RUN ON LESS ELECTRIC REPORT

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

ELECTRIC TRUCKS HAVE ARRIVED: The Use Case for Heavy-Duty REGIONAL HAUL TRACTORS

RUN ON LESS ELECTRIC REPORT

ABSTRACT This report contains information and findings on the four battery electric regional haul Class 8 tractors that took part in NACFE's Run on Less – Electric (RoL-E) commercial battery electric production vehicle demonstration. Collectively, the duty cycles for these regional haul 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 focusing only on the battery electric Class 8 regional haul segment of the market — a market NACFE believes is 50% electrifiable today.

If 50% of the Class 8 regional haul tractors in the US and Canada were electrified, it would require approximately 40,432 gWh of electricity annually for charging and result in the avoidance of 29,351,582 metric tonnes of 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 the four heavy-duty vehicles via Geotab devices.

"New things are always scary when you try to change a culture, but the buy-in here with the employees is like 'wow, this is something new' and we actually care about the environment. It's really part of Anheuser-Busch's greener initiatives. The employees are seeing that. It's a big change and well worth the investment knowing that we're going to set up a better future for the next generation."

— Christopher Cochran, senior director of operations, Anheuser-Busch

AUTHORS & ACKNOWEDGEMENTS

STUDY TEAM

Mike Roeth, NACFE executive director

Rick Mihelic, lead author, NACFE director of emerging technologies, Mihelic Vehicle Consulting LLC

Kevin Otto, NACFE electrification technical lead

Dave Schaller, NACFE director of industry engagement

Yunsu Park, NACFE director of engineering

Jennifer Wheeler, NACFE senior program manager

John Richardson, NACFE electrification consultant

Rob Graff, NACFE/RMI project consultant

James Brown, producer/director, James Brown Media

STUDY EDITORS

Denise Rondini, NACFE communications director, Rondini Communications

Kim Ehrenhaft, NACFE design director

PEER REVIEWERS & CONTRIBUTORS

NACFE thanks the reviewers and the many interviewees who contributed to the content and quality of this report.

CONTACTS

Rick Mihelic, rick.mihelic@nacfe.org
Mike Roeth, mike.roeth@nacfe.org
Denise Rondini, denise.rondini@nacfe.org

NACFE TECHNICAL ADVISORY COMMITTEE

Tim Dzojko, Air Products
Randy Cornell, CFI
Matt McLelland, Covenant Transport
John Vesey, Hirschbach
Bruce Stockton, Miller Truck Lines & Paul Transportation
Tony Morthland, Nussbaum
Dan Deppeler, Paper Transport
Ken Marko, PepsiCo
Jordan Spradling, Pilot Travel Centers
Steve Jarosinski, Schneider
Dennis Elford, UPS
Guy Welton, Werner
Rick Mihelic, NACFE
Yunsu Park, NACFE
Mike Roeth, NACFE
David Schaller, NACFE

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

2022 FISCAL SUPPORT

Platinum

Gold

Silver

Bronze

Philanthropy

Report published May 5, 2022

RUN ON LESS ELECTRIC

SPONSORS

TITLE SPONSORS

DANA

MERITOR
RUN WITH THE BULL

Event Sponsors

APTIV

Peterbilt

electriphi

GEOTAB

VOLVO

LIGHTNING eMOTORS

PEPSICO

WORKHORSE

NRECA
America's Electric Cooperatives

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

FREIGHTLINER

LION ELECTRIC

electrify commercial

EPRI
ELECTRIC POWER RESEARCH INSTITUTE

Cummins

SmartWay
U.S. Environmental Protection Agency

ROUSH CLEANTECH

AMPLY POWER

EDF
ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

Supporter Sponsors

HDR

MGL Microgrid Labs
More than renewable energy

MOTIV
it's inEVitable

TRAXEN

ORSCHELN

NACV SHOW
NORTH AMERICAN COMMERCIAL VEHICLE SHOW

ACT NEWS
Advanced Clean Tech News
FOR THE COMMERCIAL TRANSPORT SECTOR

gna CLEAN TRANSPORTATION & ENERGY CONSULTANTS

MERLIN SOLAR

HORTON

Breakthrough.

Electrification Coalition

WOMEN IN TRUCKING

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

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

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

TABLE OF CONTENTS

TABLE OF FIGURES

ELECTRIC TRUCKS HAVE ARRIVED: The Use Case for Heavy-Duty Regional Haul Tractors

This report documents the four heavy-duty regional haul 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 heavy-duty regional haul tractors — a market segment where electric vehicles would work today in 50% of the applications, especially short and medium hauls.

It includes information about heavy-duty regional haul 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 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 will encourage 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.

ACKNOWLEDGMENTS

NACFE Report Team:

Mike Roeth, Executive Director, NACFE
Rick Mihelic, Lead Author; Director, Emerging Technologies, NACFE
Kevin Otto, Electrification Technical Lead, NACFE
David Schaller, Director, Industry Engagement, NACFE
Yunsu Park, Director, Engineering, NACFE
Jennifer Wheeler, Senior Program Manager, NACFE
John Richardson, Electrification Consultant, NACFE
Rob Graff, Senior Technical Advisor, NACFE & RMI
Denise Rondini, Director, Communications, NACFE
Kim Ehrenhaft, Design Director, NACFE

RUN ON LESS ELECTRIC SPONSORS

TITLE SPONSORS

DANA

MERITOR RUN WITH THE BULL

Event Sponsors

APTIV

Peterbilt

electriphi

GEOTAB

VOLVO

LIGHTNING eMOTORS

PEPSICO

WORKHORSE

NRECA America's Electric Cooperatives

icct THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

FREIGHTLINER

LION ELECTRIC

electrify commercial

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Cummins

SmartWay U.S. Environmental Protection Agency

ROUSH CLEANTECH

AMPLY POWER

EDF ENVIRONMENTAL DEFENSE FUND Finding the ways that work

Supporter Sponsors

HDR

MGL Microgrid Labs More than renewable energy

Motiv it's inEVitable

TRAXEN

ORSCHELN

NORTH AMERICAN COMMERCIAL VEHICLE SHOW NACV SHOW

ACT NEWS Advanced Clean Tech News FOR THE COMMERCIAL TRANSPORT SECTOR

gna CLEAN TRANSPORTATION & ENERGY CONSULTANTS

MERLIN SOLAR

HORTON

Breakthrough

Electrification Coalition

WOMEN IN TRUCKING

Heavy-duty Regional Haul Basics

Defining “regional haul” is challenging. The term tends to encompass a range of interpretations. A common element is getting the driver back home on a reliable basis, a clear statement that regional haul is relevant to a driver’s quality of life. With respect to emerging battery electric Class 7 and 8 tractors, current market entrants are advertising vehicle one-charge ranges in nominal conditions of 150 miles to 250 miles. Variations with more batteries are discussed with one-charge estimated ranges of up to 400 miles, but at the sacrifice of significant payload capacity. NACFE believes the BEV heavy-duty market with respect to range can be divided into three segments, short, medium and long regional haul, where the dividing lines are approximately as shown in Figure ES1 at maximum distances from depot of 50 miles termed short regional, 100 miles termed medium regional and 100 miles to 300 miles radius being long regional with return-to-base operations.

There are several duty cycles for Class 8 tractors, like drayage, beverage delivery, city diminishing load, milk runs and dedicated fast turns including long distances, with each one presenting its own unique challenges. Currently, there are an estimated 937,563 regional haul Class 8 tractors in the US and Canada. This estimate does not include vocational trucks, off-highway tractors, or long-haul tractors.

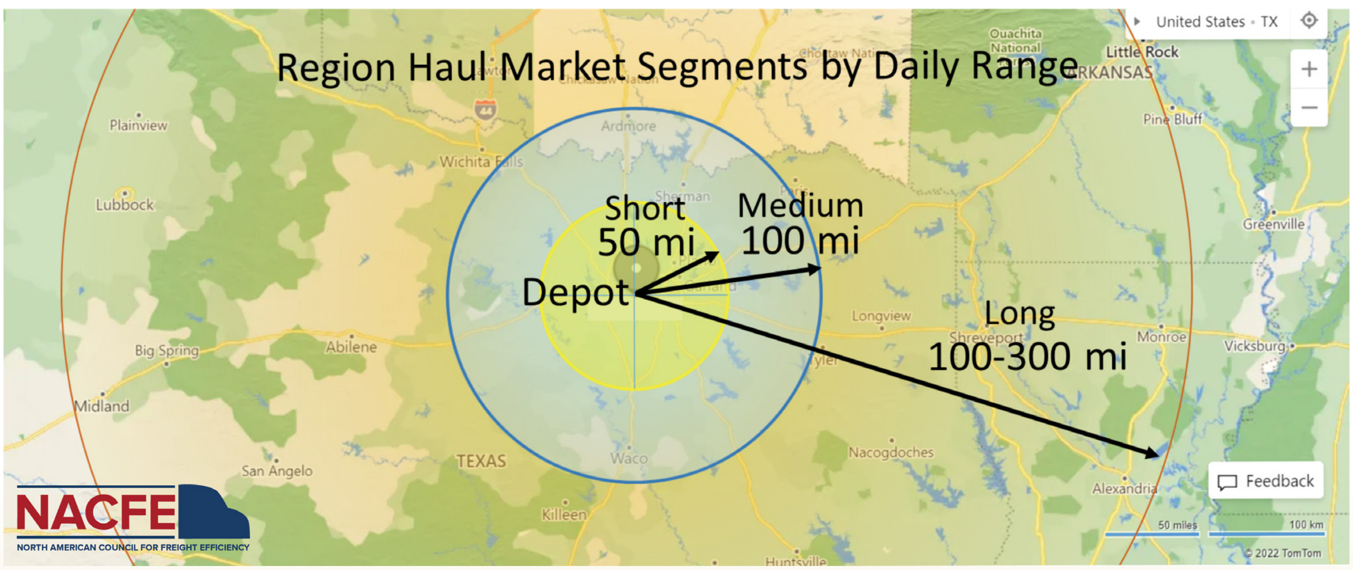
The challenge with regional haul tractors is the opportunity for dynamic (unpredictable) routing, longer routes, more wait time, and drivers not returning to base each day. As this segment transitions into the long-haul end of the regional spectrum, these opportunities are amplified and make electrification dependent, at minimum, on regional charging infrastructure.

With respect to emerging battery electric Class 7 and 8 tractors, current market entrants are advertising vehicle one-charge ranges in nominal conditions of 150 miles to 250 miles. Variations with more batteries are discussed with one-charge estimated ranges of up to 400 miles, but at the sacrifice of significant payload capacity and upfront vehicle cost.

Class 7 and 8 heavy-duty tractors are used in a wide range of duty cycles. Battery electric vehicles are not a solution today to replace every diesel, but the segment hauling below 200 miles per day is a significant portion of the market, and BEVs are capable today in that range, even with heavy loads.

FIGURE ES1

THE REGIONAL HAUL MARKET CAN BE BROKEN DOWN INTO SHORT, MEDIUM, AND LONG ROUTES.

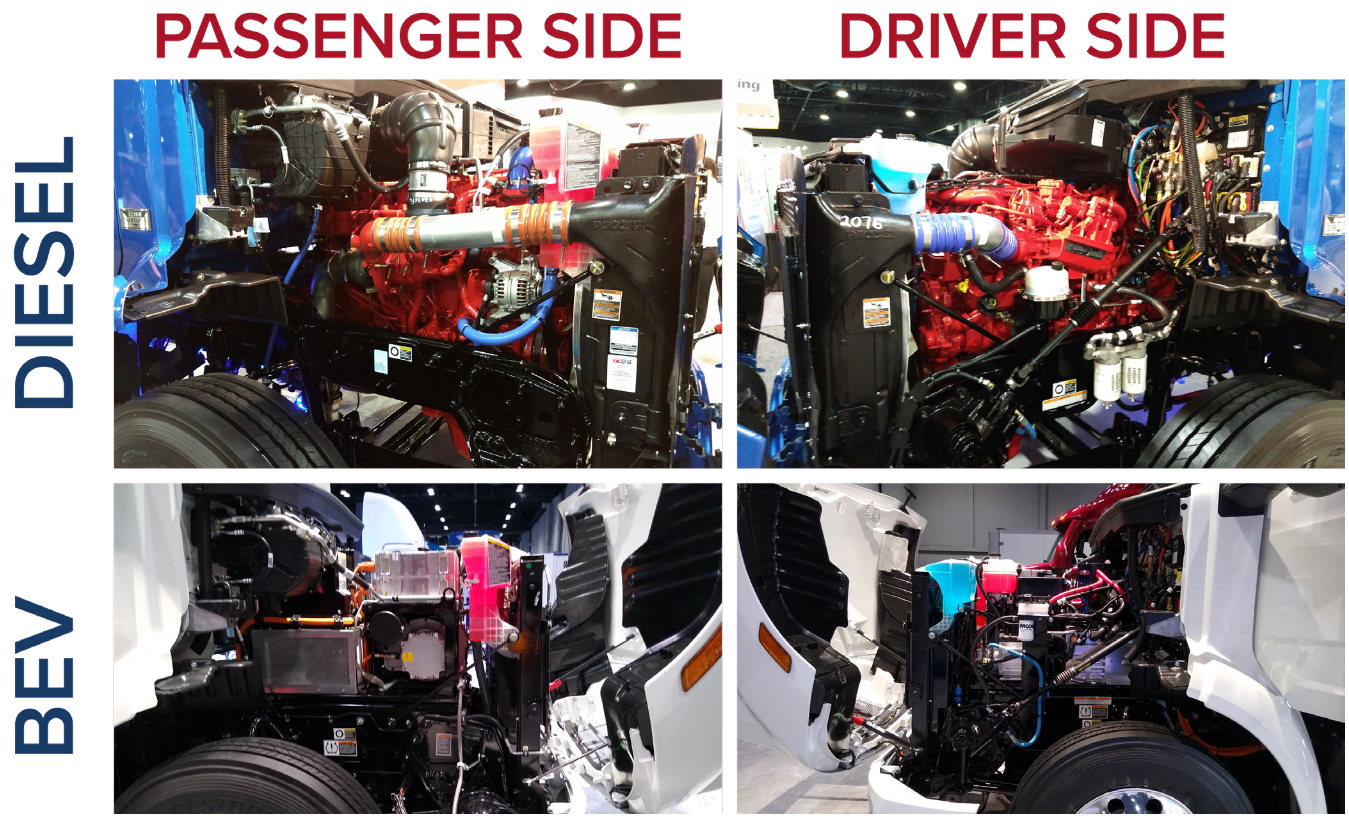


“Heavy-duty regional haul tractors drive three to 10 times more miles than their medium-duty brethren, offering a huge decarbonization opportunity. Their return to base operation also provides confidence for investing in infrastructure.”

