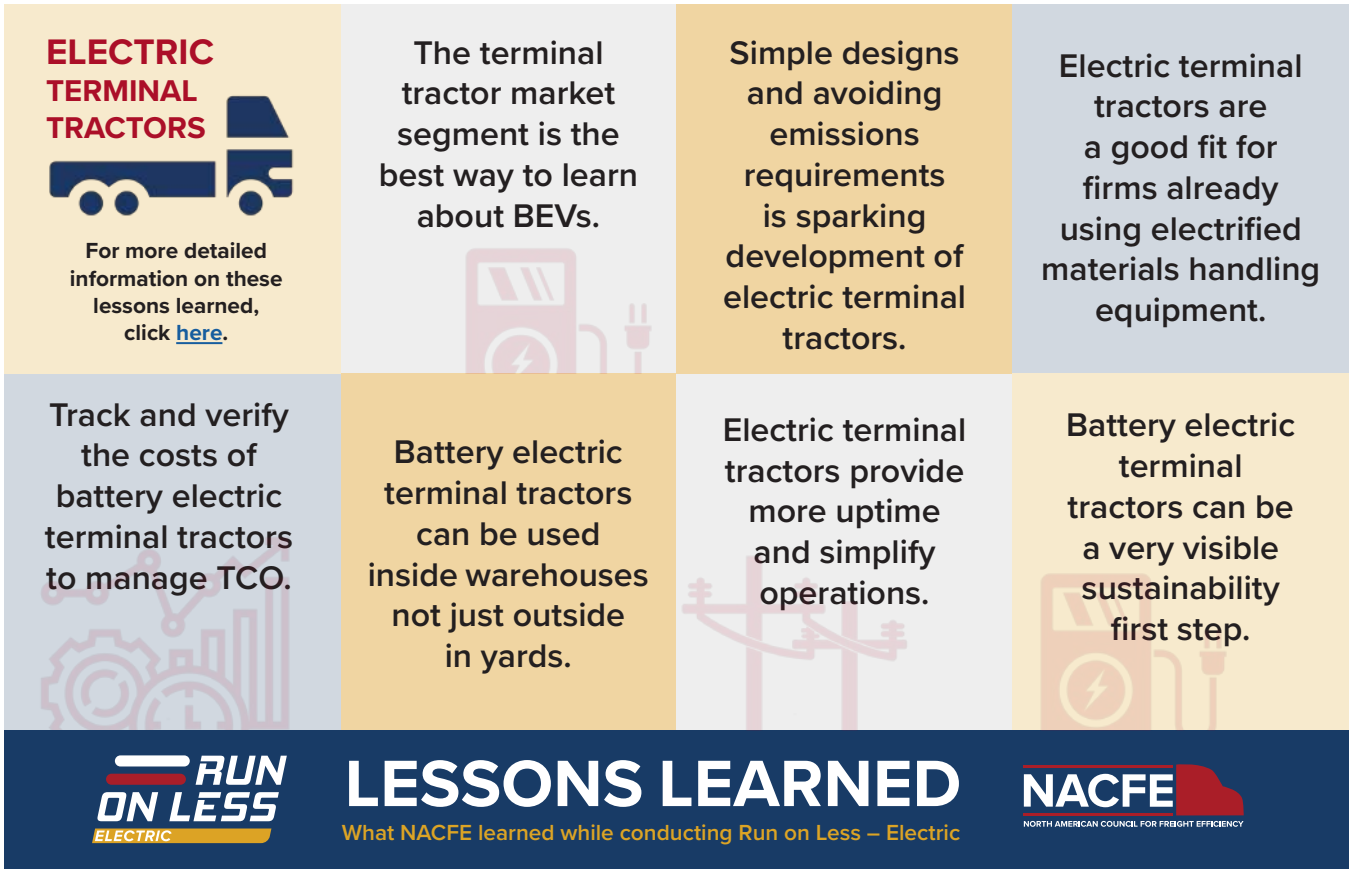
"Terminal tractors are perhaps the best way for fleets to learn more about and begin to implement battery electric vehicles into their operations. Battery electric terminal tractors can be a direct replacement for virtually all diesel-powered terminal tractors with minimal adjustments."

– Kevin Otto, Electrification Technical Lead, North American Council for Freight Efficiency (NACFE)

6. Tracking the vehicle to verify the cost benefits can be very difficult without significant prior planning. Traditionally, tracking the expenses associated with terminal tractors is not a high priority for fleet operations. In the case of the battery electric terminal tractors, tracking operational costs will be a higher priority for most fleets due to the increased capital investment and ensuring that the TCO for the vehicles is managed. In order to adequately track the costs, data from the charging equipment, the electrical meter and the vehicle itself will be important to sorting out the return on investment. Planning for tracking these items in advance will be imperative.

FIGURE ES5

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



1 Introduction

One of the ways the North American Council for Freight Efficiency (NACFE) encourages the deployment of technologies that improve freight efficiency is through Run on Less, a series of freight efficiency demonstrations. The first Run was held in 2017 and focused on long-haul trucking. Run on Less Regional took place in 2019 and centered on trucks in regional haul applications. In September 2021, NACFE undertook Run on Less – Electric (RoL-E) which looked at electric vehicles in four market segments:

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

Following RoL-E, NACFE published an initial report, *Electric Trucks Have Arrived: Documenting A Real-World Trucking Demonstration*. In addition, NACFE determined that, as we go forward with information and findings relative to the electrified vehicle markets, we will issue information when appropriate by market segment.

The focus of this report — the first of four market segment reports — will be to describe the North American market of terminal tractors, review the fleets that operated a terminal tractor during RoL-E and share specific findings for this market segment from RoL-E.

2 What is a Terminal Tractor?

A terminal tractor generally is defined as a kind of semi-tractor that is intended to move trailers within a cargo yard, warehouse facility, nearby warehouses, an intermodal facility, a large manufacturing facility or similar location. Terminal tractors can be classified as either off-highway or on-highway depending on if they are licensed to travel on public highways. Manufacturers have estimated that about 90% of all new terminal tractor sales are configured to off-highway specifications.

Terminal tractors are referred to by a variety of other names including yard spotter, yard tractor, yard dog, yard goat, yard hostler, mule, etc. NACFE will be using terminal tractors throughout this report as the most common term for these vehicles.

2.1 Features and Purpose of Terminal Tractors

Terminal tractors generally have some or all of these unique features:

- The tractor has a single-person cab offset to one side and usually has an automatic transmission for easy operation.
- Terminal tractors have a full height rear sliding door to facilitate easy accessibility to the trailer air and electrical connectors.
- The tractor has a very short wheelbase and sharp turning radius to facilitate working in very tight spaces.
- Terminal tractors can be either a 4x2, 6x4 or 6x2 configuration depending on the load requirements.

- The fifth wheel on the terminal tractor has a lifting mechanism to allow trailer movement without raising and lowering the trailer landing gear.
- Most terminal tractors have steps to make it much easier for the driver to get into and out of the vehicle.

Terminal tractors exist to move multiple trailers around a warehouse, depot, port or other such location where trailers are stored prior to and after their unloading or loading at a dock. They are much more maneuverable than a day cab tractor and move the trailer with less driver effort than is done in a normal drop and hook operation. Figure 1 illustrates the ability of a terminal tractor to move a trailer without retracting the trailer landing gear.

Figure 1. A terminal tractor moves a trailer without retracting the trailer landing gear

Also, the terminal tractor makes it easier to connect the compressed air and electrical power to the trailer due to the easy access through the door at the back of the cab which allows the driver to connect lines without getting down out of the cab. Speeding up the drop and hook operation is the primary reason why terminal tractors exist rather than having to move trailers with a day cab tractor.

According to Dean Newton, chief engineer, terminal tractors, distribution and EVs, Kalmar, “They are so much more maneuverable than a day cab truck that you might try to use. It is anywhere from three to five times faster to move a trailer with a terminal tractor.” Hear more about the Kalmar terminal tractor used by NFI in RoL-E in this video.

Terminal tractors in most applications travel very few miles in a day and their average speeds are very low. Mileages for the terminal tractors in RoL-E ranged from 14 to 29 miles. Frequently the maximum speed is limited to 15 to 25 mph. Fleets shared with NACFE that many have a 15-mph speed limit for all vehicles, including terminal tractors, on their warehouse properties. Most often, maintenance and fuel consumption are tracked by the number of hours accumulated rather than the number of miles driven.

The duty cycle means that current, primarily diesel-powered terminal tractors are known to have a very high percentage of idle time (30% or much more in some cases).

Some terminal tractors have a very high usage rate while others have substantially lower usage rates. One of the RoL-E fleets could have their terminal tractor in use for as many as 20 hours a day making well over 100 or 150 moves during that time. Of course, this varies with the demands of the business they are servicing at any given time. Many terminal tractors may only see intermittent operation over two shifts. Some may only be used for a single shift a day.

Brad Gehring, vice president of fleet services at Ruan, said, “From what we’ve seen out of this unit’s operation so far, we think we can get at least 10 years of life out of it.” To hear more about Ruan’s experience with the Orange EV terminal tractor, watch this video. Depending on the usage, it may be necessary to refurbish or rebuild some of the vehicle components at about halfway through their life cycle. Some companies make a business rebuilding/remanufacturing terminal tractors.

RUN ON LESS ELECTRIC

Lesson Learned

Warehouses are already moving to electrify with forklifts and other material handling machines that make this a natural effort to move to “outside’ of the building.