— Mike Roeth, executive director, NACFE

FIGURE ES2

DIESEL VS. BEV UNDER THE HOOD: THERE ARE FAR FEWER MOVING PARTS IN A BEV THAN IN A DIESEL



Benefits of Heavy-duty Regional Haul Tractors

BEVs offer the potential for significant operating cost reductions, extended service intervals, less maintenance, improved ability to attract and keep drivers, better driver morale, and improved brand image.

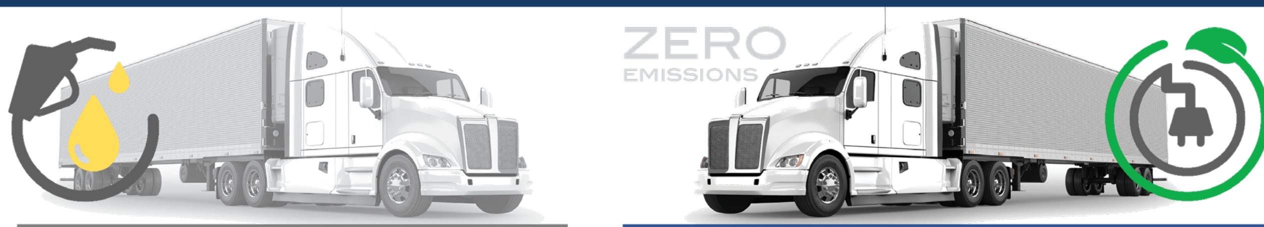
Specific to parts of the vehicle there are a number of advantages to consider including those in the areas of:

- **Emissions —** Battery electric Class 7 and 8 tractors have a significantly smaller emission footprint — both CO_2 and criteria pollutants.
- **Maintenance and Downtime —** There are fewer moving parts in a BEV, but an electric vehicle generally has more software to control the vehicle which allows for automating aspects of troubleshooting.
- **Part Count —** There are far fewer moving parts in a BEV than in a diesel. This means there are less friction and vibration sources to cause heat, wear and failure. See Figure ES2.
- **Fluids —**While BEVs will have some fluids, things like fuel, DEF and engine oil are not required. Coolant, and some amount of other lubricants likely will still be required for a BEV.
- **Emission Systems —** There are no emission systems or exhaust systems on a BEV.
- **Cooling Systems —** Diesels have a significant need for cooling systems to maintain proper conditions for the engine to operate. These all require radiators, ducting, sensors, pumps, filters, etc. BEVs also require thermal management systems, but there are fewer components.
- **Brakes —** The same air brake systems are on Class 8 BEV tractors, but they are greatly supplemented by regenerative braking which extends the life and service intervals for the friction material on air brake systems.
- **Tires —** There are arguments on both sides of the question of whether BEVs will accelerate or extend tire replacement cycles. However, one automotive tire manufacturer stated that tire life tests with similar vehicles showed that EVs can reduce tire life mileage by up to a quarter.
- **Transmission and Drivetrains —** BEV electric motors are able to deliver the same torque across nearly all speeds, requiring few if any gears.
- **12V Batteries —** The 12V batteries in BEVs do not have to provide starting power, there is no engine to start.

FIGURE ES3

FUEL COST COMPARISON BETWEEN DIESEL AND ELECTRIC HEAVY-DUTY REGIONAL HAUL TRACTORS

Fuel Cost Comparison Between Diesel and Electric Class 8 Tractors



Diesel	
Average Miles per Gallon	8.0
Average Gallons per Mile	0.125
Price per Gallon of Gasoline	$3.28*
Daily Range (mi)	200
Operational Days	250
Gallons Burned per Day	25
Cost of Fuel per Day	$82.00
Estimated Annual Fuel Cost	**$20,500**

* 2021 average weekly U.S. price per EIA

Electric	
Miles per Kilowatt Hour (kWh)	0.5
Kilowatt Hour per Mile	2.0
Price of Electricity per kWh	$0.112*
Daily Range (mi)	200
Operational Days	250
Electricity Consumed Per Day (kWh)	400
Cost of Electricity Per Day	$44.80
Estimated Annual Electricity Cost	**$11,200**

* 2021 average U.S. price of electricity – all sectors per EIA

Approximate Annual Fuel Savings per Vehicle:
$9,300

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

- **Electric cables high voltage —** BEVs bring additional high voltage cables to the vehicle but eliminate or simplify other existing cables.
- **Accessories —** BEV accessories will not be powered by belt drives because there are no belts on a BEV.

Another benefit of BEVs concerns drivers. The experience from the RoL-E interviews with drivers and their management teams is that drivers love electric trucks. Drivers universally stated the electric vehicles were better driving experiences versus diesels. There were several factors contributing to this conclusion, including reduced noise levels inside the cab, better acceleration, ease of operation, ease of charging, the fact that there are no emissions during idling, the fact that BEVs emit no fumes, and drivers find them less tiring to drive. In addition, there is the novelty factor about driving a BEV and they portray a positive brand image for the fleet.

Electricity costs are less volatile than diesel fuel prices. However, just looking at energy, current data supports Class 8 BEVs can operate at 0.5 mi/kWh. Comparing a Class 8 diesel to a BEV for a 200-mile daily range over a year shows a fuel costs savings of $9,300. See Figure ES3.

While the capital costs for both the BEV and its charging infrastructure are generally greater than that for diesels, there are grants, incentives and credits to offset the cost. These incentives will be in place for some years in order to get high volumes of BEVs into the marketplace. Over time, as production volumes increase and later models are subject to the forces of cost reduction and newer technology evolves, the list cost of these vehicles and infrastructure is expected to fall.

Challenges of Heavy-duty Regional Haul Tractors

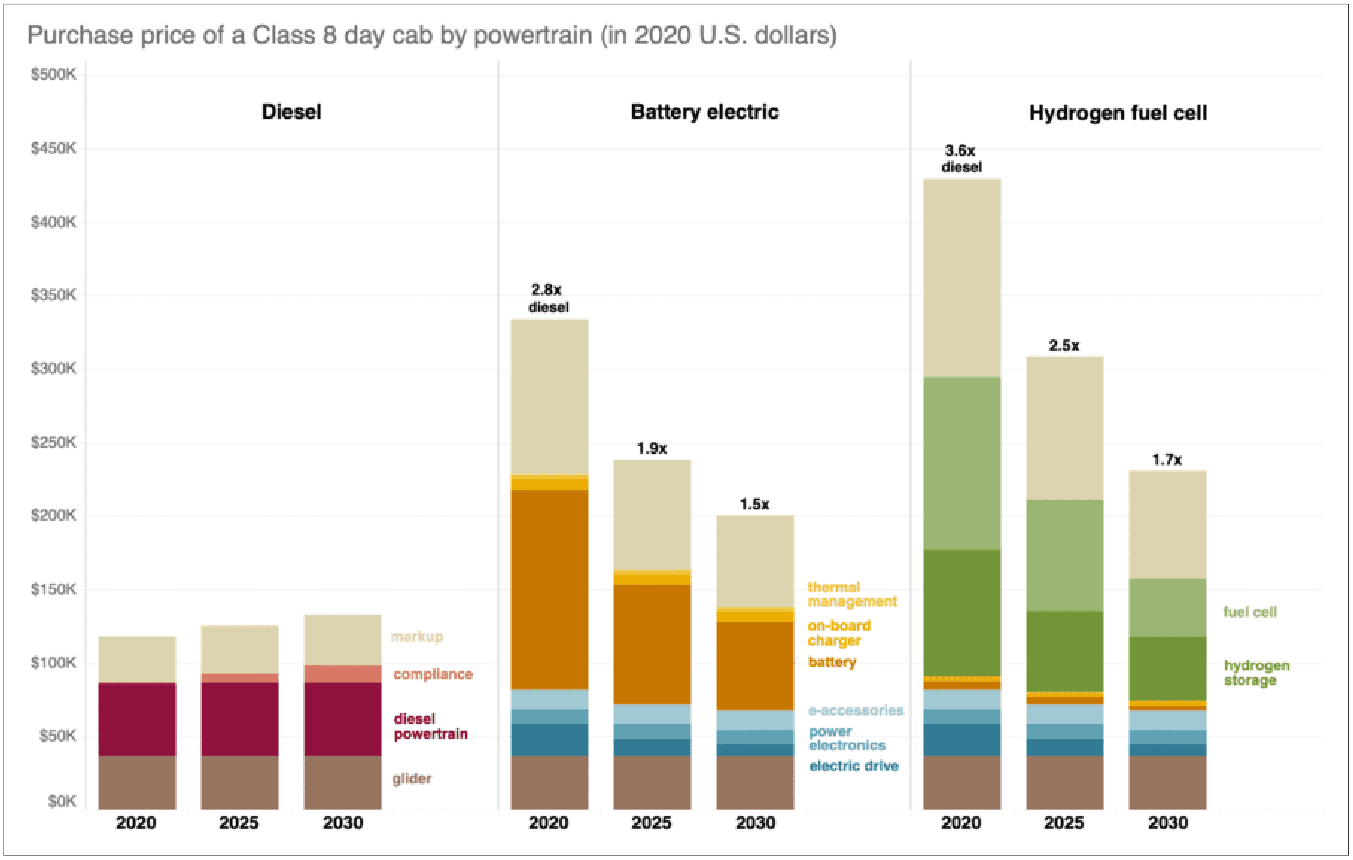
BEVs are not the solution for replacing every diesel truck in every duty cycle. BEVs for regional haul are best fits for shorter daily routes. The shorter the daily route for a BEV, the heavier the possible payload because of the trade-off between range and payload weight for batteries.

- **Purchase price —** Pricing of series production tractors is just now being documented on various purchase orders. While the list price of a BEV is two to three times higher than a comparable diesel, the out-the-door price with help of credits, grants or other incentives may be similar, and the actual TCO over a five-year period of ownership will show the BEV is better. See Figure ES4.

- **Charging time —** Battery electric 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 BEV.
- **Chargers —** Diesel fueling stations are everywhere; the same is not true for public charging stations. Regional haul BEVs are most likely going to be charged at their depots. This places the charging equipment, the electric vehicle supply equipment (EVSE), on site and the responsibility of the site.
- **EVSE Installation time —** Planning, permitting, procuring and installing utilities to support chargers can take months to perhaps a couple years to complete.
- **High voltage cable and connectors —** Thick, orange high voltage cables and connectors replace many of the mechanical drive components for a BEV versus a diesel. Cables will be expensive to replace, but when damaged they likely will be required to be

FIGURE ES4

PURCHASE PRICE COMPARISON FOR DIESEL, BEV, AND HYDROGEN FUEL CELL TRACTORS (SOURCE: EV NEWS)



“We have been working with the OEs. That was our point when we started this, to help them get their trucks to the point where they can scale. And that is where we are at today — a little more range, a little less weight — and we are good to go.”

— Bill Bliem, senior vice president, fleet services, NFI

replaced rather than repaired because of their high voltage.

- **Battery Life —** Batteries are one of the greatest concerns fleets have. Their durability — their expected life spans — are critical to estimating future costs, choosing duty cycles for the vehicles, and determining residual value.
- **Battery Cost —** A goal for battery pack price is $100/kWh. Current estimates from consulting firm Roland Berger are that 2021 prices ended the year at approximately $130/kWh.
- **Training —** Safety training is critical for BEVs including training of drivers, technicians, first responders, and other fleet personnel that might come near the vehicles. Safety protocols need to be second nature to operating around BEVs.

Heavy-duty Regional Haul In RoL-E

Four of the 13 vehicles in RoL-E were battery electric heavy-duty regional haul tractors: Anheuser-Busch with a BYD 8TT tractor, Biagi Bros. with a Peterbilt Model 579EV, NFI with a Volvo VNR Electric and Penske with a Freightliner eCascadia. Each of the heavy-duty regional haul 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 electric vehicle was equipped with a telematics device that reported the tractor activity throughout each day.

One of these vehicles, a BYD 8TT used by Anheuser-Bush to make beverage deliveries around Pomona, CA, completed the Run and its assigned job in an equivalent manner to its diesel counterpart. In fact all eight of these electric trucks at this location do. The other three tractors — Penske used the Freightliner eCascadia to haul freight from Temecula, CA to San Diego, CA; Biagi Bros used the Peterbilt 579EV to run shuttle loads between Napa, CA and Sonoma, CA; and NFI used the Volvo VNR on routes between Chino, CA and the Port of Long Beach — all performed as expected but as of 2021 did not have the range to complete the full day's work of their diesel incumbents. See Figure ES5. Collectively, the duty cycles and use cases for the Run on Less – Electric heavy-duty tractors are highly representative of return-to-base, single-shift operations within this market segment.

Market Segment Performance

Heavy-duty regional haul battery electric trucks are viable solutions today for improving fleet freight efficiency and

METHODOLOGY

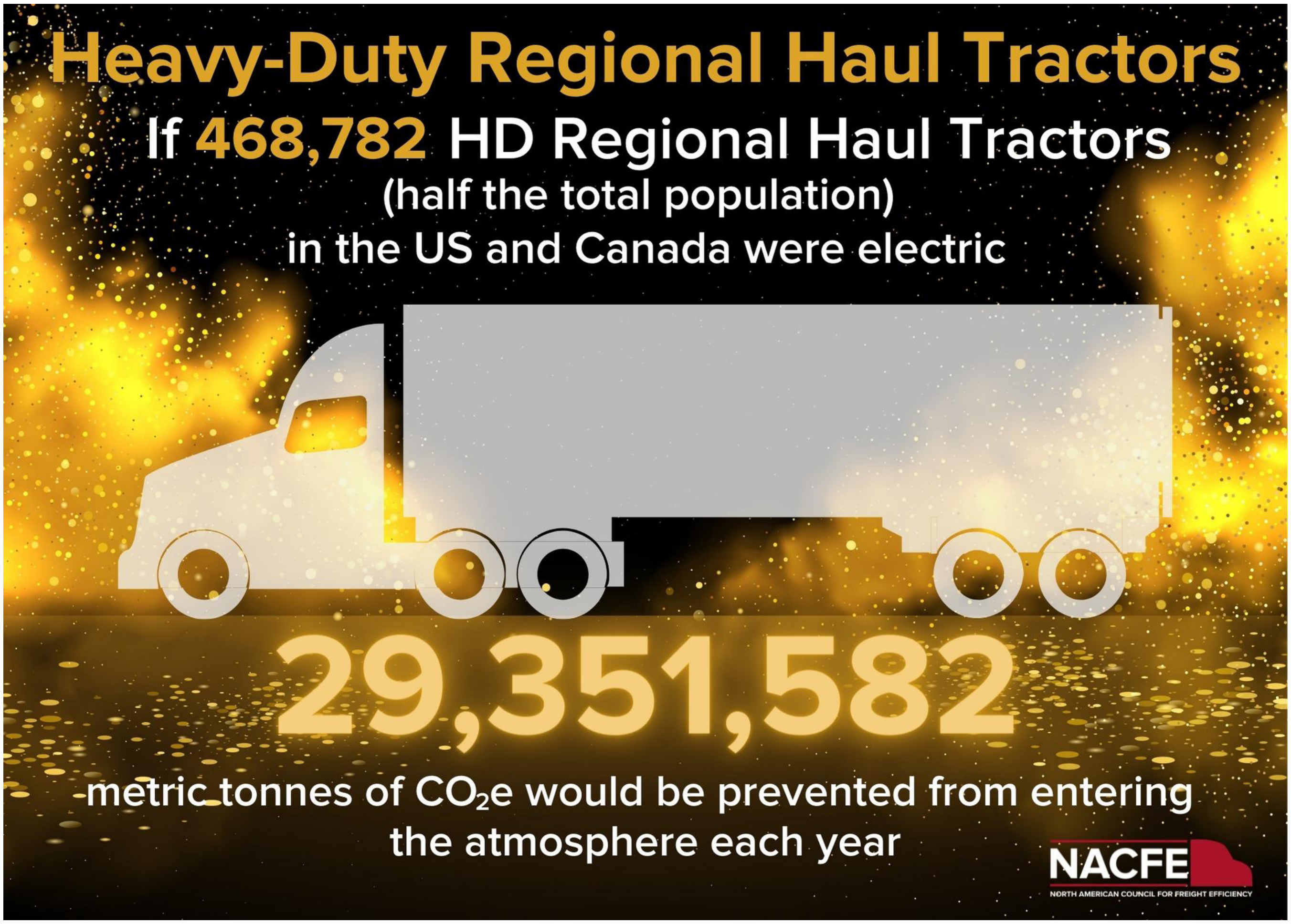
This report's conclusions were generated through the data collection and calculations from the four heavy-duty regional haul tractors that participated in Run on Less – Electric, interviews conducted with representatives from the participating fleets and tractor builders and input from other industry experts. All four vehicles were instrumented with a Geotab telematics device. The vehicle operations were continuously digitally tracked, and their metrics updated daily via a public website with the ability to view results by day or over a span of days. Metrics such as daily range, speed profiles, state of charge, charging events, amount of regenerative braking energy recovery, weather and number of deliveries were shown in near real time. Information on weather conditions was also observed.

FIGURE ES5

ANHEUSER-BUSCH, BIAGI BROS, NFI INDUSTIRES AND PENSKE HEAVY-DUTY REGIONAL HAUL TRACTORS THAT PARTICIPATED IN RUN ON LESS – ELECTRIC

FIGURE ES6

ESTIMATED NET EMISSIONS SAVINGS FOR RUN ON LESS – ELECTRIC REGIONAL HAUL TRACTORS



helping achieve sustainability goals on short and some medium length routes where daily mileage is 200 miles, with one shift return-to-base operations where overnight vehicle dwell time allows for lower cost overnight charging. Other variations of duty cycles also may be very viable where higher rate en route charging can extend vehicle range.

As Run on Less – Electric concluded in September 2021, NACFE predicted that 70% of this market segment was electrifiable. Given the more detailed analysis, interviews with industry experts and further research for this report, we now consider this market segment to be 50% electrifiable today. With lower average daily miles of 150, this results in the avoidance of nearly 29.4 million metric tonnes of CO_2e annually (e equals carbon dioxide equivalent). NACFE estimates the entire CO_2e to be eliminated by this segment at an average of 250 miles per day to be 97.8 million metric tonnes. See Figure ES6.

"We have continuous conversations to review what we've learned from various routes that the vehicles are running. How is it performing in different ambient temperatures? How it is working with different loads and route that have hills and no hills. We are trying to understand all the different way the vehicles can be utilized."

— Paul Rosa, senior vice president, procurement and fleet planning, Penske

Total Cost Of Ownership Discussion

Several of the OEMs that manufacture battery electric tractors have a TCO calculator that they use to help evaluate whether the purchase of a battery electric regional haul Class 8 tractor makes financial sense.

When calculating TCO for a heavy-duty regional haul electric tractor there are key inputs to include.

- The purchase price of a new diesel-powered unit vs. that of the electrified unit with comparable capabilities and features. See Figure ES7.
- The current fuel consumption numbers for diesel units.
- The cost of electricity per kWh coming into the property.
- The maintenance cost of diesel regional haul Class 8 tractors.
- The available incentives to lower the purchase price of a battery electric regional haul Class 8 tractors.
- The cost of adding charging infrastructure to the property where the battery electric regional haul Class 8 tractors will be operating.
- Include "difficult to monetize" benefits of EVs such as driver attraction and retention.

Findings for Heavy-duty Regional Haul Tractors

The study team has five key findings.

1. NACFE considers short and medium regional heavy-duty tractors electrifiable today with their range of 200 miles, about 3,000 to 4,000 lbs. of freight capacity penalty compared to diesels and improving total cost of ownership when monetizing all benefits. Regional haul tractors perform in various duty cycles including out-and-back, hub-and-spoke and diminishing return. Tractors currently available are meeting the needs of about 50% of this market segment.
2. Regional haul tractors return to base daily giving fleets confidence about making investments in charging infrastructure. These trucks often have 10+ hours of overnight dwell time for charging. Many people mistakenly assume Class 8 heavy-duty tractors are used in mostly long-haul disparate routes. In fact, only 40% are used in long-haul and 30% are vocational trucks and regional haul tractors respectively. These regional haul tractors are good

FIGURE ES7
COMPARISON OF DIESEL AND ELECTRIC HEAVY-DUTY REGIONAL HAUL TRACTORS

Diesel vs. Electric Comparison

Diesel	Factor	Electric
80,000	GVWR	82,000
152"-256"	Wheelbase	166"-200"
400-565	Horsepower	360-536
up to 2050	Torque (lbs-ft)	up to 4050
~50,000	Max Payload (lb)	~47,000 lb
$123,000	List Price	$250,000+
0	Incentives etc	$100,000+

candidates for electrification due to their shorter daily distances and return to base operation.

3. Operational changes such as the choices of the truck for each daily route, en route opportunity charging, driver incentives and managed charging are all examples of actions to improve the TCO of heavy-duty regional haul BEVs. Many actions are emerging to improve the TCO of operating electric vehicles in this market segment with many having to do with increasing range. Batteries are expensive and heavy so fleets can reduce the up-front cost by taking actions to extend the range. Others include lowering other costs such as charging during off peak hours.
4. The drivability (particularly in getting up to speed), quietness and other aspects make these trucks ones that drivers prefer over diesels, improving driver attraction and retention for fleets. Drivers of all sizes of electric vehicles share how much they like the driving experience over internal combustion engines. For regional haul driving much time is spent accelerating to highway speeds and this specific aspect of day cab electric tractors definitely will help attract and retain drivers in this segment.
5. Some medium and longer regional haul duty cycles pose more demanding requirements for current BEVs, but the next generations of products are bringing larger battery packs, better performing systems and lighter solutions to improve the TCO. Incentives are key to help the financials for these applications. NACFE defines medium and longer regional haul as vehicles that return to base frequently and travel in a radius of 100 to 200 miles or 200 to 300 miles respectively. Improvements are needed to make these vehicles – with their more than 200 and up to 600 miles of range – acceptable for total cost of ownership operations.

FIGURE ES8

LESSONS LEARNED ABOUT HEAVY-DUTY REGIONAL HAUL TRACTORS DURING RUN ON LESS – ELECTRIC (CLICK HERE FOR A LARGER VIEW)

1 INTRODUCTION

Heavy-duty regional haul battery electric trucks are viable solutions today for improving fleet freight efficiency and helping achieve sustainability goals on short- and medium-length routes, where daily mileage is less than 200 miles with one-shift return-to-base operations where overnight vehicle dwell time allows for lower cost overnight charging. Other variations of duty cycles also may be very viable where higher rate en route charging can extend vehicle range. Freight maximum capacity for battery electric vehicles (BEVs) with these 200 or less mile ranges may only reduce ~3,000 lbs. from an estimated ~49,000 lbs. maximum freight weight for a typical diesel day cab and trailer, to an estimated ~46,000 lbs. maximum freight weight for a BEV day cab and trailer. Range and freight weight capabilities are in context of the environment in which the vehicles operate.

The performance of the vehicle, expressed in kilowatt-hours/mile, is optimum in flat terrain and at moderate temperatures. Grade and temperature changes tend to decrease range, as they also do for diesels. The initial list price of battery electric tractors still is being determined by manufacturers, with estimates and early adopters seeing costs anywhere from 1x to 3x the price of comparable new model diesels. In many cases, total cost of ownership for these vehicles is equivalent or better when factoring in available BEV incentives, grants, tax benefits, credits, lower maintenance, higher uptime, and a variety of other economic factors. If 50% of the Class 8 regional haul tractors in the US and Canada were electrified, it would require approximately 40,432 GWh of electricity annually for charging and result in the avoidance of 29,351,582 metric tonnes of CO_2e annually (e equals carbon dioxide equivalent).

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 is the North American market for short and medium regional haul heavy-duty battery electric tractors. It will review the four fleets that operated Class 8 BEVs during RoL-E and other recent early market adopters, and share specific findings for this market segment from RoL-E.