2.2 Terminal Tractors And Emissions

Starting around 2017 (exact timing varied by manufacturer), off-highway terminal tractors were required to meet what is known as Tier 4 final off-highway emissions regulations. [36] This forced the diesel engine systems to be equipped with both diesel particulate filters (DPF) and selective catalytic reduction (SCR) in order to meet these tougher emission requirements. The typical duty cycle for a terminal tractor is quite challenging for these aftertreatment components because the exhaust system rarely gets to the temperatures necessary for proper DPF regeneration to occur.

Customers have reported that they have experienced very high rates of DPF replacement on these types of applications — a very expensive repair. A DPF repair can run $2,500 to $8,000, depending on whether a remanufactured unit or a new one is installed and other factors like additional parts that must be replaced. [37] As a result, maintenance costs (and the consequent downtimes) for these vehicles have gone up substantially in the last few years. It is likely that the DPF/SCR aftertreatment system will be required on all diesel-powered terminal tractors going forward.

One fleet operating these new emission-compliant terminal tractors informed NACFE that their maintenance cost on these aftertreatment systems is more than $5,000 per year. It might be expected that this penalty will decrease with improvements to these production systems but will likely remain significant. Another fleet stated that they expect the life of diesel terminal tractors to be reduced from about 12 years to under 10.

RUN ON LESS ELECTRIC

Lesson Learned

Terminal tractors can be very visible sustainability first steps.

2.3 Terminal Tractor Market Scope

NACFE consulted with many manufacturers and organizations that follow the truck market in order to understand the scope of this heavy-duty tractor market segment. The size of the North American terminal tractor market is relatively small with the total population estimated to be about 50,000. Terminal tractors are Class 8 heavy-duty tractors and as such are reported when companies account for Class 8 production and sales. A 10-year average of production is about 2,500 per year with five manufacturers dominating the market. See Figure 2.

Terminal Tractor Market Share

Manufacturer	Approximate US and Canadian Share	Manufacturing Plant Locations
Kalmar/Ottawa	40%	Kansas City, MO
Capacity	25%	Longview, TX
Tico	15%	Ridgeland, SC
Autocar	10%	Hagerstown, IN
Orange EV, LSV, Others	10%	Riverside, MO; Texarkana, TX

Figure 2. Major terminal tractor manufacturers

Recently, there has been growing discussion about terminal tractors as an early adopter of electric heavy-duty vehicles. Figure 3 is an estimate of annual sales volumes of new terminal tractors as well as an estimate of the portion of those that will be battery electric terminal tractors. [28]

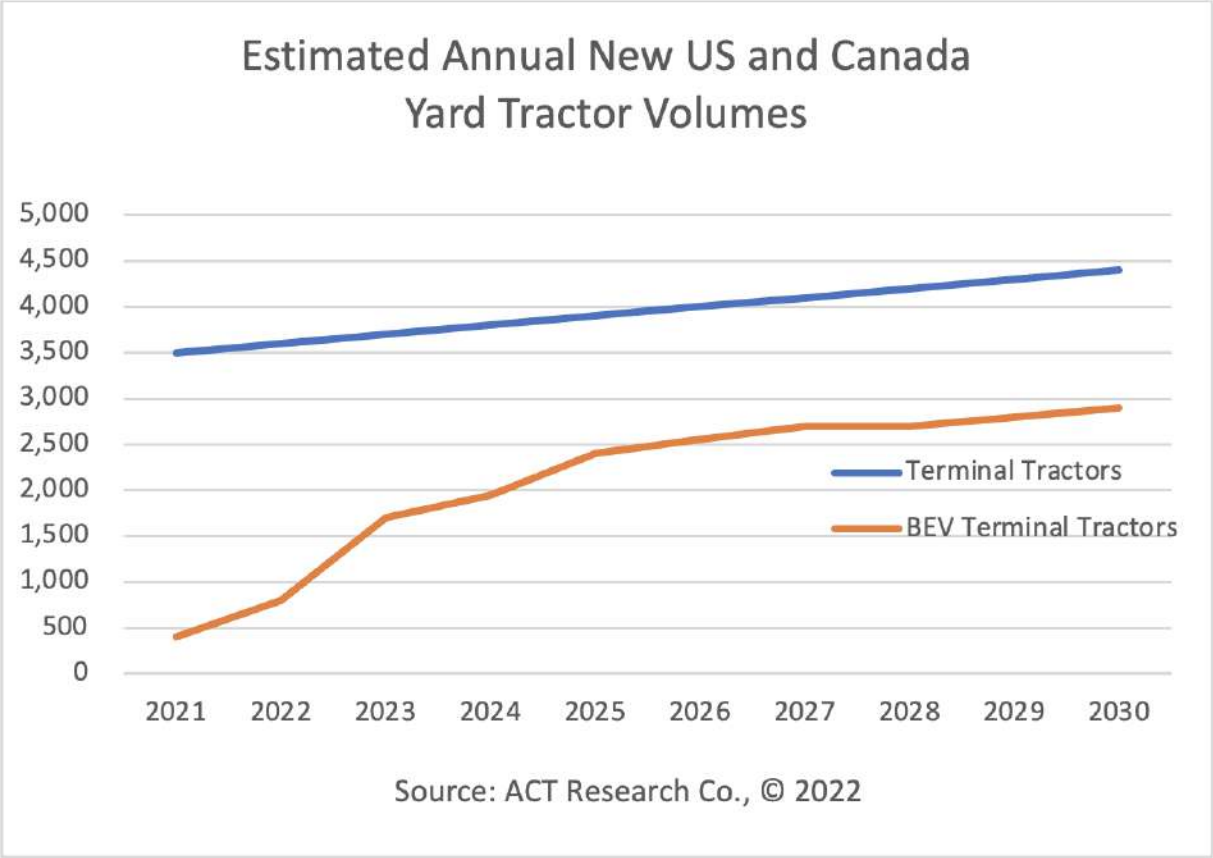


Figure 3. Estimated Annual North American terminal tractor sales volume

2.4 Automation and Terminal Tractors

One other technological trend that will impact the future of terminal tractor operation is automation. A number of companies are developing and testing driverless terminal tractors, including startups such as Outrider. [27] Similar to highway tractor automation developments, these vehicles will use the emerging safety technologies to enable this operation. Lower speeds and known, generally private operations are dynamics that make automation easier, but automating the labor intensive and high number of trailer drops and hooks will be the biggest challenge to overcome. Automation generally is independent of electrification, but both will likely occur over the next few decades.

2.5 Key Market Players

As mentioned in section 2.3, five manufacturers dominate the market for terminal tractors: Kalmar, Capacity, TICO, Autocar and Orange EV. [3] [33] [29] [30] [7]

RoL-E featured terminal tractors from Kalmar, Orange EV and Lonestar. Figure 4 shows products from these three manufacturers.

Figure 4: Terminal tractors from Kalmar, Lonestar SV and Orange EV that participated in Run on Less – Electric

There are at least three additional manufacturers that have announced battery electric terminal tractors. These include BYD, Dina/Meritor/TransPower and Terberg. [10] [12] [13] See Figure 5. As of February 1, 2022, BYD has deployed 130 terminal tractors.

In addition, Lazer Spot, a leading provider of yard management services including leasing both diesel and battery electric terminal tractors in North America, said it deployed 30 [electric] terminal tractors in 2021 with a goal to get to 75 trucks in 2022. David Stringer, vice president of innovation at Lazer Spot says, "The transition to EVs has been cost effective and beneficial in many ways. The zero-emission vehicles have led to more efficient workdays, safer working conditions, and greater employee retention."

Stringer reflected on Lazer Spot's transition to renewable energy, saying, "There doesn't have to be a compromise. It's a win for everyone: employees, customers, the environment…and the bottom line."

Figure 5. Terminal tractor offerings from BYD, Dina/Meritor/TransPower, and Terberg

Other manufacturers have electric terminal tractors under development. Some are listed below.

- Capacity and Hyster/Yale Group announced a Memorandum of Understanding in December 2020 to produce electric- and hydrogen-powered terminal tractors to begin market testing in late 2021. [15]
- In March 2021, TICO announced a partnership with both Volvo Penta and Cummins to produce electric terminal tractors. [16]

- In May 2021, Autocar announced that an electric version of one of its terminal tractor models would be available in late 2021. The tractors were scheduled to be tested with customers in the fourth quarter of 2021. [17] See Figure 6.

Figure 6. Electric terminal tractor from Autocar

Remanufacturing can be done to convert a diesel terminal tractor to a battery electric version by removing diesel engines and drivetrains, and replacing them with electric motors, drivetrains and other components such as battery-operated HVAC systems.

RUN ON LESS ELECTRIC

Lesson Learned

Many new companies are preparing to build these trucks partly due to the simple design of the powertrain and avoiding meeting emissions requirements.

3 Duty Cycle Considerations

There are many factors that must be considered when evaluating whether a battery electric terminal tractor can replace a diesel-powered unit on a one-for-one basis.

- Does it make sense on a total cost of ownership (TCO) basis?
- What is the duty cycle of the diesel-powered units?
- Can an electrified unit do the same job as the diesel with adequate time for recharging?
- Does the electrical service to the property support the charging needs of the battery electric terminal tractor?

- What incentives are available to offset either the purchase of the vehicle or the purchase price and installation cost of the electrical infrastructure?
- Does the purchase or lease of a battery electric terminal tractor support the sustainability goals of the fleet?
- What are the minimum requirements for upgrading maintenance facilities and support for staff to ensure that the implementation is successful?
- How should the vehicle(s) be tracked to understand if they are meeting requirements and goals for the operation?

Many other questions need to be asked and answered in order to determine if battery electric terminal tractors will work in the proposed application.

One factor to study when considering purchasing a battery electric terminal tractor is making sure that fleets understand the current vehicle duty cycle to ensure that an electrified vehicle is able to accomplish those same tasks at least as efficiently as its diesel-powered counterpart.