2 WHAT IS A REGIONAL HAUL TRACTOR?

Defining "regional haul" is challenging. The term tends to encompass a range of interpretations. NACFE documented several examples in the report *More Regional Haul – An Opportunity for Freight?* as shown in Figure 1. [1]

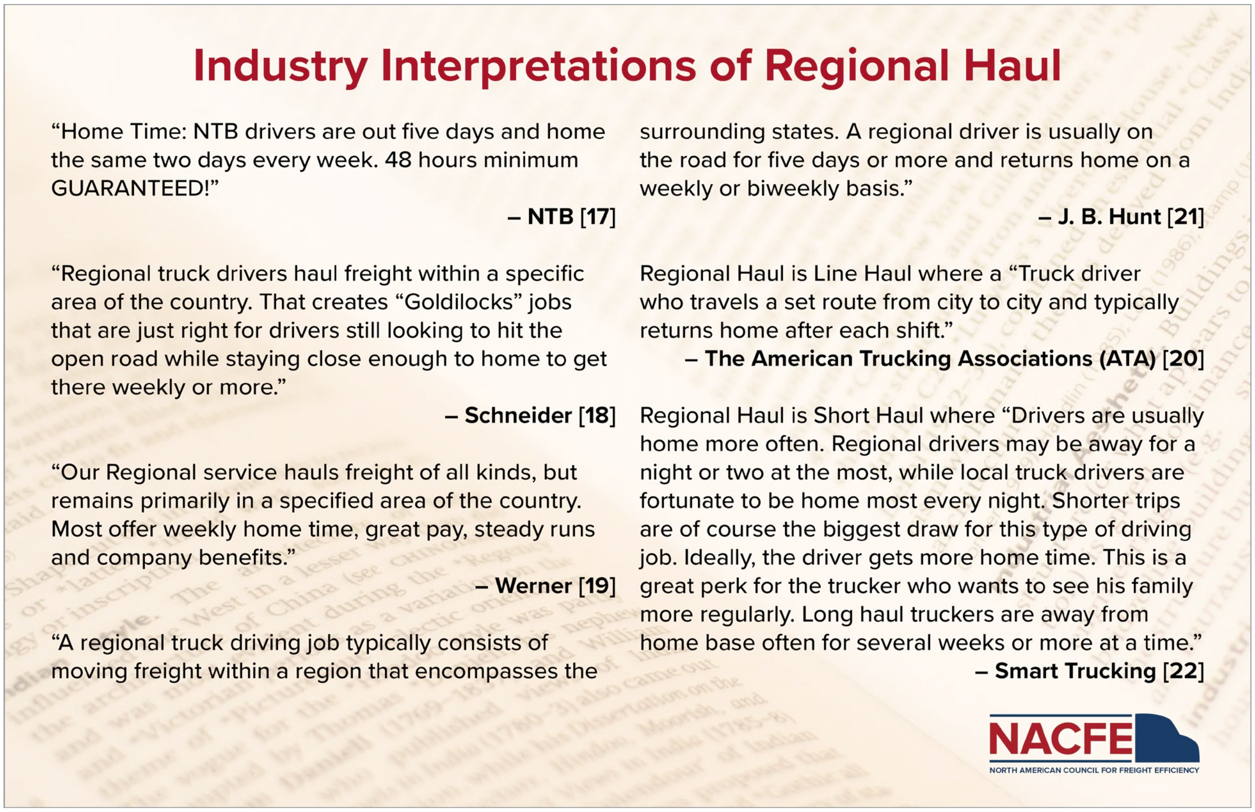


Figure 1. Example regional haul interpretations

A common element is getting the driver back home on a reliable basis, a clear statement that regional haul is relevant to a driver's quality of life. The driver's available hours of service also are key to interpreting regional haul. A driver's time behind the wheel is limited in many circumstances to 11 hours in a 14-hour maximum workday. This time includes:

- Time the vehicle is moving,
- Time waiting in line to drop off or pick up loads at a warehouse or distribution center,
- Handling the paperwork to get into and out of facilities,
- Time spent looking for parking,
- Time spent fueling,
- Time in traffic,
- Time hauling empty trailers or driving bobtail to pick-up a load, and
- Many other factors.

A 2015 J.B. Hunt investigation of driver time estimates that drivers actually may only be driving on average about 6.6 hours per day. The report, titled *660 Minutes: How Improving Driver Efficiency*

Increases Capacity, estimates a favorable day illustrated in Figure 2 at 406 total miles actually moving freight. [9]

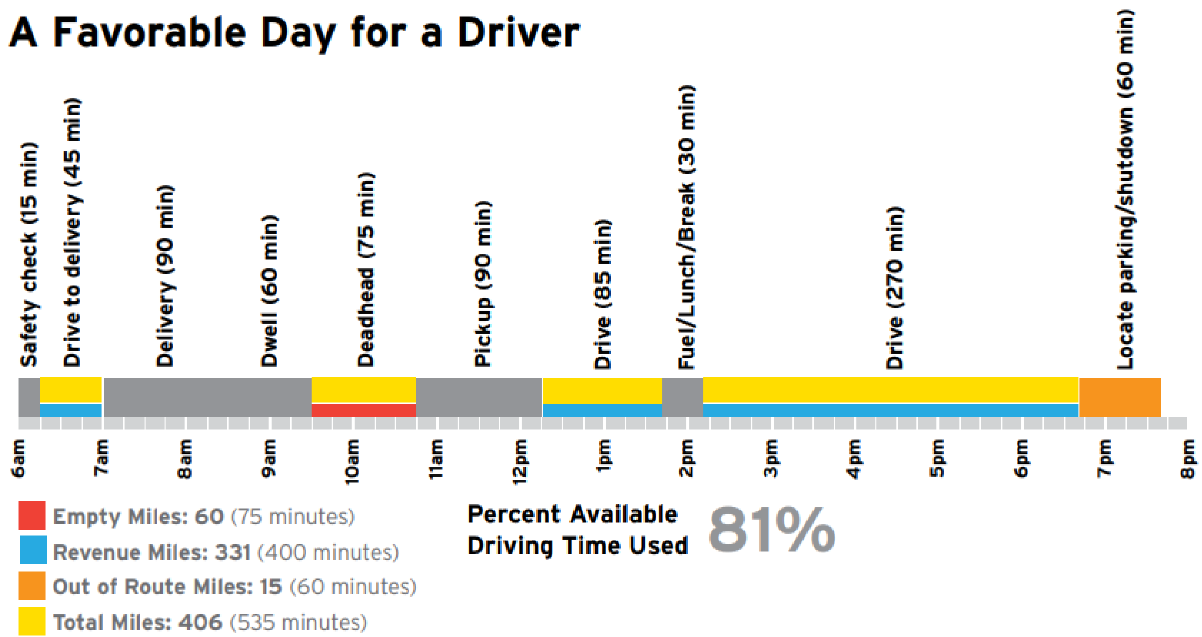


Figure 2. Time spent in a favorable day for a truck driver

On-highway drivers on a one-way trip can achieve distances of as much as 600 to 660 miles per driving day averaging 60 mph over the 11 hours allowed by hours-of-service regulations. NACFE's discussions with fleets and drivers reinforces that 60 mph is at the upper end of the averages attainable since the driving day includes dealing with traffic congestion, adverse weather, construction, accidents, and more. It is not uncommon for fleet speed averages to be in the low 50s mph ranges and even in the mid 40s mph range. They may have stretches of road where they drive at the posted speed limit, but all the other factors contribute to slower averages over a day's drive.

RUN ON LESS ELECTRIC

Lesson Learned

Time for en route charging might require new driver pay models and operational modifications.

A driver on a one-day round trip might achieve a 300-mile maximum range outbound from base, for a total daily mileage of 600 miles. NACFE's initial definition of regional haul was based on this assessment as shown in Figure 3. [1]

NACFE's Initial Definition of Regional Haul

Regional haul is defined as an operation where the truck stays within a 300-mile radius of a home base. This may include trucks that return to a home base every day or ones on a route for multiple days but that stay within that 300-mile radius.

Figure 3. Regional Haul initial definition (NACFE)

NACFE found that this definition was lacking specificity as a result of analyzing the 2019 Run on Less Regional fleet data. That efficiency demonstration focused on nine production diesel tractors and one production compressed natural gas (CNG) Class 8 tractor operating in regional haul operations where the vehicle predictably returned to base either daily or nearly daily. NACFE added greater granularity to the definition of regional haul by segmenting it further by duty cycle as shown in Figure 4. [16]

RoLR Stated Duty Cycles		Duty Cycles	Definition
A-B-A	"Out and back," same place every time	Shuttles	Short multiple runs <150 round trip
		Dedicated	150 to ~400 miles RT
		Dedicated Fast Turn	Full 1/2 day drive out ~500 miles RT
Hub and Spoke	Different destination each day "out and back"	Hub and Spoke	A-B with different place each day
A-B-C-D-A	Multiple stops during day	City	Multiple drops, low miles
		Diminishing Load	Drop offs only
		Milk Run	Drops and pickups later in the run

Figure 4. Regional Haul duty cycle definitions (NACFE)

With respect to emerging battery electric Class 7 and 8 tractors, current market entrants are advertising vehicle one-charge ranges in nominal conditions of 150 miles to 250 miles. Variations with more batteries are discussed with one-charge estimated ranges of up to 400 miles, but at the sacrifice of significant payload capacity and upfront vehicle cost. NACFE believes the BEV heavy-duty market with respect to range can be divided into three segments, short, medium, and long regional haul, where the dividing lines are approximately as shown in Figure 5.

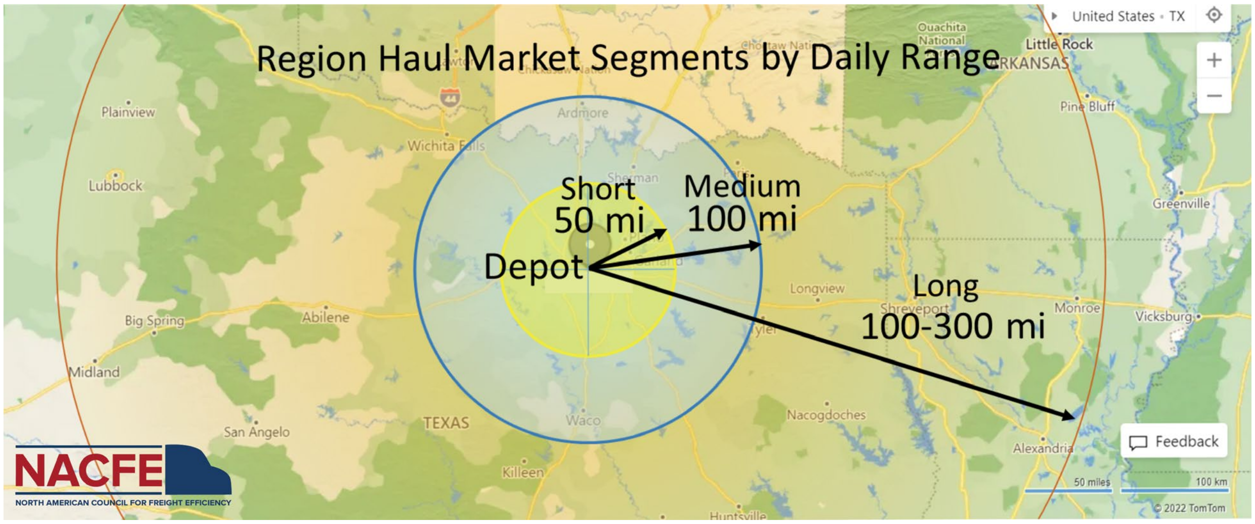


Figure 5. Short, medium, and long regional haul (NACFE)

Regional haul in the perspective of Class 7 and 8 tractors then encompasses a range of operational duty cycles with the underlying theme of both the tractor and driver returning to base on a reliable, definable, recurring schedule — typically daily. The tractor may make multiple trips in that day. NACFE started defining regional haul with Run on Less Regional that was conducted in 2019. Now, as electric trucks are explored, we are defining net daily mileage for one-shift operation as short regional haul if under 100 miles, medium regional haul if between 100 and 200 miles, and long regional haul as between 200 and 600 miles per day with return-to-base operation.

Regional haul may include both day cabs and sleeper tractors, although the nature of daily return-to-base operation suggests that day cabs are likely preferred for these duty cycles, especially short and medium regional haul. Tractors may be configured as 4x2, 6x4, or 6x4 with a liftable axle depending on the required freight loads and fleet or driver preferences. The primary trailers are dry van or refrigerated van 53’ in length, but other lengths may be in use as short as 28’ or even doubles. Drayage operations may be hauling 20’ or 40’ oceangoing containers or 53’ intermodal containers on chasses.

3 Duty Cycle Considerations

The predictable routes and return-to-base operations are duty cycles that make BEVs viable zero-emission alternatives to diesel engine Class 8 tractors. The two greatest concerns expressed about BEVs in NACFE’s experience, are about range and freight capacity. Those concerns tend to be overly biased by over-the-road long-haul experience and expectations. Regional haul is a different segment from long haul as detailed in NACFE’s report *More Regional Haul – An Opportunity for Trucking?*. [1]

Regional haul vehicles, in contrast to long haul, typically are driving predictable routes with predictable loads where fleets can readily assess whether a particular BEV’s specifications, over the life of the vehicle, will be adequate. NACFE’s RoL-E findings are that a significant portion of current regional haul duty cycles can be done with BEVs. The key is understanding each fleet’s specific regional haul operations rather than assuming all trucks by default are over-the-road long-haul trucks.

A starting point for fleets in considering replacing tractors is accurately quantifying their own duty cycles with respect to daily range and freight weight.

RUN ON LESS ELECTRIC

Lesson Learned

Focus on setting BEV parameters to optimize performance of each truck and route.

The discussion on range splits into four distinct quantifiable topics:

- Individual trip range,
- Driver's one shift day range,
- Truck's one day range, and
- Truck's one week range.

The discussion on freight weight splits into three operational types:

- Cubing out — where cargo is filled by volume but weighs less than maximum rated capacity.
- Weighing out — where cargo is filled by weight and reaches maximum rated capacity.
- Mix of both cubing out and weighing out.

Vehicles may be able to easily handle some number of round trips before recharging, but they may not be able to do all the multiple round trips over one driver's entire shift. In the case of slip-seat operations, the vehicle may need to do two or three driver shifts per day with little dwell time at the depot available for charging. However, where the trip distance is short, and/or operations have lengthy delivery dwell times with opportunities for en route charging, BEVs can adequately handle the entirety of one-shift operations.

Payload weight factors into capability to accomplish a day's work for the truck. Lighter payloads place lower demands on power, but even heavy beverage loads may be fine if the net daily mileage is not very demanding of the batteries.

Ambient temperatures, wind conditions, rain, snow, ice, and road grades also impact range just as those factors also impact diesel trucks.

3.1 Batteries and Duty Cycle Factors for BEVs

The heart of a diesel is the internal combustion engine (ICE). The heart of a BEV is the battery pack. A great deal of discussion revolves around capacity and weight of this system. Some background is relevant to evaluating whether a fleet's duty cycles are compatible with those of BEVs. This section provides a basis for determining the suitability of BEVs to a specific fleet's operations.

3.1.1 Battery Size and Duty Cycles

Battery specifications can be confusing. The battery pack is typically listed in kilowatt hours (kWh), but NACFE is seeing more transparency coming into the market by also listing how much of that battery pack is actually useable. There is somewhat of a parallel to this in diesel and gasoline tanks. A fill-up of a

100-gallon diesel tank may show up on the dash fuel gauge as full. But it can take some miles before the driver sees the gauge move. At the other end, the E for empty, drivers may not really know what that means, how much fuel is left when the fuel gauge needle points to E. Further, when the fuel stops flowing to the engine, there is some fuel still left inaccessible in the tank.

The battery pack has a need for safety margins at both ends of the state of charge gauge. At the top end, where state of charge is nearly full, that last bit of charging capacity has the greatest potential to damage a battery. Manufacturers may not make all of the battery available for driver use to protect the battery. Often the recharge times are specified to 80% of capacity. This is because charging to that level is quickest and poses the lowest risk to the battery pack. Above that point, charging can create excessive heat in the battery pack and cause chemistry changes that can reduce the life of the battery. That last 20% of charging may take as much time as going from 20% to 80%.

At the bottom end of the state of charge gauge, battery packs can be damaged if the charge actually goes to zero. Manufacturers provide a safety margin again at the bottom end to prevent damaging the battery life. They do this by reducing access below 15% to 20% of the battery. Software controls may derate power similar to the way diesel engine emission systems may derate if the emission systems are not working effectively.

The upper and lower safety margins in these battery packs are each unique for every battery pack design and potentially uniquely tuned by the OEMs for each fleet. Fleet buyers need to make sure that their vehicle provider is stating battery pack size as the nominal gross size and then the useable size. Graphically, this can be described as shown in Figure 6, using the analogy of a familiar AA battery.

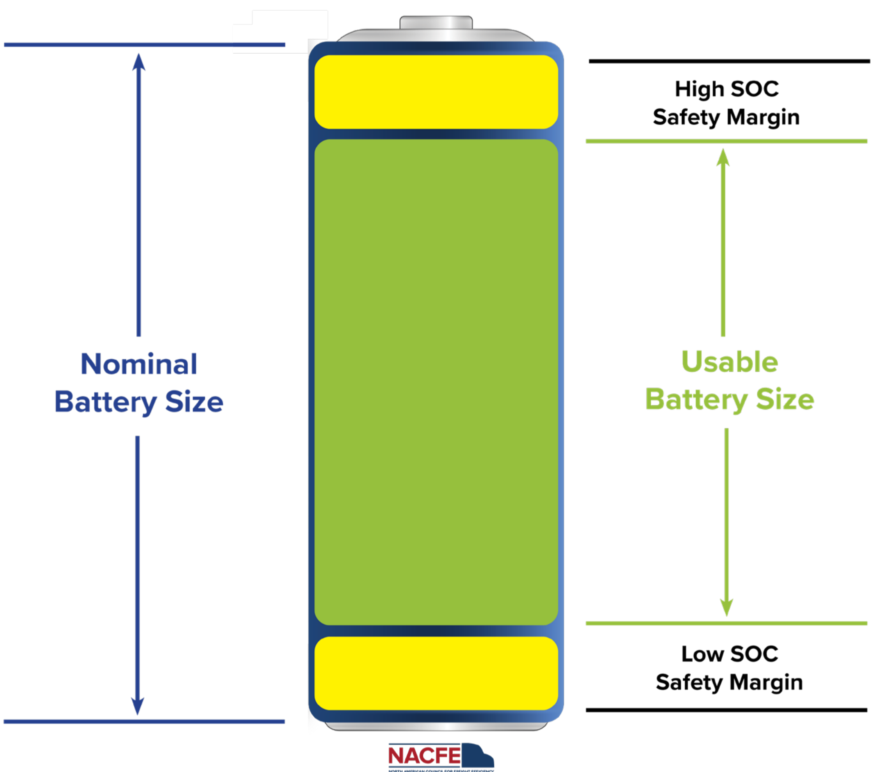


Figure 6. Nominal vs. useable battery size

3.1.2 Consumption and Duty Cycles

Battery consumption is the BEV factor stated as kWh/mi, or kilowatt-hours/mile. This is the estimated consumption of energy per mile for a particular battery pack. kWh/mi is the equivalent unit to gal/mi for diesels. Consumption is the mathematical inverse of efficiency. Efficiency is usually stated as mpg for diesels, but mi/kWh for BEVs.

NACFE stated in the report *Electric Trucks – Where They Make Sense* that BEV consumption values vary based on the technology and are improving over time, but generally are in the range 1 to 3, with 2.0 kWh/mi being a reasonable estimate of a typical heavy-duty truck battery pack today. [2] Fleets can do rough estimates of consumption from OEM specifications, typically provided on websites, where the OEM provides the battery pack size in kWh and the estimated range in standard conditions in miles. Just divide the kWh number by the range and you have an approximate value for consumption. The actual performance of the battery will depend on each specific user's duty cycles and environmental conditions. The battery capacity for a range of consumption values and vehicle estimated ranges is shown in Figure 7.

**Battery Capacity (kWh)
as a function of Energy Consumption and Range**

Energy Consumption (kWh/mi)	Range (mi)			
	50	100	150	200
1.0	50	100	150	200
1.2	60	120	180	240
1.4	70	140	210	280
1.6	80	160	240	320
1.8	90	180	270	360
2.0	100	200	300	400
2.2	110	220	330	440
2.4	120	240	360	480
2.6	130	260	390	520
2.8	140	280	420	560
3.0	150	300	450	600

Figure 7. Battery capacity kWh as a function of consumption and range

An example of using the chart, if the manufacturer's specification sheet states there is a 400 kWh battery pack with an estimated range of 200 miles, then the estimated consumption is 2 kWh/mi. Alternatively, if consumption is known to be 2.2 and the range is estimated as 100 miles, then the useable battery pack capacity is estimated as 220 kWh.

RUN ON LESS ELECTRIC

Lesson Learned

Today, lighter weight battery electric tractors are within 3,000 lbs. to 4,000 lbs. of their diesel counterparts.

Fleets should obtain actual consumption values for each of their expected duty cycles and regional conditions from their OEMs. Many factors can contribute to altering this rough estimate. Care also should be taken not to assume that one fleet's reported consumption value will be identical to another for the same vehicle, again because there are many variables that are unlikely to be identical between fleets.

3.1.3 Battery Weight and Duty Cycles

There are many battery chemistries in production and development. Research continues to make progress with increasing the energy density of batteries. New battery chemistries are seemingly announced every week, but fleets should bear in mind that it can take five to 10 years for those new chemistries to become production batteries at the OEMs.

NACFE reported in *Electric Trucks – Where They Make Sense* that battery pack weights derived from various sources range from 25 lb/kWh down to projected goals of 5 lb/kWh. [2] A reasonable estimate today for a production battery pack is 15 to 20 lb/kWh. That value is expected to continue to improve with newer generations of battery pack designs. The battery weight is estimated as a function of the energy density and battery pack capacity as shown in Figure 8.

Battery Weight (lb)
as a function of Energy Density and Battery Capacity

Energy Density (lb/kWh)	Battery Capacity (kWh)									
	100	200	300	400	500	600	700	800	900	1,000
5.0	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
10.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
15.0	1,500	3,000	4,500	6,000	7,500	9,000	10,500	12,000	13,500	15,000
20.0	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
25.0	2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	22,500	25,000
30.0	3,000	6,000	9,000	12,000	15,000	18,000	21,000	24,000	27,000	30,000

Figure 8. Battery weight (lbs.) as a function of energy density and range (NACFE)

An example of using the chart, if the battery capacity is 400 kWh, and the estimated energy density is 20 lb/kWh, then the battery weight is 8,000 lbs. Alternately, if the battery is known to weigh 4,500 lbs. and is nominally a 300-kWh pack, then the estimated energy density is 15 lb/kWh.

Fleets should obtain actual energy density values for each of their expected duty cycles and regional location from their OEMs. Many factors can contribute to altering this rough estimate. All batteries also are not alike in terms of cycle life. A million-mile EV battery pack has been demonstrated in automotive examples, and the expectation is that a million-mile truck battery pack is technically viable. OEMs may choose to provide shorter life batteries in trade-offs with other factors such as charging rates, cost, reliability, weight, etc.

Bill Bliem, senior vice president of fleet services at NFI, presented insights on NFI's experience to date with BEVs at the 2022 American Trucking Associations (ATA) Technology & Maintenance Council (TMC). NFI is one of two current companies with plans to deploy 50 or more Class 8 battery electric tractors and associated depot charging infrastructure in California. NFI's BEV expectations are shown in Figure 9 and Figure 10. [23]

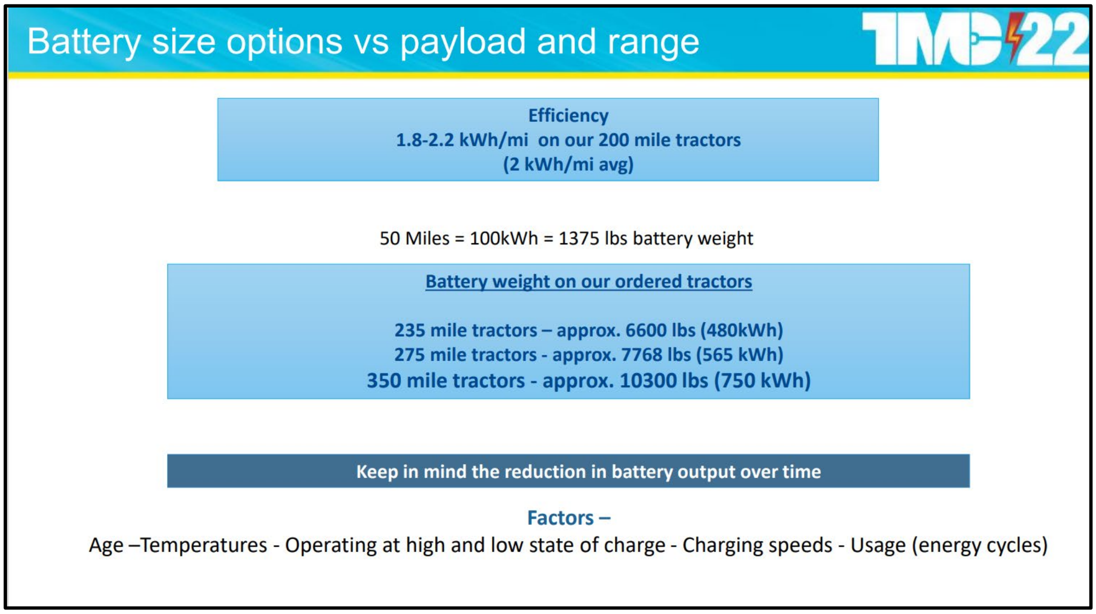


Figure 9. Example production BEV weight, range and consumption (NFI/TMC)