There are some key data points to keep in mind:

- **Fuel consumption:** Typically, this can be miles/gallon or gallons/hour. If, for example, a current terminal tractor gets about 4 miles/gallon and runs 60 miles a day, it would use about 15 gallons of fuel per day. An electric version of that same tractor might use 2.5 kWh/mile for that same 60 miles. Therefore, it would use 150 kWh/day. The battery pack size for the electric version of the tractor would need to be 225 kWh or larger to do the same job as the diesel-powered version. ***Note:*** *A better unit of measure for terminal tractors is to relate critical data to hours of operation rather than miles due to the typical usage profile for terminal tractors. However, Run On Less – Electric featured 13 trucks with three terminal tractors and NACFE chose to measure and report data in miles. It is very difficult to recalculate given the way the data was collected. NACFE will take this into consideration as we move forward with other terminal tractor efforts.*
- **Idle time:** Terminal tractors often have very high idle percentages because of several factors. First, the engine generally is left running during pickup and drop maneuvers. In many cases, even when the tractor is not moving a trailer, the engine is left running to maintain the cabin environment for the driver. Idle fuel consumption on a typical diesel engine is usually one-half gallon of fuel per hour. Electrified terminal tractors are different as they don't require energy to sit in one place, although they may require some energy to maintain the cabin environment.
- **Key off time:** Understanding this is critical since battery charging can theoretically be done any time the key is off as long as the vehicle is near a charger so it can be plugged in. Plugging in a battery electric terminal tractor is a very quick process if the tractor is within range of the cable.
- **Number of moves per day or moves per shift:** Understanding this will help the battery electric terminal tractor OEMs understand the most appropriate specifications for the battery and powertrain system. This also will help to understand the number of fifth wheel cycles and the energy required for those operations.
- **The need to be used in overtime situations:** Understanding the frequency of events where overtime is necessary for the terminal tractors combined with key off times during the shifts will help in figuring out the proper mix of charging power to ensure the tractor does not run out of power on a high use day.
- **Maintenance cost per hour or mile:** As mentioned before, the terminal tractor application can be quite difficult for today's modern aftertreatment systems. This can frequently result in high

maintenance costs. The battery electric terminal tractor powertrain is simpler, has fewer moving parts and is projected by several manufacturers to reduce maintenance costs by as much as two-thirds of that of its modern diesel counterparts. Not only will the costs be lower, but the uptime for the vehicles also will be higher over the long run. "I am optimistic that the electric vehicle is going to save on maintenance costs and increase uptime at the end of the day," said Joe Champa, director of customer logistics at Ryder. To hear more about Ryder and Lonestar Specialty Vehicles watch this video.

- **On-road or solely off-road capability:** Can the terminal tractor be driven on the road if needed?

Fleets should consult with the vehicle manufacturer about battery size and range, and must consider many other factors including:

- Onboard AC charger KW rating,
- DC connector type (CCS),
- System operating voltage (400V or 800V),
- Maximum DC charge rate,
- Vehicle ability for over-the-air software and firmware updates, and
- Communication including monitoring the health of the battery pack and reporting charge event data.

4 CHARGING CONSIDERATIONS

Electrified vehicles must be charged in order to maintain operation. With diesel-powered equipment, it often is possible to store several days of diesel fuel in the vehicle tank with a relatively small weight penalty. However, since batteries are very heavy per stored energy unit compared to diesel fuel, it is not economical to carry more energy than necessary on a battery electric vehicle. Therefore, the battery pack is generally sized to comfortably complete one day's operation between charges. There should be enough extra battery capacity so there is virtually no risk of running out of power if the vehicle cannot get back to its charging location. This also must include taking into account the upper limits of the duty cycle as well as factoring in capacity for cold weather operation and possible stoppages due to a variety of factors (traffic, etc.).

Note: The battery pack size could be less than one day's charge if the duty cycle allows for opportunity charging of sufficient length to maintain adequate capacity.

Battery electric terminal tractors take a significant time to charge. Depending on the capability of the charging system as well as the limits of the on-vehicle charging equipment, it can take several hours to recharge the batteries of the terminal tractor. This is fundamentally different than a diesel-powered terminal tractor where it only takes a few minutes to fill the fuel tank at a fueling station. This difference may mean that a fleet considering implementing battery electric terminal tractors might have to consider some operational and yard layout changes in order to accommodate this difference.

For example, if the terminal tractor uses 100 kWh during its shift and the charging system's capacity is 25 kW, then it will take 4 to 5 hours to recharge the batteries to their full capacity. Figure 7 gives some examples of charging times vs. the charger power level for typical battery pack sizes for battery electric

terminal tractors which are in the 150 to 220 kWh range. Charging times per day as shown are for replenishing a battery with a 120 kWh capacity.

Battery Pack Size and Charging Times

Approximate charging times per day to replenish 120 kWh of battery capacity

Low Power (220V single phase AC – 7kW)	Medium Power (19.2kw)	480 3-phase AC or DC (40kW)	DC Fast Charging (150kW)
17+ hours	6.25 hours	3 hours	1 hour

Figure 7. Approximate charging times for battery electric terminal tractors

As the power level of the charger goes up, so does the price. Therefore, it is most economical to make the best use of vehicle idle time to opportunity charge as this will keep charging infrastructure costs as low as possible.

Many early adopters of battery electric terminal tractors are setting up their operations so that anytime the terminal tractor is idle and near the charger, it is plugged in to get a little charge while not in use. This is normally referred to as “opportunity charging.” This means that the charger for the vehicle should be located strategically near the places where the driver might be taking breaks throughout the day. Using this strategy may allow for the use of a much less expensive lower power charger as well as perhaps a reduction in the battery capacity of the vehicle. See Figure 8.

NFI shared its experience with opportunity charging. “We opportunity charge every chance we get,” said Bill Bliem, senior vice president fleet service at NFI. “We’ve never had a low battery or a dead battery issue.”

“We charge intermittently during breaks and lunches,” said Marco Molina, transportation manager at NFI. “Currently our charging ports are situated next to the break rooms on the campus.”

Figure 8. Placing a charging unit near a break room allows for opportunity charging

Note: In a review of the three RoL-E terminal tractors, one always operated above 65% battery state of charge (SOC) while the other two would occasionally get down to 25% to 35%. Each fleet should evaluate the duty cycle that will drive battery sizing and charging speeds given the dwell time for charging and the opportunity to charge during driver breaks. Batteries and charging speed are expensive, so finding the right balance significantly improves the total cost of ownership.

To learn more about charging electric vehicles, listen to replays of NACFE's Electric Truck Bootcamp training, Charging 101 — Planning and Buildout and Charging 202 — Power Management and Resilience.

5 Benefits of Electric Terminal Tractors

Battery electric terminal tractors offer many advantages in the marketplace. First, the electrical power for a battery electric vehicle (BEV) should be much less expensive than diesel fuel on an equivalent energy basis. Second, the maintenance cost for a BEV should be much less than that of the most recent terminal tractors.

5.1 Obvious Advantages

There are other obvious advantages of the battery electric terminal tractor.

- The operation of the battery electric terminal tractor is very quiet compared to a diesel-powered unit, putting less stress on the operator and enabling them to hear dispatch commands over the radio much more easily. In addition, the lower noise levels can allow the operator to hear other things going on in their surroundings that they might not hear otherwise. All three drivers in RoL-E were very positive about operating battery electric terminal tractors. Here is what they said. "It feels like it is noise cancellation from in here," said Jazmin Vasquez, driver for NFI. "You

do not hear much from the outside." To learn more about what Vasquez thinks about electric terminal tractors, watch this video. Ray Hancock, driver for Ryder said, "It is a lot quieter. It is easier on the senses during the day so it makes things a little more comfortable." To learn more about what Hancock thinks about electric terminal tractors, watch this video. The final session in NACFE's Electric Truck Bootcamp focused on drivers. To learn more about drivers and electric vehicles, watch the replay of Drivers and Electric Trucks.

- Battery electric terminal tractors generally have a slight performance advantage over their diesel-powered counterparts. Electrical propulsion systems tend to be more responsive, especially accelerating from a stop.
- Battery electric terminal tractors always are near their charging facilities since they are never far from their home base, thus minimizing any range anxiety the operator might have. Longer term, if there are a large number of both electrified delivery vehicles and electric terminal tractors at a facility, the electric terminal tractors could share charging equipment with the electric delivery vehicles. Burt Fosse, operations lead at Ruan, talked about the company's practices. "We don't just charge the truck at one single point. Whenever the driver has an opportunity to do paperwork or to take a break, he plugs it in. Anytime that the truck is idle and sitting, it is typically plugged in and charging." To learn more about Ruan's experience with an electric terminal tractor watch this video.
- In both cold and hot weather, it is often customary to leave the engine in the terminal tractor idling to maintain temperatures in the driver's cabin. NACFE has been told that idle times can be 30% to 40% or even higher in many situations. This can be a fuel waster and it likely increases the stress that is placed on the vehicle's aftertreatment system. With a battery electric terminal tractor, the cabin temperatures can be maintained by electrical accessories powered by the battery. This uses substantially less energy than an idling diesel and still maintains cabin comfort levels for the operator. Fosse also talked about weather and battery electric terminal tractors. "I was very apprehensive if the batteries would work within the winter environment of the upper Midwest where ambient temperatures can reach 23 degrees below zero. The batteries have held very well. I can't remember a time when a unit was under 70% charged."
- The battery electric terminal tractor has a significantly smaller emission footprint — both CO_2 and criteria pollutants — even in areas where the electrical power generation is more carbon intensive. (Criteria pollutants are carbon monoxide, ground-level ozone, lead, nitrogen dioxide, particulate matter, and sulfur dioxide.) This can be quite helpful in meeting corporate sustainability goals. In addition, emissions that are generated from the creation of power to charge the battery electric terminal tractor are "moved" from the location where the tractor operates to where the power is generated. Paul Jensen, senior vice president of supply chain at Ruan said, "It is more sustainable long-term. It is a better work environment for the driver too." Many warehouse districts where these tractors operate are located in areas where there also is higher risk of respiratory disease and other effects of emissions in the surrounding neighborhoods. Moving the point of power generation can alleviate some of the harmful emissions in these high-risk areas." [38][39][40]
- Diesel fuel smells and can be an irritant to the operator and others if it is spilled. This problem is eliminated when the energy to power the vehicle is electricity.