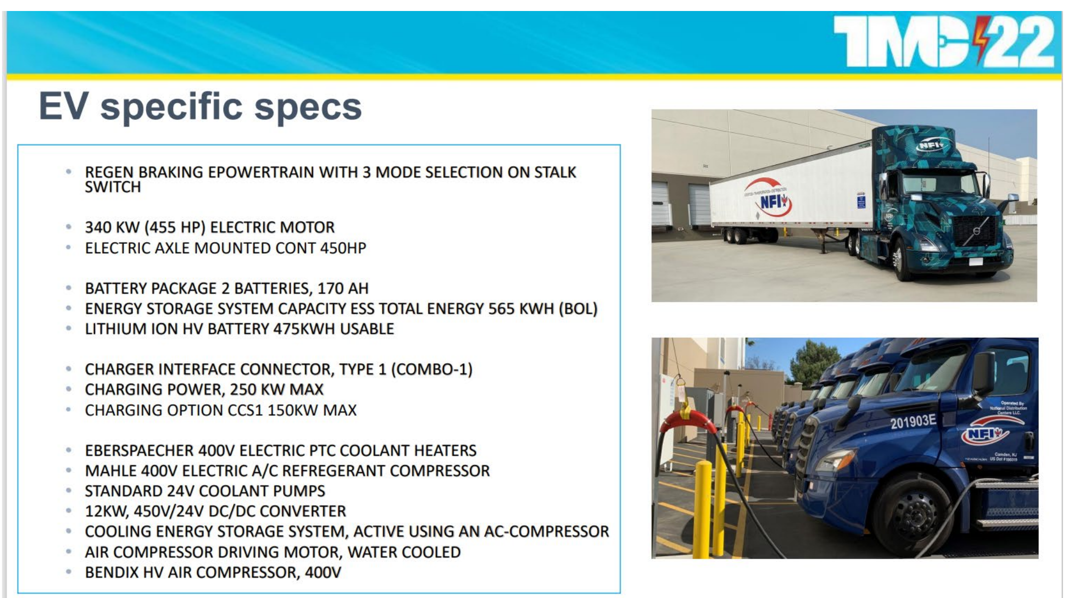


Figure 10. NFI Volvo BEV truck specifications (NFI/TMC)

3.1.4 Vehicle Specifications Regarding Batteries

Production tractor specifications are becoming available from manufacturers and vehicles are being displayed at industry events. Three examples of Class 8 BEV details shown at the 2022 TMC meeting are illustrated in Figure 11. This level of marketing information is insufficient to clarify how much battery actually is accessible by the driver. Similarly, battery charge times need to clarify what the state of charge starting points and end points are that correspond to the quoted charging times. A footnote on one specification indicates that the charge times shown for one vehicle were based on charging from 10% state of charge to 80% state of charge at 240 kW charging level. No details were listed as to 80% of what battery level, the gross battery pack kWh, or the useable battery pack kWh. None of these indicated what assumptions were made about the amount of energy recovered through regenerative braking in estimating ranges. No detail is shown as to what environmental conditions correspond to the quoted data. There was no detail on what assumptions were made on trailer and freight weights for these values.

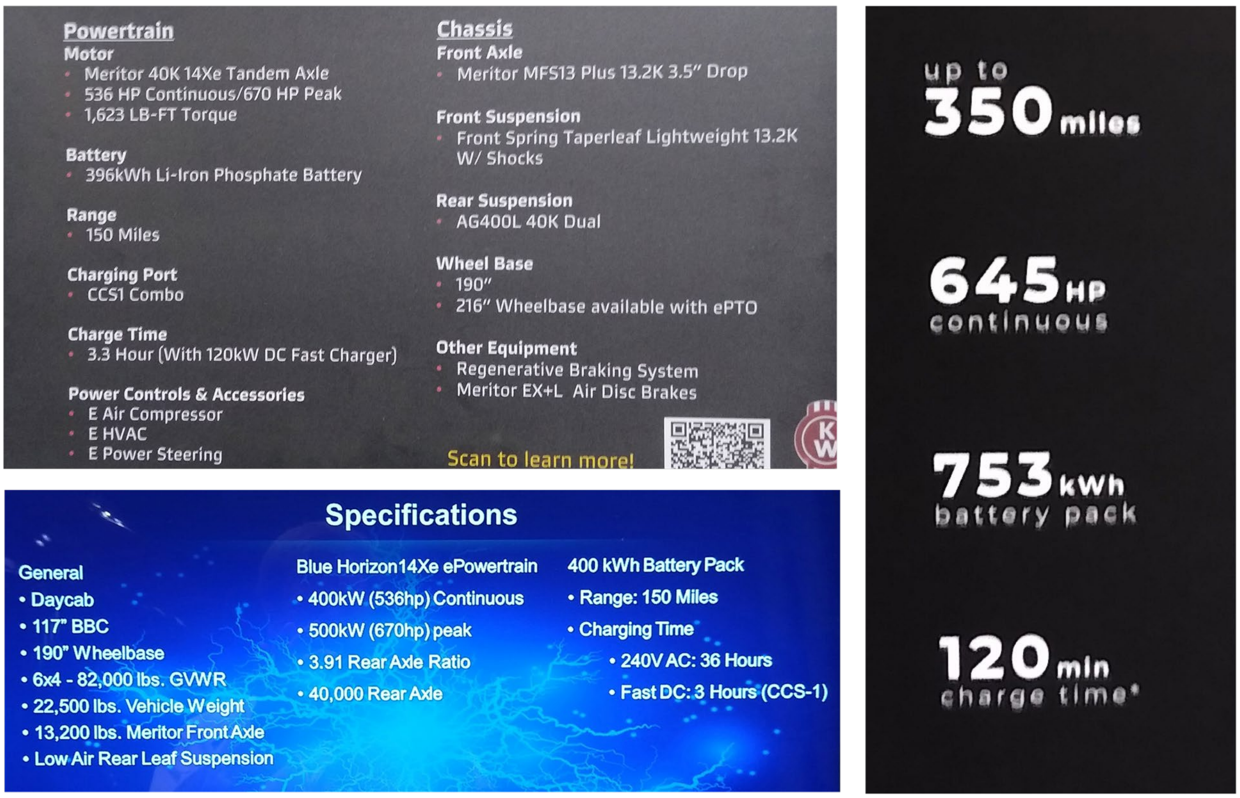


Figure 11. Example marketing specifications for Class 8 BEV (photos by Rick Mihelic)

Fleets should obtain detailed vehicle specifications from OEMs when considering BEVs. The specifications should be reviewed and validated just as fleets have in the past with diesel specifications. Fleets should obtain tare values through certified scales to validate tractor weights and validate performance factors such as range through their own duty cycles for their specific operating regions. Factors such as energy recovered through regeneration are not standardized in the industry at this time, nor are ambient conditions or assumptions on freight and trailer weights used by OEMs in estimating ranges.

RUN ON LESS ELECTRIC

Lesson Learned

Using the highest regenerative braking setting will extend range.

3.2 Weight

Weight is a primary concern for fleets considering BEVs to replace their diesels. How much freight can be carried depends on the tare weight of the tractor and trailer, and the regulated allowed gross vehicle weight rating (GVWR). BEVs are heavier than their diesel counterparts. Each fleet needs to understand their own vehicles and loads to determine if BEVs are suitable for their operations.

3.2.1 Estimating Vehicle Tare Weight

Vehicle tare weight seems pretty simple; fleets run their unloaded tractors and trailers over a certified weigh scale, and they know the tare weight within a reasonable tolerance, usually ±200 lbs. Finding BEV tare weights is made more difficult by a lack of published information by OEMs and fleets. There also is a very small number of production vehicles in the hands of fleets. At this early stage of BEV production and sales, tare weights are considered very sensitive numbers with respect to competitive marketing. What some OEMs and the fleets don't seem to realize is that the cloak of secrecy is pretty minimal since production trucks will be operating in 2022-2023 and will go across weigh scales loaded and unloaded, and fleets, drivers, media, competitors, and bloggers likely will likely post this information.

Today however, fleets can generally only estimate weights of future BEVs unless they already are in possession of the few production units on the road. NACFE estimated the tare weight of BEVs in the report *Electric Trucks – Where They Make Sense*. [2] More recent values on Class 8 battery electric day cab tractor weights have been observed or discussed by fleets and media ranging from 22,000 lbs. up to 29,000 lbs. depending on the model, specifications and OEM.

Estimates of production diesel day cab tare weights vary between 15,500 lbs. up to perhaps 18,000 lbs. depending on option content. NACFE estimated in the *Electric Trucks – Where They Make Sense* report that approximately 7,000 lbs. to 8,000 lbs. of diesel related equipment would be removed in converting a diesel truck into a battery electric truck. All of these numbers thrown together place the estimated tare impact of a BEV versus a comparable diesel at between approximately 6,500 lbs. to as much as 13,500 lbs. for published BEV vehicle ranges on the order of 200 to 250 miles. Other ranges are being planned or currently offered. Just as diesels can be specified with larger fuel tanks for longer ranges, BEVs can be specified with more battery packs for longer ranges. As with adding tanks to diesels, adding more battery packs to BEVs adds tare weight to the truck.

One key part of the vehicle tare weight is the trailer. Trailers vary in weight based on age (or vintage), material, length and type. The ubiquitous 53' dry van trailer can vary between 12,000 lbs. to more than 15,000 lbs. depending on option content and OEM. A typical value for a dry van trailer is estimated as 14,000 lbs. A tractor will be paired with many trailers over its operational life and those trailers vary considerably in age, construction, weight, etc. Some trailers may be more than 20 years old. The net tare weight of the tractor and trailer is estimated in Figure 12 based on assumptions on each.

Tractor Trailer Tare Weight (lb)
as a function of Tractor Tare Weight and Trailer Tare Weight

Trailer Tare Weight (lb)	Tractor Tare Weight (lb)									
	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000
12,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000
12,500	26,500	28,500	30,500	32,500	34,500	36,500	38,500	40,500	42,500	44,500
13,000	27,000	29,000	31,000	33,000	35,000	37,000	39,000	41,000	43,000	45,000
13,500	27,500	29,500	31,500	33,500	35,500	37,500	39,500	41,500	43,500	45,500
14,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000
14,500	28,500	30,500	32,500	34,500	36,500	38,500	40,500	42,500	44,500	46,500
15,000	29,000	31,000	33,000	35,000	37,000	39,000	41,000	43,000	45,000	47,000

Figure 12. Net tractor trailer tare weight (NACFE)

An example of using the chart, if the trailer tare weight is 13,500 lbs. and the tractor tare weight is 24,000 lbs. then the net tractor trailer tare weight is 37,500 lbs. Alternatively, if the net tractor trailer tare weight is 36,000 lbs. and the trailer weight is 14,000 lbs. then the tractor tare weight is 22,000 lbs.

Tare weight typically does not include the driver or their possessions. This can total to 200 to 400 lbs. The tare weight on diesels also may or may not include full fuel and DEF tanks, depending on who is providing the data.

3.2.2 Loaded Vehicle and Freight Weights

Loaded vehicle weight for diesels is limited generally to 80,000 lbs. GVWR without special permits or allowances for special equipment. There is a federal allowance for BEV vehicles of 2,000 lbs. additional GVWR for an allowed maximum weight of 82,000 lbs. as reported in NACFE's Guidance Report: *Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors*. [3]

Estimating the freight weight maximum capacity differences between the BEV and an equivalent diesel is challenging because a true equivalence of specifications is unlikely. For example, a diesel may have 120 to 200 gallons of fuel on board allowing it at 7 mpg to travel 840 to 1,400 miles — multiple days before refueling if the daily range is only 200 miles. An equivalent BEV would have a massive battery pack to attain the same total range. Instead, the BEV refuels each night by recharging. It accomplishes the same daily range, and over the course of the same week, can go the same distance as the diesel, but has done so with nightly charging. Another difference is that a BEV produces zero emissions while a diesel has emissions. There are multiple other apples-to-oranges differences buried in the phrase "equivalent" truck. The reality is that a fleet has a diesel doing a daily duty cycle(s) today and they want to replace it with a BEV doing the same daily cycle. The equivalence desired is with respect to the daily duty cycle(s), not the truck.

There are many factors in estimating the freight weight differences between a diesel and a BEV. As one example, assume the diesel tractor tare weight is 16,000 lbs., the trailer tare weight is 14,000 lbs., for a total of 30,000 lbs. The maximum permissible freight weight is then 50,000 lbs.

Assume the BEV has a 200-mile range with a 400-kWh battery pack and the tractor tare weight is 24,000 lbs. including 8,000 lbs. of battery. Mated to the same 14,000 lbs. trailer, the total tractor-trailer tare is 38,000 lbs. The maximum permissible freight weight for this example BEV is 44,000 lbs.

The diesel in this example can carry 6,000 lbs. more freight than the BEV. While the BEV maximum possible freight capacity is reduced compared to the diesel, the BEV can still carry 44,000 lbs. of freight which is a statistically significant amount of freight.

NACFE has reported on the statistical distribution of actual weights of Class 8 tractor-trailers. There is a bias in the industry that assumes all tractor-trailers operate at 80,000 lbs. all the time. In reality, the number of vehicles that actually weigh out at 80,000 lbs. is statistically small.

The graph shape of the distribution of freight weights over time on highways looks like the Golden Gate Bridge in Figure 13, what engineers call bimodal, meaning there are two peaks representing the highest volume of vehicles. The two towers of the bridge — the peaks of the graph — occur at the low end around 37,000 to 40,000 lbs. gross vehicle weight (GVW) and at the high end about 72,000 to 80,000 lbs. Just like the bridge's vertical cables vary in length, truck weights vary all the way across the span.