Lesson Learned

Because of their smaller emissions footprint, businesses may be able to operate battery electric terminal tractors inside warehouses not just outside in yards.

5.2 Less Obvious Advantages

Battery electric terminal tractors also offer some other less obvious advantages that should be considered as part of the decision-making process.

- As mentioned in Section 2, terminal tractors are normally classified as on-highway or off-highway depending on whether they must be licensed to travel on commercial highways or stay confined to a warehouse or yard area. If the only reason that an on-highway vehicle must be purchased and licensed is so that it can get to a fueling station that is near the facility in which it works, then a battery electric terminal tractor might be able to avoid the licensing fees if the electricity to charge the vehicle can be obtained on site. One fleet indicated this was the primary reason they had to specify on-highway tractors.
- Similarly, the maintenance of a diesel-powered terminal tractor requires that fluids and filters be serviced periodically. The demand for this kind of maintenance on a battery electric terminal tractor are much reduced. Depending on the location of the service facility, it may be possible to avoid licensing and other considerations with the battery electric terminal tractor. Brake lining maintenance for battery electric terminal tractors should be lower compared to their diesel counterparts due to the regenerative braking function in the BEV that takes some of the braking function away from the traditional service brakes. It might be possible that most, if not all, of the maintenance could be completed onsite. Jason Sidders, senior manager, advanced applications engineering group, Dana Commercial Vehicles, said, “As you take advantage of that regen braking, you are getting less wear and tear on your traditional service brake system which makes those components last longer and reduces the interval times you have on those service brakes.”
- From the drivers’ perspective, the fueling process for a battery electric terminal tractor is actually easier than for a diesel-powered tractor. Filling diesel tanks can take anywhere from five to 15 minutes and the driver must be present throughout the process. However, fueling battery electric terminal tractors simply requires pulling up to the charging station and connecting the power cable. This process can be accomplished in much less time but may need to be done more frequently than the diesel fueling operation.
- Operating the terminal tractor inside warehouse operations, although not a common practice today, could be an option for these zero-emission battery electric trucks where they are not generally an option for diesel powered units. See Figure 9.

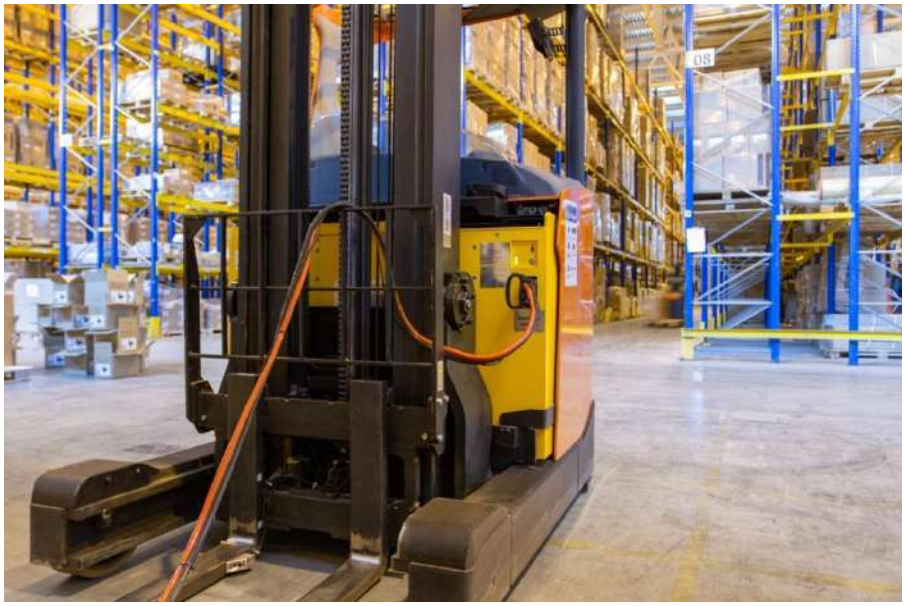


Figure 9. Battery electric forklifts already operate inside warehouses. Will battery electric terminal tractors be next?

Lesson Learned

The lack of the need to go offsite for fueling and maintenance offers more uptime and simpler operations on site.

6 Challenges of Electric Terminal Tractors

Offsetting benefits of battery electric terminal tractors, of course, is their purchase price. The cost of a battery electric terminal tractor is significantly higher and charging infrastructure to supply electricity for the vehicle is required. While incentives are available to offset the purchase price, it can be difficult to apply for them.

Battery electric terminal tractors take a significant time to charge. Depending on the capability of the charging system as well as the limits of the on-vehicle charging equipment, it can take several hours to recharge the batteries of the terminal tractor.

The process of procuring both infrastructure and the EV itself is long and requires fleet personnel to focus and interact with more functional areas both within the fleet as well as with utilities and government entities. This can be challenging.

Once the vehicle is in place, training of drivers, technicians, first responders, and other fleet personnel that might be coming near the vehicle is required to assure safety.

7 Terminal Tractors in Run on Less – Electric

Run on Less – Electric (ROL-E) was a freight efficiency demonstration that featured a total of 13 electric vehicles. Three of them were vans and step vans, three were medium-duty box trucks, four were regional haul heavy-duty tractors and three were terminal tractors. All the vehicles in RoL-E were electric.

Three fleet-OEM pairs in RoL-E operated terminal tractors: NFI with a Kalmar Ottawa T2E, Ruan with an Orange EV T Series and Ryder with a Lonestar SV S22.

Figure 10 highlights the three vehicles that were featured in the Run.

Terminal Tractor Participants

Fleet	Location	Tractor Make & Model	Battery Capacity
NFI	Chino, CA	Kalmar Ottawa T2E	220 kWh
Ruan	Otsego, MN	Orange EV T Series	160 kWh
Ryder	Georgetown, KY	Lonestar SV S22	224 kWh

Figure 10. Terminal tractors that participated in RoL-E

Each of the terminal tractors that participated in RoL-E are in production (although volumes are limited at this time) and can be ordered from the various manufacturers. The Run was conducted over 18 days in September 2021. Each tractor was equipped with a telematics device that reported the tractor activity throughout each day and some of the results of this are reported in detail later in the report. (See section 7.2.)

Figure 11 shows details about the three battery electric terminal tractors that participated in Run on Less – Electric.

	Kalmar T2e	Orange EV T Series	Lonestar SV S22
ROL-E Site	Chino, CA	Otsego, MN	Georgetown, KY
Fleet	NFI	Ruan	Ryder
Facility Details	8 warehouse complex	300,000 sq ft warehouse	1,300 acre campus
Weather – Temp Range	58 – 101 degrees F	46 – 89 degrees F	54 – 86 degrees F
Duty Cycle Requirement	22 hours / day	10 hours / day	22 hours / day
Battery Capacity	132 - 220 kWh	160 kWh	224 kWh
Battery Range	Up to 20 hours	22 hours	More than 22 hours
Battery Chemistry	Li-ion	LFP	Li-ion NMC
Charging Power	70 kW	22 kW	163 kW
Battery Charger	Proprietary	Proprietary (not UL certified)	CCS1
Total Runtime	125 hours	-	169 hours
Total Miles	386	270	598
Estimated Moves	718	60 / day (per fleet)	462
% of Speed <20 mph	77%	-	100 %
Charging Opportunity	Intermittent	Intermittent	Intermittent
Charger Location(s)	Near breakroom	Near office / breakroom	Near breakroom / shop
Charging Port on Tractor	Behind cab on left side	Nose	Nose
Parking to Charge	Back-in	Nose-in	Nose-in

Figure 11. Specifications of the battery electric terminal tractors from RoL-E

All three terminal tractors completed the Run and their assigned job in an equivalent manner to their diesel counterparts. There was significant variation between the three locations. The Ruan Minnesota location only requires one terminal tractor, an electric one, moving only a few trailers around each day. It is only operated one shift a day. Near the other end of the spectrum is the Ryder tractor in Kentucky, which is one of more than 40 operating at this large manufacturing complex. Finally, NFI operates about eight terminal tractors across its Chino warehouse complex. Average mileage per day on the three terminal tractors varied from a high of 29 to a low of 14 throughout the Run. One terminal tractor, the Ryder Lonestar SV22, had a one-day high of 73.5 miles.

In all three cases, these deployments provided a good comparison of their characteristics and suitability to handle the same tasks as their diesel predecessors. Each of the fleets involved (and some of their customers) has sustainability goals that are prompting them to be early adopters of battery electric terminal tractors and invest in new technologies that will reduce their carbon and emission footprints in the future.

7.1 Details On Vehicles and Fleets in RoL-E

The battery electric terminal tractors that were in RoL-E are listed in sections 7.1.1, 7.1.2 and 7.1.3 with a description of the fleet and the vehicle. A chart is included with each vehicle highlighting the data

collected throughout the Run. To discover more about each vehicle, you can select the appropriate vehicle and explore the data collected on the Run on Less – Electric website.

Once you select the fleet, you can enter the day or range of days of data you would like to display, and the system will adjust the results. The examples show data collected during all 18 days of the Run.

7.1.1 NFI Terminal and Kalmar

NFI is a privately held North American supply chain solutions provider. NFI has a significant drayage presence at nearly every major US port, and its business lines include dedicated transportation, distribution, brokerage, transportation management, port drayage, intermodal, global logistics, and real estate [4]. NFI employs a significant number of terminal tractors which operate on a 24/7 basis supporting warehouse operations. NFI's RoL-E participant vehicle was a Kalmar Ottawa T2E that operated in Chino, California. Kalmar is a major producer of terminal tractors with a 60-year history [3].

According to Gina Lopez, vice president terminal tractors, they have about 100 battery electric terminal tractors in the field as of RoL-E. An overview of the NFI Terminal Kalmar vehicle is shown in Figure 12. NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on NFI Terminal and Kalmar. There is also a fleet profile and video.

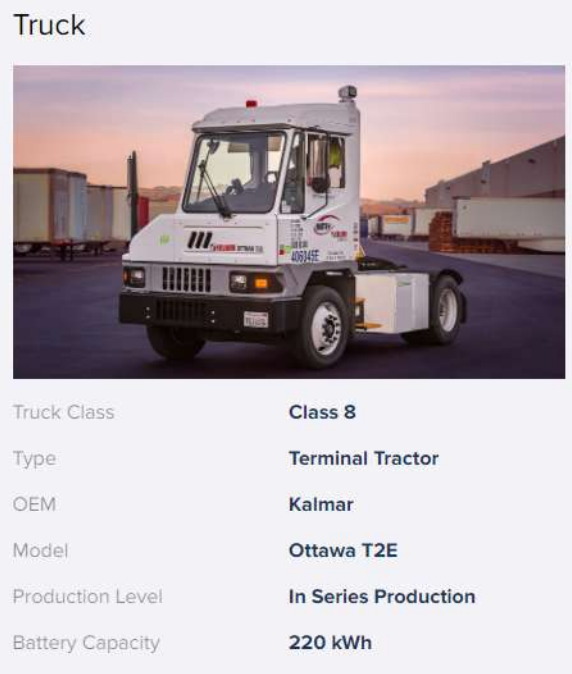


Figure 12. NFI Terminal and Kalmar

Figure 13 contains data collected during all 18 days of RoL-E on the Kalmar terminal tractor operated by NFI in California.

Figure 13. NFI and Kalmar data (Click here for a larger view.)

7.1.2 Ruan and Orange EV

Ruan is a family-owned transportation management company and is one of the top 10 privately owned transportation service companies in the country. 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 an Orange EV T-Series operating in Otsego, Minnesota. The Minnesota operations expose the vehicles to harsh winter conditions. 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 [6]. Range and payload weight are not an issue. An overview of the Ruan Orange EV vehicle is shown in Figure 14. NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on Ruan and Orange EV. There also is a fleet profile and a video.

Truck

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

Figure 14. Ruan and Orange EV

Figure 15 contains data collected during the 18 days of RoL-E on the Orange EV operated by Ruan in Minnesota.

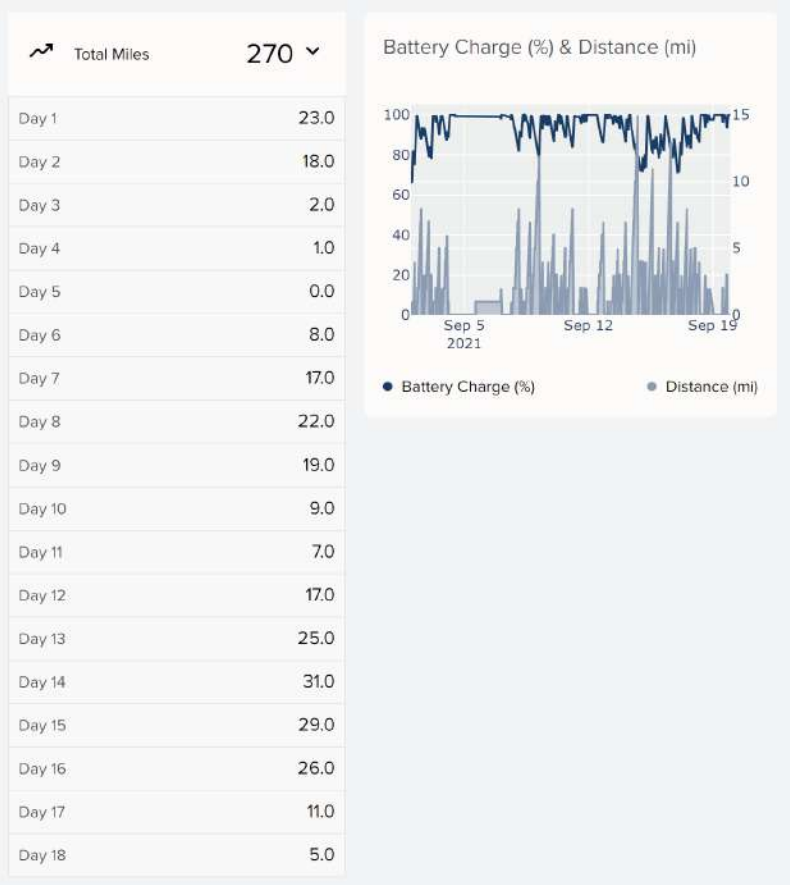


Figure 15. Ruan and Orange EV data (Click here for a larger view.)

7.1.3 Ryder 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. The terminal tractor used by Ryder in RoL-E had a duty cycle with a high idle percentage and high hourly run rate. The truck can run for more than 22 hours before needing charging. The Ryder System RoL-E participant vehicle is the Lonestar SV S22 electric terminal tractor operating in support of a major automotive manufacturer in Georgetown, Kentucky. Lonestar Specialty Vehicles is a Texas headquartered manufacturer of terminal tractors. The remanufactured line of electric terminal tractors was introduced in 2019 [8]. As of late summer 2021, Lonestar is producing all of its electric terminal tractors with new frames and other components. An overview of the Ryder Lonestar vehicle is shown in Figure 16. NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on Ryder and Lonestar SV. There is also a fleet profile and video.

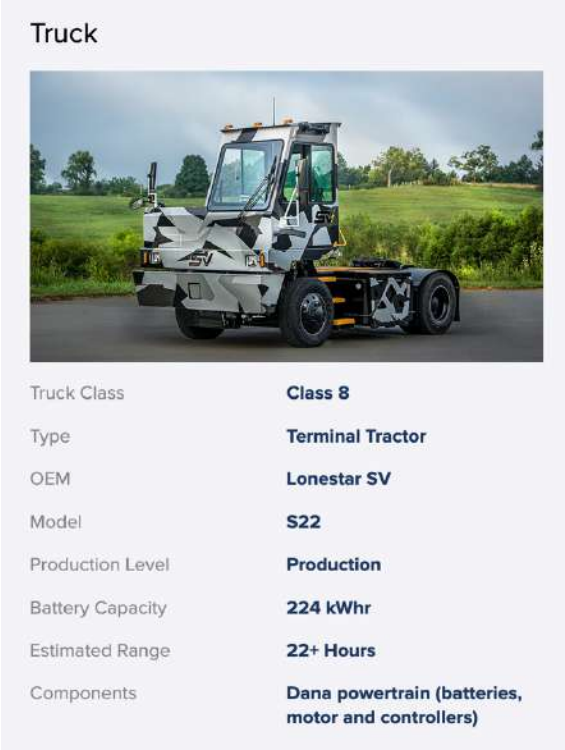


Figure 16. Ryder and Lonestar SV

Figure 17 contains data collected during all 18 days of RoL-E on the Lonestar SV terminal tractor operated by Ryder in Kentucky.

Figure 17. Ryder and Lonestar SV data (Click here for a larger view.)

Note: *In the graphic above, the Energy In data is not accurate, since it is reporting that 100% of the Energy In was from regeneration; there was some error with reporting data in this metric. The Truck Activity area of the graphic shows that the vehicle was charging 6.72% of the total truck activity during the Run. In the mileage section of the graphic, the dashes indicate that the vehicle was completely offline for that time period and did not report any data.*

7.2 What Was Measured

The RoL-E website dashboard was developed to capture and present data on BEV operations for a variety of end users' interests. All data originates from the vehicles themselves through the Geotab integration on two of the terminal tractors that participated in the Run and through the proprietary data system on the third vehicle. See Figure 18. The following sections contain a synopsis of the data measured during RoL-E. For a more complete discussion of what was measured, read NACFE's report, *Electric Trucks Have Arrived: Documenting A Real-World Trucking Demonstration*.

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 18. Vehicle parameters reported

Vehicle performance is always in context of the operating environment. For RoL-E, NACFE pursued regions with diverse weather conditions. The local weather data for each day and fleet location were obtained from OpenWeather. [4]

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 of SOC.

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. Speed is not a significant factor with the terminal tractors in the Run. Frequently the maximum speed is limited to 15 to 25 mph.

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.

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.

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.

Deliveries, the act of stopping the vehicle and unloading (or loading), are metrics NACFE captured for RoL-E. Deliveries also have different parameters when looking at a terminal tractor versus a box truck due to the differences in what constitutes a delivery. 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).

For RoL-E, NACFE described 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 the vehicle was plugged into the charger. The vehicle data bus continuously reported voltage and amperage, and integrated that over time to provide SOC.

Consumption is the inverse of efficiency. Diesel 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. ***Note:*** *A better unit of measure for terminal tractors is to relate critical data to hours of operation rather than miles due to the typical usage profile for terminal tractors. However, Run on Less – Electric featured 13 trucks with three terminal tractors and NACFE chose to measure and report data in miles. It is very difficult to recalculate given the way the data was collected. NACFE will take this into consideration as we move forward with other terminal tractor efforts.*

For RoL-E, trucking activity was categorized as: inactive, idling, charging and driving. These terms can mean different things for BEVs than for diesel-powered vehicles.