Figure 13. Vehicle weights vary bi-modally in graphs that look like the Golden Gate Bridge (Mihelic)

In several reports, NACFE has cited freight weight data, including data shown in Figure 14, Figure 15, and Figure 16 from M.J. Bradley and New West Technologies. [3][4] The graphs were originally reported in a 2010 National Academies of Sciences, Engineering and Medicine Transportation Research Board (TRB) report, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.* [4][3]

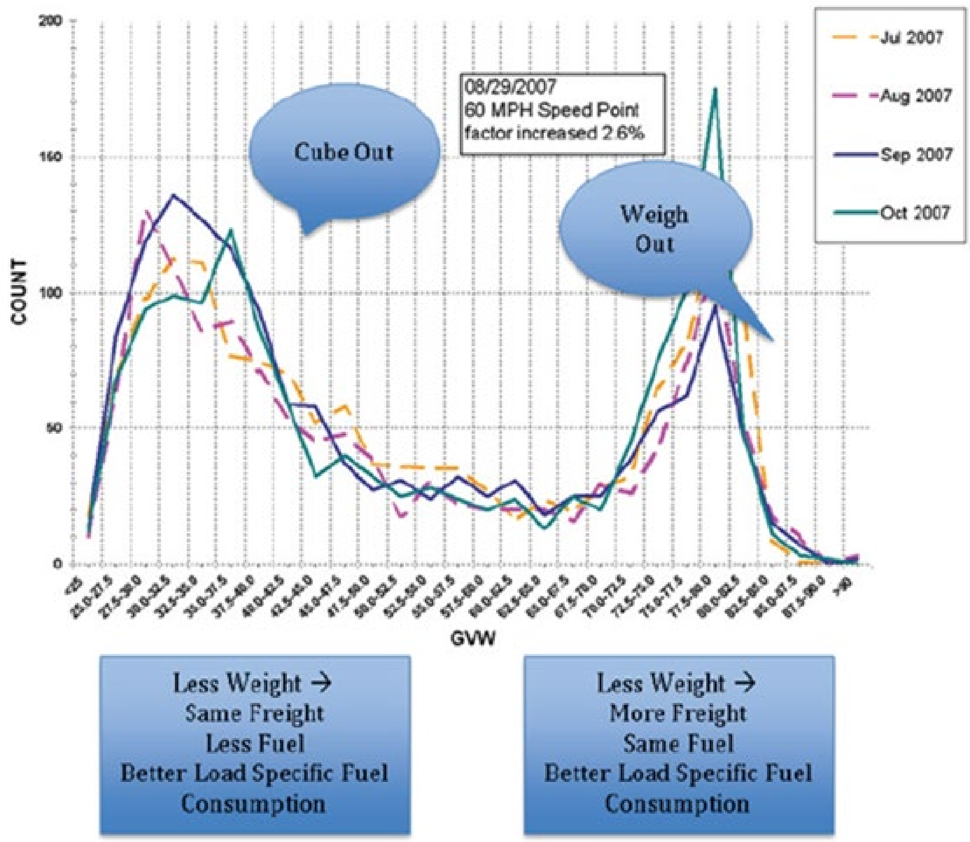


Figure 14. Bimodal distribution of truck gross vehicle weight for five axle vehicles from Weigh-in-Motion data (Quinley)

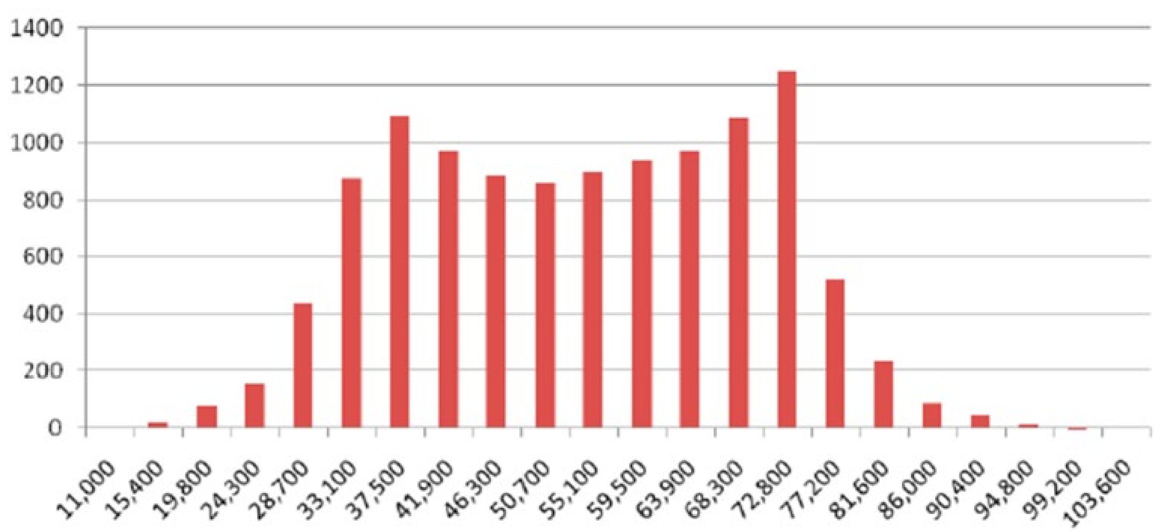


Figure 15. Truck weight distribution from 2008 weigh-in-motion (New West Technologies)

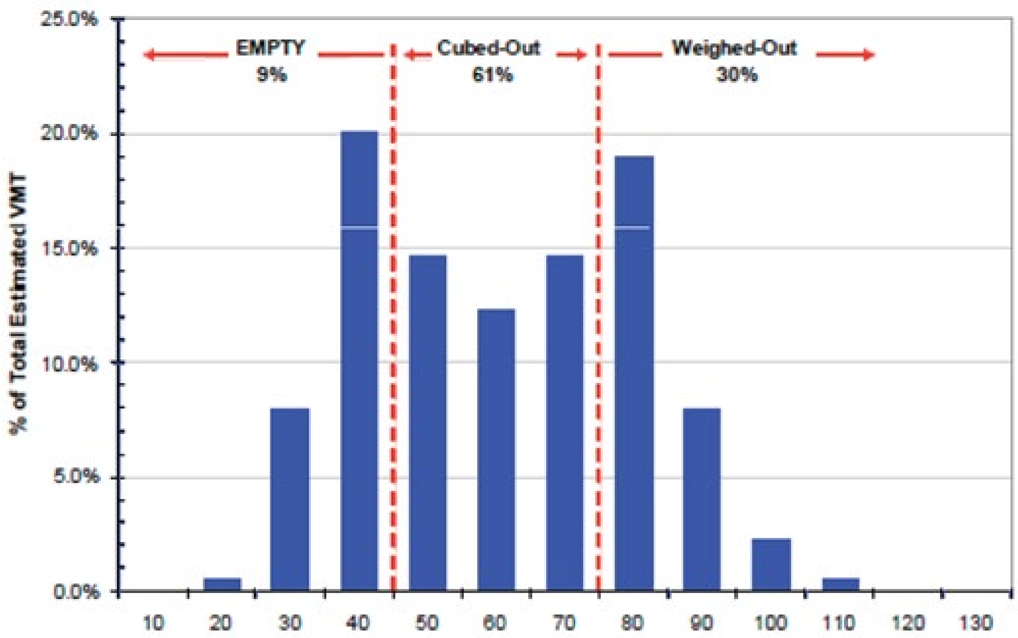


Figure 16. Truck weight distribution from 2009 (M.J. Bradley & Associates)

More recently NACFE talked with Professor Sarah Hernandez of the University of Arkansas about studies she has participated in using weigh-in-motion (WIM) data from real-world highway weigh stations. An excellent resource on weight is her TRB paper *Estimation of Average Payloads from Weigh-in-Motion Data*. [5] Another with Hernandez as a co-author published by the American Society of Civil Engineers (ASCE) is *Gaussian Mixture Model to Characterize Payload Distributions for Predominant Truck Configurations and Body Types*. [6] A third with Hernandez as co-author from TRB discusses data from the *Truck Activity Monitoring System for Freight Transportation Analysis*. [7]

Professor Hernandez explained that weigh-in-motion has a base system that measures and records axle weights, but with some modification and the addition of photography, the system can monitor the type of vehicle that was carrying the load. These reports then quantify actual real-world data of trucks passing on various highways. One categorizes them as van, livestock, low boy, drop-frame, basic platform (flatbed) and tank trailers. Another categorizes them as van, platform, bulk, reefer, logging, livestock, auto carrier and tank. These reports are an amazing clarification with photographs and auditable data of what these example highways see over time. These researchers recorded the actual measured weights and vehicle types, then, typical of data scientists, created mathematical models to represent the data for further uses. NACFE's focus is on freight, so Figure 17 shows just the van trailer data from one report. The data illustrates that 80,000 lbs. tractor trailers are statistically rare on the example routes used in the study.

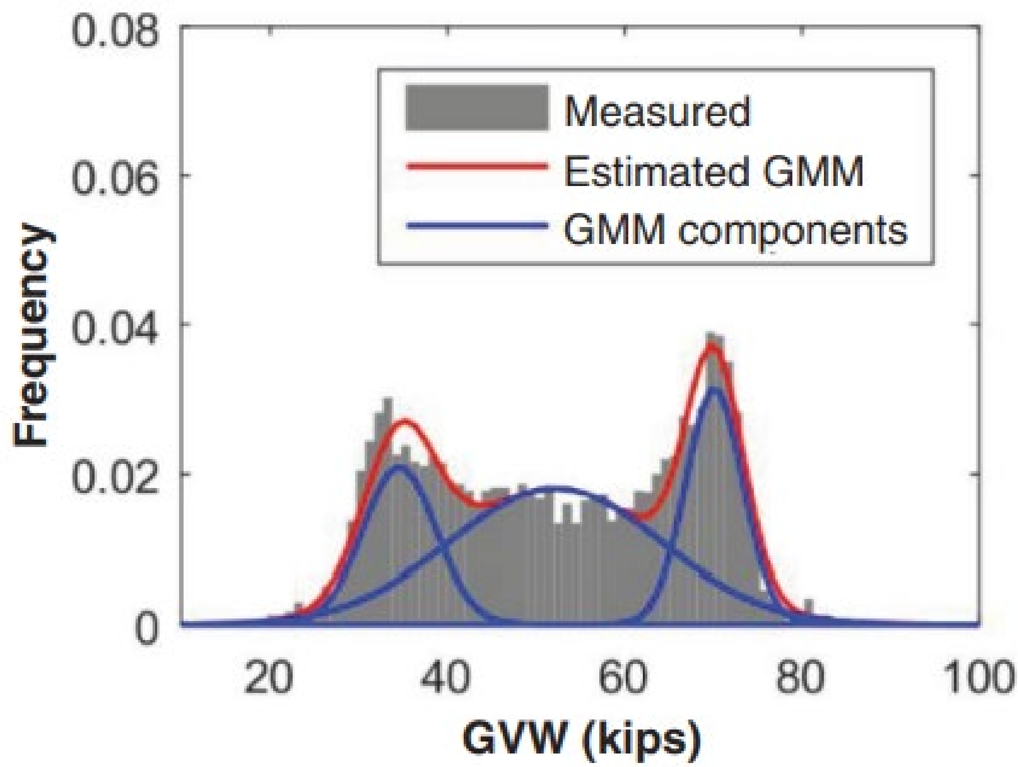


Figure 17. Van trailer WIM vehicle weights and frequency (Hernandez)

Figures 14, 15, 16 and 17 show the actual statistical distributions of the vehicles for each load, not averages. Averages do not tell the entire story of the spread of the data. However, people often need to use one value to represent a diverse population of data. Looking at the Golden Gate Bridge shaped bimodal graphs, NACFE concluded before that more than 50% of vehicle runs are below 70,000 lbs. GVW.

There is a lot of complexity in that statement. Often that gets interpreted as 50% of trucks operate below 70,000 lbs. That is not correct. The metric here is loads, not trucks. NACFE has stated before that diesel trucks are the Swiss Army knife of vehicles, able to haul in multiple duty cycles. [8] NACFE's Chairman, Rob Reich, executive vice president and chief administrative officer of Schneider, clarified that because many loads are unpredictable, one day the truck may cube out and the next it might weigh out. Diesels generally are capable of doing it all.

The research on the amount of empty backhauls, or what is often termed deadheading, shows there is a surprising amount of hauling empty trailers. A 2016 J.B. Hunt report, *660 Minutes: How Improving Driver Efficiency Increases Capacity,* highlights data that deadheading can take 75 minutes each day from a driver's time. [9] A National Private Truck Council (NPTC) *Benchmarking Survey Report 2021* concludes from survey data that empty backhaul miles occur between 21% to 33% each year. [10] NACFE's review in the past of annual reports to the Securities and Exchange Commission (SEC) for publicly traded fleets has shown on the order of 13% reporting empty miles per year is not uncommon. For some dedicated fleets, empty back hauls may be as high as 50%. The left side of our Figure 17 Golden Gate Bridge graph – below ~32,000 lbs. (an estimated tare weight of an empty tractor trailer) – reflects that a lot of empty miles are hauled. Each fleet is different, but trailers and loads are not always in the same place. For a deeper dive on that, see NACFE's 2019 report *The Feasibility of Intentional Pairing*. [11]

Discussions with drayage hauler NFI's Bliem, and public statements by other NFI representatives, talk to another point on weight. All trailers are not alike. Drayage tractors are hauling oceangoing containers that are 40' in length. The average weight of these is somewhere between 35,000 and 40,000 lbs. Paired with a day cab diesel tractor and container chassis, these combinations rarely, if ever, reach 80,000 lbs. NFI's Jim O'Leary, vice president fleet services, said "we are maxing out of the ports with our current customer base at around 72,000 pounds." [12] This is one of the reasons that drayage has a great deal of interest in BEVs in the southern California regions and at other ports. The picture in Figure 18 is at a warehouse in North Texas showing an example of the variety of trailer lengths seen hauling freight. This photo shows tailers with 53', 48', and 40' lengths, but there are many others.