The battery on a BEV is continuously changing its SOC value based on the amount of energy that is going out and the amount of energy coming in. This occurs at the same time, for example, a BEV exiting from an Interstate engages regenerative braking by removing pressure on the accelerator pedal to slow the vehicle.

8 Market Segment Performance of Terminal Tractors in Run on Less – Electric

The terminal tractor market globally is estimated to grow from about $700M in 2021 to more than $850M in 2026.

Based on the duty cycle and frequency of intermittent charging, fleets may be able to reduce the battery pack size, which will lower the overall cost of the vehicle without sacrificing performance.

If 100% of the terminal tractors in the US and Canada were electrified, it would require approximately 726 gWh of electricity for charging and result in the avoidance of 929,687 MT CO_2e annually. (e equals carbon dioxide equivalent.)

Figure 19 contains information on the terminal tractor population in the US and Canada, the carbon that would be avoided annually if all terminal tractors were electric and the electricity needed to charge them annually.

Figure 19. Carbon avoided if all US and Canadian terminal tractors were battery electric

9 TCO And ROI Discussion

Several of the OEMs that manufacture battery electric terminal tractors have a TCO calculator that they use to help evaluate whether the purchase of a battery electric terminal tractor makes financial sense.

Key inputs include:

- Knowing the purchase price of a new diesel-powered unit vs. that of the electrified unit with comparable capabilities and features.
- Knowing current fuel consumption numbers for diesel units.
- Understanding the cost of electricity per kWh coming into the property.
    - **Note:** Determining this number can be harder than you think. Many utilities have rate structures that are determined by usage (both peak throughout a month as well as consumption by short intervals of time throughout the day). Details of these rate structures for a given location are only available through the supplying utility. For tips and information on charging infrastructure, see NACFE's Guidance Report, *Amping Up: Charging Infrastructure For Electric Trucks*.
- Factoring in maintenance cost of diesel terminal tractors.
- Understanding available incentives to lower the purchase price of a battery electric terminal tractor. Many incentives have criteria associated with them that must be met in order to receive the benefit. For example, receiving an incentive in some states requires that an existing vehicle must be scrapped — not simply sold. Each locality may have different requirements that must be met.
- Understanding the cost of adding charging infrastructure to the property where the battery electric terminal tractors will be operating. Incentives for adding charging systems also may be available.

- Understanding business payback requirements for investments (including those that aid in meeting business sustainability goals).

If only considering purchase price, the fuel savings and maintenance cost savings for a typical battery electric terminal tractor application, the payback can be eight years or more. In reality though, the many other benefits of electric versus diesel offer other real cost benefits. Therefore, in these situations, most businesses would require other factors like incentives, the need for learning about operating and maintaining electrified vehicles, driver acceptance, and other advantages to help tip the scales of the business decision.

See Figure 20 for a comparison of a battery electric terminal tractor and a comparable diesel-powered terminal tractor.

Comparison
Diesel vs Electric

Using Kalmar specs as a representative sample for terminal tractors

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** (lbs-ft)	500
25 mph	**Max Speed**	45 mph
$100,000 – $117,000	**Purchase Price** (USD)	$272,000 - $349,000

Figure 20. Comparison of diesel and electric terminal tractors

9.1 Other Factors In The TCO Equation

In Section 5 above, a number of obvious and less obvious benefits to operating an electric terminal tractor were described. Fleets should monetize these benefits when determining the TCO of a battery electric terminal tractor.

Environmental Impact of battery electric terminal tractors: If 100% of the terminal tractors in the US and Canada were electrified, it would require approximately 726 gWh of electricity for charging and result in the avoidance of 929,687 MT CO_2e annually. (e equals carbon dioxide equivalent.)

Driver Acceptance: The feedback that drivers have given NACFE on battery electric terminal tractors has been overwhelmingly positive. The biggest advantages the drivers mentioned were much improved noise performance, better acceleration, and the lack of having to deal with diesel fueling and odors. Conrad Hanson, driver for Ruan, said, "Originally when I was first introduced to the idea that I was going to be driving an electric vehicle, I was very hesitant about the technology. But it has been a game changer for me, and I strongly recommend it." To hear more about what Hanson thinks of electric terminal tractors, watch this video.

Maintenance Costs: All the RoL-E participants indicated that the improvement in maintenance costs over their most recent terminal tractors was substantial. None quoted exact numbers, but they were sure that the benefits were clear.

Note on TCO: *This section uses the data from the three terminal tractors that operated in Run on Less – Electric and these comments are an example of one such use case's TCO; they are not meant to present a definitive TCO for every fleet. Each fleet should do its own calculations based on its business model and vehicle duty cycles. The less obvious benefits should be factored in as well as fleets go after incentives to help with early electric vehicle deployments.*

9.2 Tracking Costs

It is important to track the costs and benefits of battery electric terminal tractors versus the baseline diesel unit to determine ROI.

In many fleets, tracking either the exact costs or the benefits of terminal tractors can be difficult. Generally, the big costs in an ROI analysis for terminal tractors are the difference in purchase price or lease price, the ongoing costs of fuel (either diesel or electricity) and ongoing maintenance costs.

9.2.1 Diesel Costs

Let's start with diesel-powered units since these costs would be the starting point for any ROI analysis of purchasing or leasing a battery electric terminal tractor.

From a purchase price standpoint, a diesel-powered terminal tractor will cost somewhere between $100,000 and $120,000, depending on configuration, options, etc.

In many fleets, fuel consumption of the terminal tractors is not tracked closely as it is a very small percentage of the overall fuel bill for a given operation. Maintenance costs, on the other hand, generally are tracked more closely especially when repairs result in very high costs or downtime. In some operations, the maintenance costs are included as part of a lease agreement for the tractor rather than being tracked separately. Often, fuel cost and maintenance for terminal tractors are tracked using hours of operation rather than miles as is the case with other vehicles in a fleet. In fact, tracking by hours is probably a more relevant measure for a very low speed and high idle operation like a terminal tractor.

Given all these factors, determining the true costs of an existing group of terminal tractors can be difficult.

9.2.2 Electric Vehicle Costs

Understanding the costs of a battery electric terminal tractor can be even more challenging. Let's start with purchase price. OEMs have stated that a new battery electric terminal tractor can cost between $275,000 and $350,000 depending on configuration, options, etc.

Fuel cost for a battery electric terminal tractor consists of the cost of electricity that is used to charge the vehicle. Of course, this cost is determined by the rate and how much electricity the unit consumes as it passes the electric meter going on to the property. If the electrical service for the property includes other loads like buildings, lights, etc. in addition to the vehicles, then it will be impossible to use the electric meter charges as input for the analysis. Several fleets and utilities have recommended using a separate meter to track only vehicle energy for this reason.

Why does this matter? It matters because, unlike diesel fuel that has very few losses between delivery and fuel tank, there are significant losses of power between the electrical meter and when it ends up in the batteries of the vehicle. Input from suppliers and fleets indicate that these losses are between 5% to 20%, depending on the charger selected and other choices about the installation. Therefore, to put 100 kWh of energy into the batteries of a battery electric terminal tractor, you need to flow approximately 110 kWh of electricity past the electric meter. Manufacturers and system suppliers are working to minimize these losses going forward.

Some charging systems will track the energy as it is delivered to the vehicle and the electronics on the vehicle also may track a similar number. Each will be a different number, and some will be of somewhat questionable accuracy, at least in the early days of BEV adoption. Keep in mind that these energy numbers are subject to both measurements and assumptions that model the system components, and all can be subject to inaccuracies for a variety of reasons. Manufacturers will work diligently over time to improve the accuracy of these estimates. The numbers recorded on the RoL-E vehicles were from the vehicle itself, not the charger or the electrical meter. Also, the RoL-E vehicles were tracked via mileage vs. hours because this is how the data was reported to NACFE. NACFE does not have the information from the Run measured in hours.

To further complicate this picture, the vehicle will track how the energy from the battery is consumed during operation. This includes power for propulsion and accessories during operation, power consumed while the vehicle is not moving, and power recovered during regenerative braking. The net result of this is the overall power consumed by the vehicle over a specific shift which is then replenished during charging. The RoL-E vehicles also tracked this energy consumption. Figure 21 shows the energy charged vs. the energy consumed for each of the three RoL-E vehicles. In one case, no charging data was available.

You can see that in one case, the power consumed by the vehicle was substantially more than the power that was replenished during charging. This, of course, is impossible and contrary to the laws of physics. NACFE has been unable to determine the source of this discrepancy. It is likely the higher of the two numbers is a more accurate measure of the actual vehicle power consumption.

Run on Less – Electric Fleet/OEM	Consumption (kWh/mi)*	
	Net Charging	Net Consumed
NFI / Kalmar Ottawa	3.21	4.06
Ruan / Orange EV	2.49	2.47
Ryder / Lonestar SV	Not tracked**	2.12

Figure 21. Electricity consumption of RoL-E terminal tractors

** **Note:** A better unit of measure for terminal tractors is to relate critical data to hours of operation rather than miles due to the typical usage profile for terminal tractors. However, Run on Less – Electric featured 13 trucks with three terminal tractors and NACFE chose to measure and report data in miles.*

*** **Note:** NACFE took every measure possible to collect and report accurate data during and after the Run. Given the nascent nature of these trucks, their charging infrastructure and measurement tools, some data errors occurred.*

One other key measure that is an input to the ROI model is the cost of electricity at a given location. This is determined by the electrical rate schedule that the supplying utility has. Unlike diesel fuel, electrical rates can vary widely based on time of day, peak power consumption and other factors. A common method of determining rates is by both the peak power required over a very short timeframe during a given month and rates that are applied by the time of day that the power is consumed. This can be a very complicated equation to estimate in an ROI analysis. In addition, there are more than 3,000 utilities that supply electricity to locations across the US and Canada and each will have its own schedules for how electrical rates vary.

Many utilities have determined that traditional rate structures for industrial electrical supply may not be the best or easiest to apply when supplying large numbers of electrified vehicles. Some have modified their rate structures for BEVs to encourage adoption.

For early adopters of battery electric terminal tractors, the relatively modest power requirements of a small number of vehicles are unlikely to make a large difference in the electrical rates that most locations are paying. When the number of battery electric vehicles gets larger or when the charging demands force large peaks in the electrical consumption, these factors become more and more important. For more information on charging, see NACFE's Guidance Report*, Amping Up: Charging Infrastructure For Electric Trucks.*

The next input to an ROI model is the savings to maintenance expenses associated with a battery electric terminal tractor. Feedback from both manufacturers and fleets is that this number is substantially better than the diesel counterpart. In the case of terminal tractors, it is reasonable to estimate this reduction from 50% to 75% — probably somewhere in the middle of this range.

9.3 Incentives

Another factor that should be taken into account when calculating ROI is the potential incentives that might be available to offset the front-end costs of purchasing and implementing a battery electric terminal tractor. Of course, this varies both by state and municipality, so consult with OEMs, government agencies, charging system manufacturers and others to determine what kind of incentives apply and

what additional requirements are involved. This is a critical early task in the process. Applying for and obtaining these incentives can be time consuming and involved.

Many areas of the country have incentives available to help offset the cost of implementing zero-emission vehicles. A good resource to explore for these opportunities is the US Department of Energy Clean Cities Coalition Network. See Figure 22.

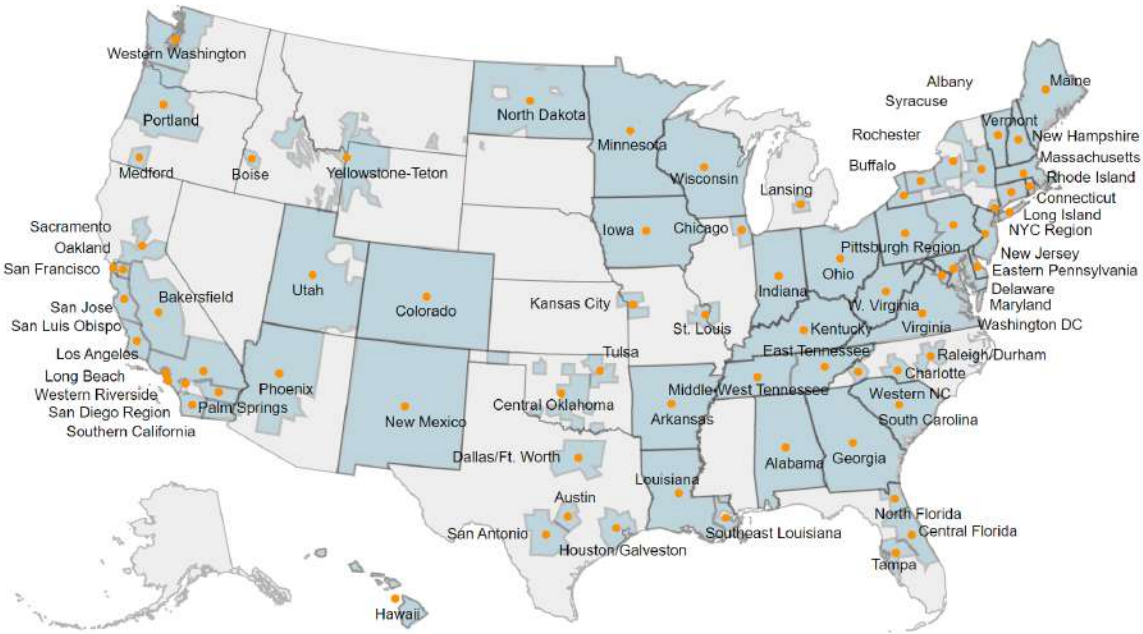


Figure 22. Electric vehicle incentives in the US

The website also has a list of contact information for each area where these coalitions exist.

NACFE's Electric Truck Bootcamp conducted a session on incentives. To learn more about this subject, watch a replay of that training session.

9.4 PLANNING

There are also planning considerations to factor in. Unlike purchasing and implementing a diesel-powered terminal tractor, implementing a battery electric terminal tractor takes considerable front-end planning. One of the keys is making sure there is an adequate way to charge the vehicle during times when it is idling. This process can be quite involved and may mean several months of work with utilities, charging station suppliers, electrical and construction contractors, etc. It is imperative that this process start early because a battery-powered vehicle is useless without an adequate means to charge it as necessary. You can learn much more about setting up the infrastructure for charging battery electric vehicles from NACFE's Guidance Report, *Amping Up: Charging Infrastructure For Electric Trucks*.

Performing a complete ROI analysis for implementing battery electric terminal tractors can be quite involved. The above discussion should help highlight most of the many factors to consider.

NACFE conducted an Electric Truck Bootcamp session, Working With Your Utility, that may be helpful to fleets making the move to electrification.

9.5 RoL-E Example

Here's an example of what an initial ROI analysis might look like.

The price difference between a diesel terminal tractor and a battery electric terminal tractor can be $150,000 to $200,000. Fuel savings for the battery electric terminal tractor per year might be approximately $4,000/year and maintenance savings might be $3,000/year. Given this example, it would take well over 10 years to recoup the extra investment necessary to purchase the battery electric terminal tractor. Clearly, there are other aspects that need to be incorporated in the ROI analysis including operational advantages, driver retention, corporate sustainability goals, early learnings on implementing electrified vehicles, etc. NACFE will continue to work on the total cost of ownership cost and benefit elements to help fleets with these analyses.

10 Terminal Tractor Report Findings

The study team has six key findings based on the three battery electric terminal tractors that participated in RoL-E.

1. NACFE considers terminal tractors one of the best, if not THE best, paths for a heavy-duty tractor fleet to learn about and implement a BEV in a fleet operation.
    - Choosing to purchase a battery electric terminal tractor will help mobilize the fleet to understand the many aspects of what will be required in future larger purchases of BEVs. This would include evaluating the areas of purchasing, TCO considerations, facilities, vehicle parking, operations changes, selecting and installing electric charging infrastructure, driver training and reactions, maintenance, etc.
    - The battery electric terminal tractor is limited to a small area around the facilities, so it is always close to home. This allows for opportunity charging.
    - Electric units are available to be a direct replacement of virtually all diesel-powered terminal tractor use cases with very few operational adjustments.
    - Most terminal tractor duty cycles can get by with low power level (and thus less expensive) charging stations.
2. The drivers in Run on Less – Electric all rave about their quieter operation and improved performance. All the drivers mentioned that they liked the responsiveness of the battery electric terminal tractor, and they also liked the regenerative braking feature once they got used to it. In fact, Ryder driver Hancock, said, "For me the difference between an electric and a diesel tractor is response. When you drive an electric truck, when you press the accelerator, you get an immediate response." Drivers all mentioned the quiet operation, and some mentioned that this made hearing dispatch orders much easier. Also, one driver mentioned that it was great not having to deal with diesel fuel odors and spills.

3. The maintenance cost of a battery electric terminal tractor compared to the most recent diesel-powered terminal tractors (2017 and later with DPF and SCR aftertreatment systems) is dramatically reduced (approximately 60% to 75%). Multiple fleet leaders mention that newer diesel terminal tractors have created significant maintenance headaches and costs. Even with very little early experience with the battery electric terminal tractors, fleets are clear that these are a big improvement.
4. Battery electric terminal tractors have a positive environmental impact and will contribute to overall business sustainability goals.
5. Payback times for a battery electric terminal tractor compared to diesel-powered units are currently long for most applications (eight or more years) without incentives and other factors to help the TCO calculation.
    - Initial cost of a battery electric terminal tractor is currently $275,000 to $350,000 compared to $100,000 to $125,000 for a diesel-powered unit.
    - In most cases, electricity will be much less expensive than the diesel fuel that would be consumed by a conventional terminal tractor. In addition, there are significant maintenance cost benefits to the battery electric terminal tractor.
    - In many areas of the country there are incentives available to offset some of the purchase price of the electric equipment as well as incentives to help substantially with the costs of installing charging equipment. In addition, in some areas, Low Carbon Fuel Standard credits are available to offset some of the ongoing electricity costs of charging the vehicles.
    - Many additional less obvious benefits should be monetized specific to each fleet's circumstances.
6. Tracking the vehicle to verify the cost benefits can be very difficult without significant prior planning. Traditionally, tracking the expenses associated with terminal tractors is not a high priority for fleet operations. In the case of the battery electric terminal tractors, tracking operational costs will be a higher priority for most fleets due to the increased capital investment and ensuring that the TCO for the vehicles is managed. In order to adequately track the costs, data from the charging equipment, the electrical meter and the vehicle itself will be important to sorting out the return on investment. Planning for tracking these items in advance will be imperative.

Lesson Learned

The terminal tractor market segment is the best way for fleets to learn about and implement a BEV in their operation.

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12 Appendix A – Terminal Tractors Fact Sheet

TERMINAL TRACTORS

Jennifer Wheeler, Senior Program Manager, NACFE

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

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

Terminal tractors are Class 8 vehicles used to move semi-trailers and shipping containers (loaded or empty) short distances quickly and efficiently. They are commonly operated in warehouses, ports, cargo yards, truck terminals and cross dock facilities, and can be configured for both on-road and off-road applications. They are known by a variety of names, including yard truck, yard hostler, yard jockey, spotter truck and shunt truck.

Notable features include a single cab offset for improved driver visibility, a short wheelbase for tighter turning radius and a sliding rear door for drivers to efficiently couple and uncouple from trailers.

Increased maneuverability, especially in small spaces, make terminal tractors three to 10 times faster at moving trailers and/or containers than day cabs.

Diesel vs. Electric Comparison

Using Kalmar specs as a representative sample for terminal tractors

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** (lbs-ft)	500
25 mph	**Max Speed**	45 mph
$100,000 – $117,000	**Purchase Price** (USD)	$272,000 - $349,000

Market Summary

The terminal tractor market, globally, is estimated to grow from about $700M USD in 2021 to more than $850M USD in 2026. Currently in the US and Canada, there are approximately 25,242 terminal tractors in operation. Traditional OEMs include Kalmar, Terberg, Capacity Trucks, TICO Tractors, and Autocar. However, Kalmar, BYD, Lonestar SV, and Orange EV are also producing electric versions.

Run on Less – Electric included three brand new or remanufactured fully electric terminal tractors, all of which are available in the market today. Remanufacturing reuses the durable parts of an existing tractor, like the cab and frame, and restores them to like-new condition before they enter the electric truck production line.

The terminal tractors featured were the Kalmar Ottawa T2e, which is the electric version of the company's diesel T2 product platform; the Orange EV T Series, which offers both new and remanufactured options; and the Lonestar SV S22, which is fully a remanufactured tractor. Collectively, the duty cycles for these terminal tractors were highly representative of the overall market segment.

Both the Kalmar T2e and the Lonestar SV S22 terminal tractors operated alongside traditional diesel yard trucks at their respective locations.

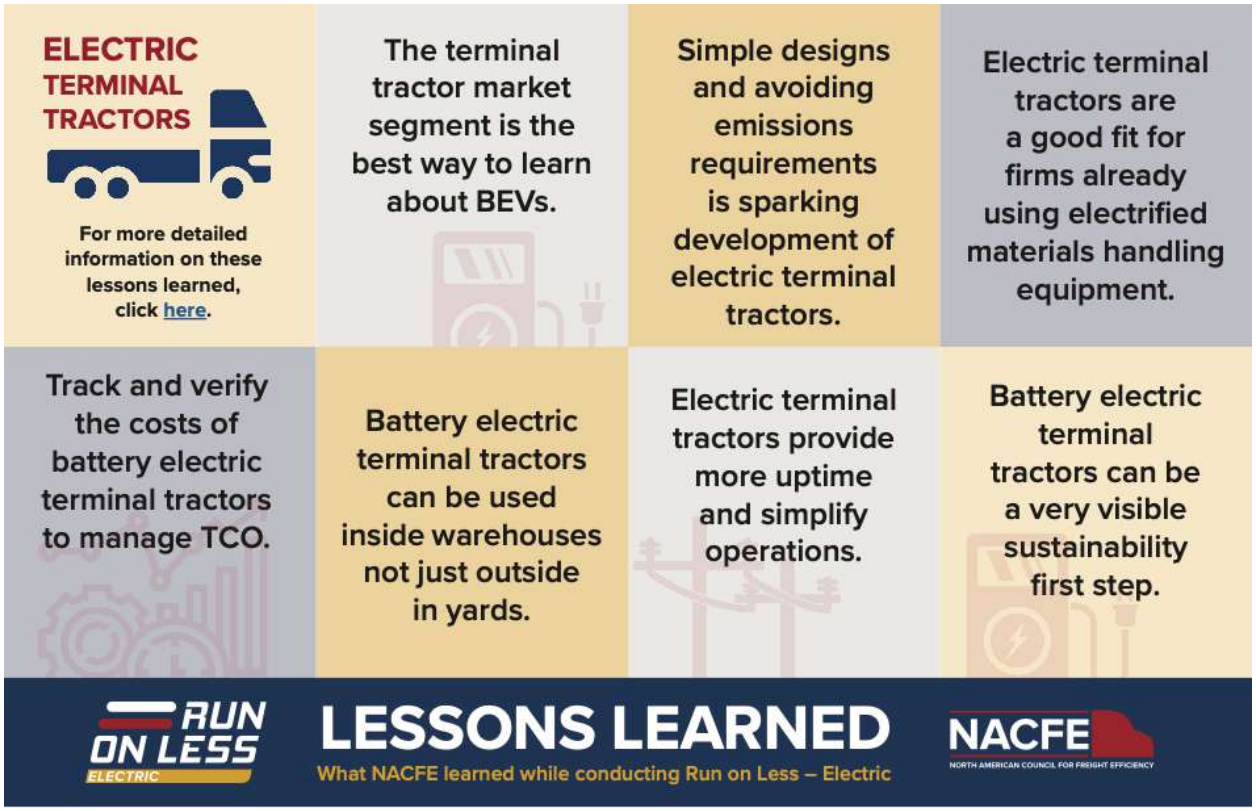
Because they are captured assets limited to warehouse yards or complexes, and the current battery technology fits the operational requirements of terminal tractors, **NACFE considers this segment to be 100% electrifiable.**

12/15/21 Terminal Tractors: Market Segment & Fleet Profile Fact Sheet 1

Download the entire Fact Sheet below:

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

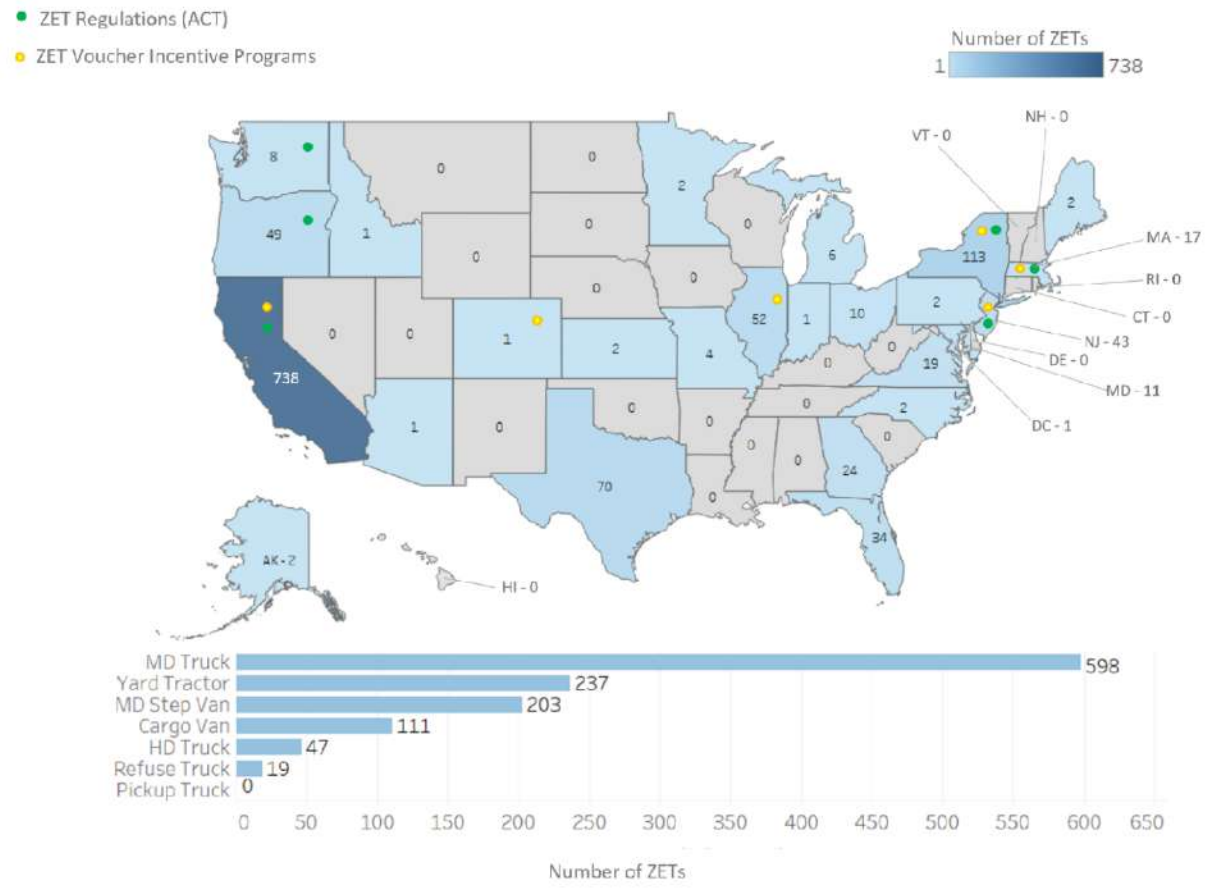
13 Appendix B – Lessons Learned



Download the Terminal Tractors Lessons Learned Graphic here.

14 Appendix C – Zero Emission Commercial Vehicle Deployment by State

Deployments of zero emissions commercial vehicles is not taking place everywhere across the United States. According to a report, *Zeroing in on Zero-Emission Trucks* from CALSTART, "They are concentrated in areas with supportive electric truck policies and regulations." The map below shows the deployment of zero emissions commercial vehicles by state.



Today, zero emissions vehicles have a high cost when compared to diesel-powered vehicles, so some states are offering incentives or grant funding opportunities to help defray the cost so more zero emission trucks will be purchased. The map also shows states that offer voucher incentive programs.

The map also details states that have the Advanced Clean Trucks rule, which will set targets for the sales of zero-emission commercial vehicles.