Figure 18. Trailer types vary in length and weight (Mihelic)

Intermodal and drayage are deploying electric vehicles in volume at two sites in California. Schneider announced in August 2021 that it would deploy 50 Freightliner eCascadias at a southern California intermodal site. [13] In parallel, NFI announced a similar deployment of 60 drayage BEVs, a mix of Freightliner eCascadias and Volvo VNR Electrics, at its Ontario, California facility. [14]

3.3 Length of Haul

Length of haul is important to determining the suitability of BEVs. Beverage hauling is another example of complexity. Companies like PepsiCo, Anheuser-Busch and Biagi Brothers — all beverage haulers — are very interested in electric vehicles. Their freight management teams have told NACFE that they are focused on BEVs for these heavy loads. Keshav Sondhi, vice president of fleet and sustainability at US Foods, (formerly at PepsiCo), and a NACFE board member, has presented several times at major industry events on why beverage hauling is an attractive fit for electric trucks. The combination of short overall daily distances, long overnight dwell times and shorter trailers means these payloads and daily operations are not constrained by the weight of the battery packs. They are a path to helping companies meet their sustainability goals.

Sondhi presented at the North American Battery Show in 2020 on annual and daily miles for Pepsi's Class 8 beverage hauling fleet as shown in Figure 19. [25] He concluded that in excess of 93% (8,008 out of 8,561) of Pepsi's Class 8 delivery tractors averaged less than 100 miles per day and 56% (4,859 out of 8,561) of them averaged less than 50 miles per day. Only 6% (553 out of 8,561) exceeded 100 miles per day. [25]

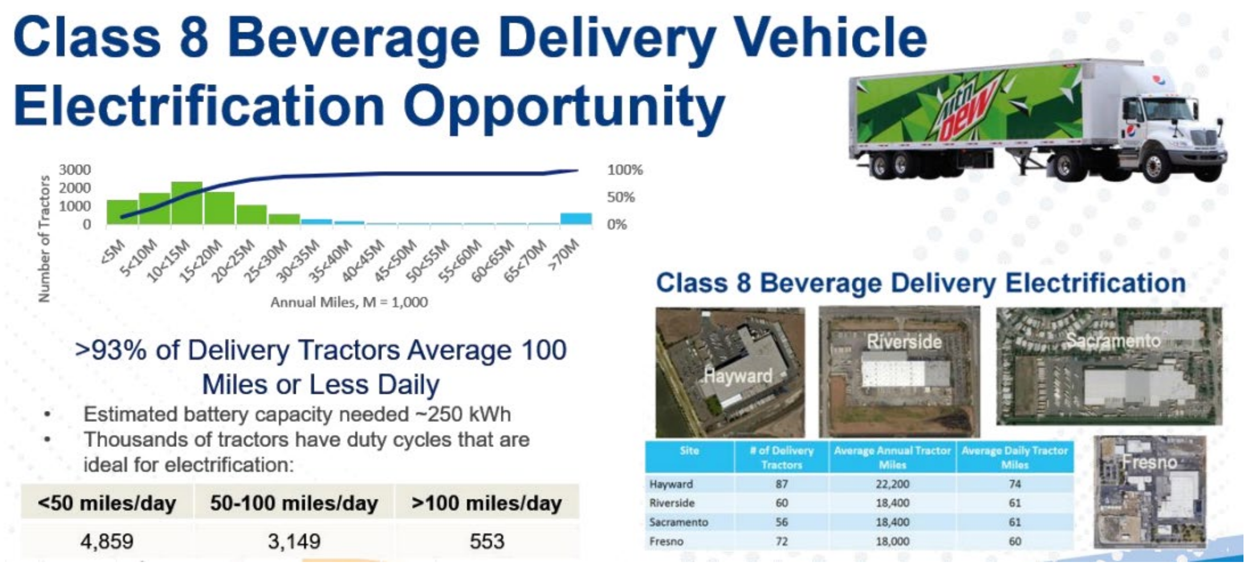


Figure 19. Beverage example fleet (Pepsi/NACFE)

Sondhi also has reported on US Foods' duty cycles. The graph in Figure 20 illustrates miles per day for an electric truck based out of La Mirada, CA, showing battery capacity used as a function of daily range driven. [24] The graph illustrates that a 150-mile range consistently returned to base with 22% state of charge remaining on the battery.

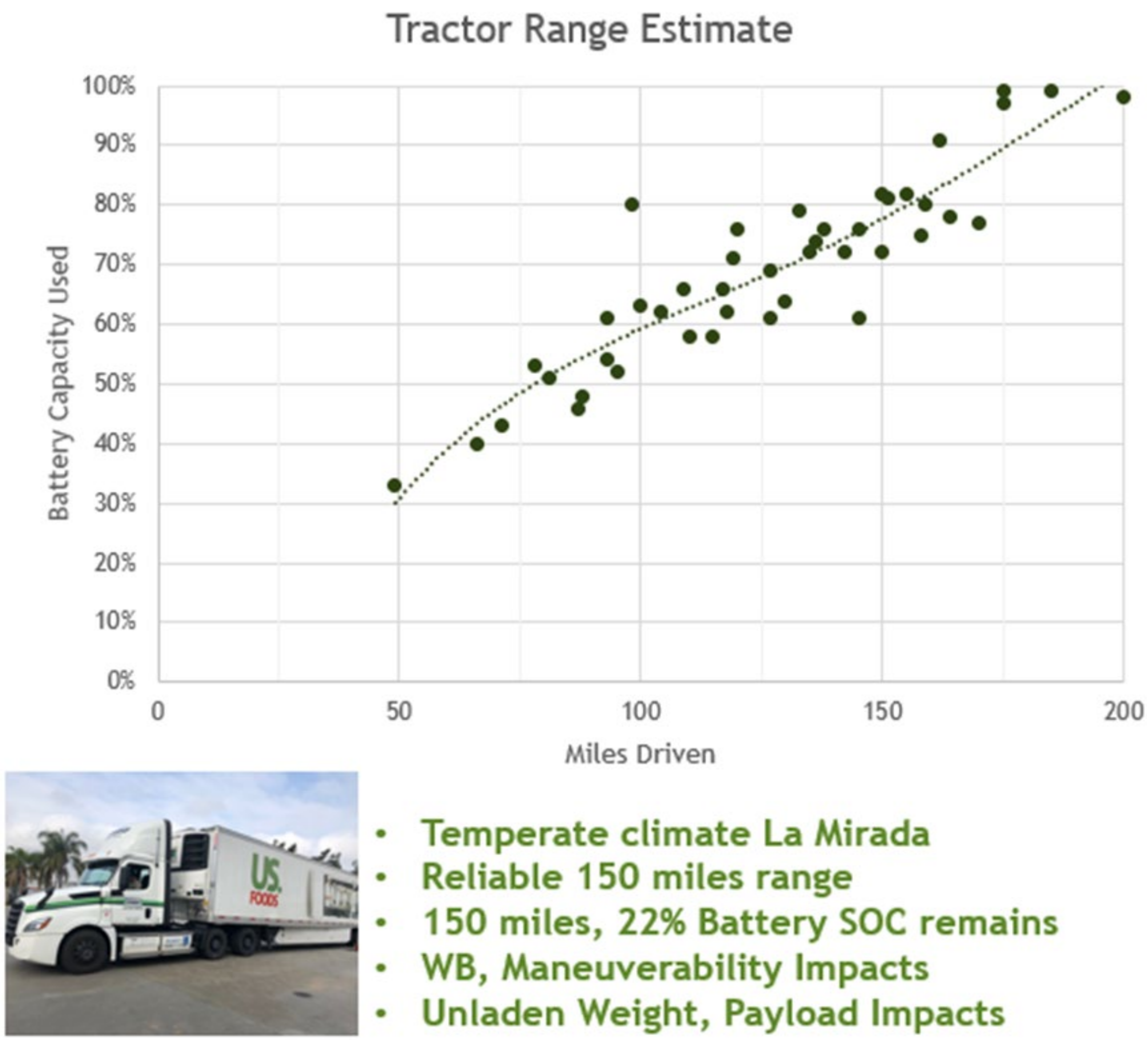


Figure 20. Example BEV duty cycle (US Foods)

Graphs showing the distribution of daily routes by miles for multiple distribution centers are shown in Figure 21. [24] These highlight that a significant portion of daily routes are below 100 miles for many distribution centers in US Foods' system.

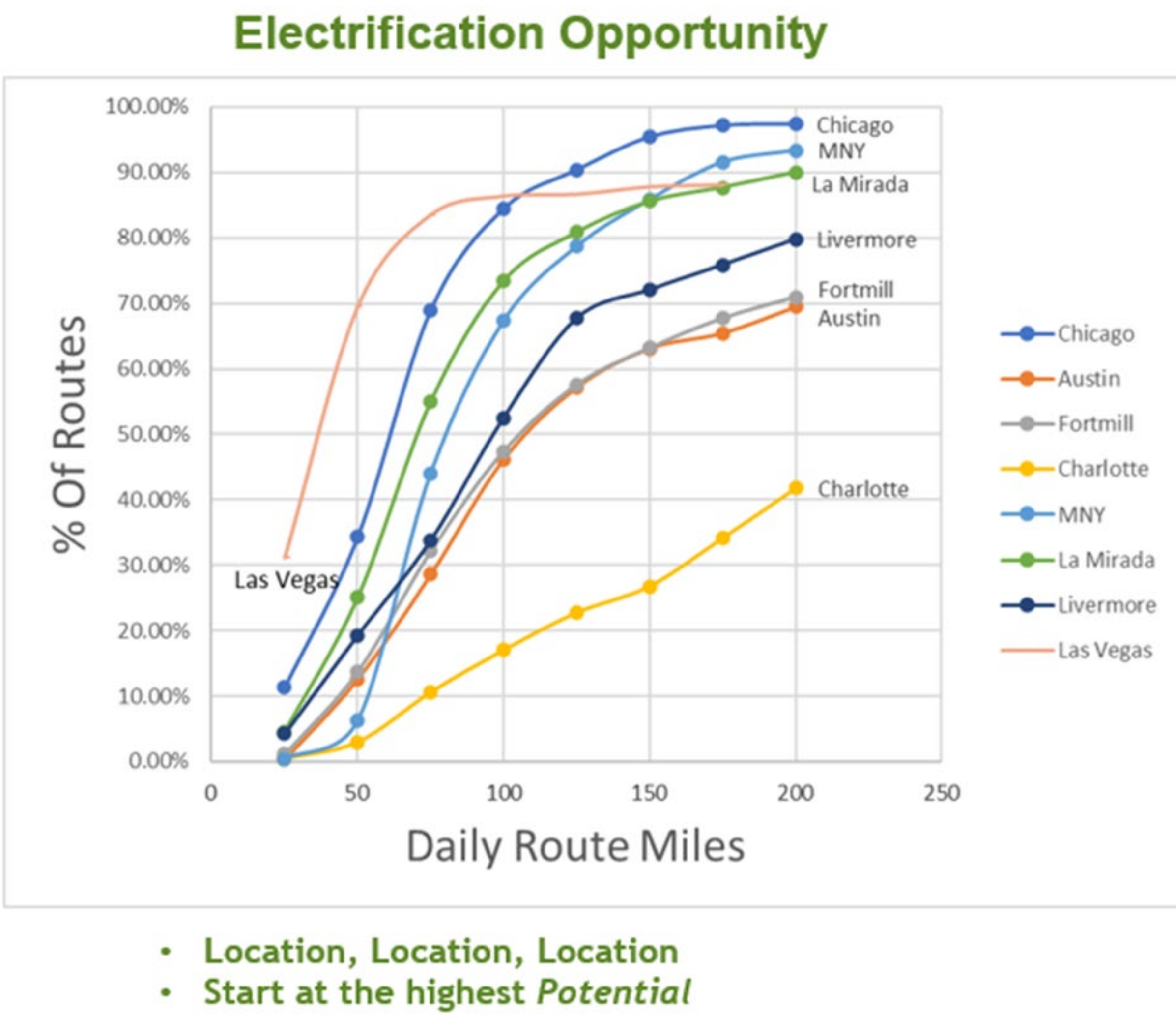


Figure 21. Example daily range distributions US Foods

NACFE provided the distribution curve for Class 7 and 8 trucks versus range shown in Figure 22. The curve was adapted by NACFE from the U.S. Environmental Protection Agency (EPA) Greenhouse Gas (GHG) Phase 2 Regulatory Impact Analysis (RIA) quoting the U.S. Department of Energy (DOE) - Energy Information Administration (EIA) data on annual miles. The X-axis scale was adjusted by NACFE from annual miles to daily miles with an assumption of 250 driving days per year. NACFE estimates from this that 90% of Class 7 and 8 trucks average less than 500 miles per day and a significant portion less than 200 miles per day. This data set likely includes all Class 7 and 8 trucks and tractors, including vocational urban trucks like those used in refuse and construction applications from the U.S. Department of Energy estimates.

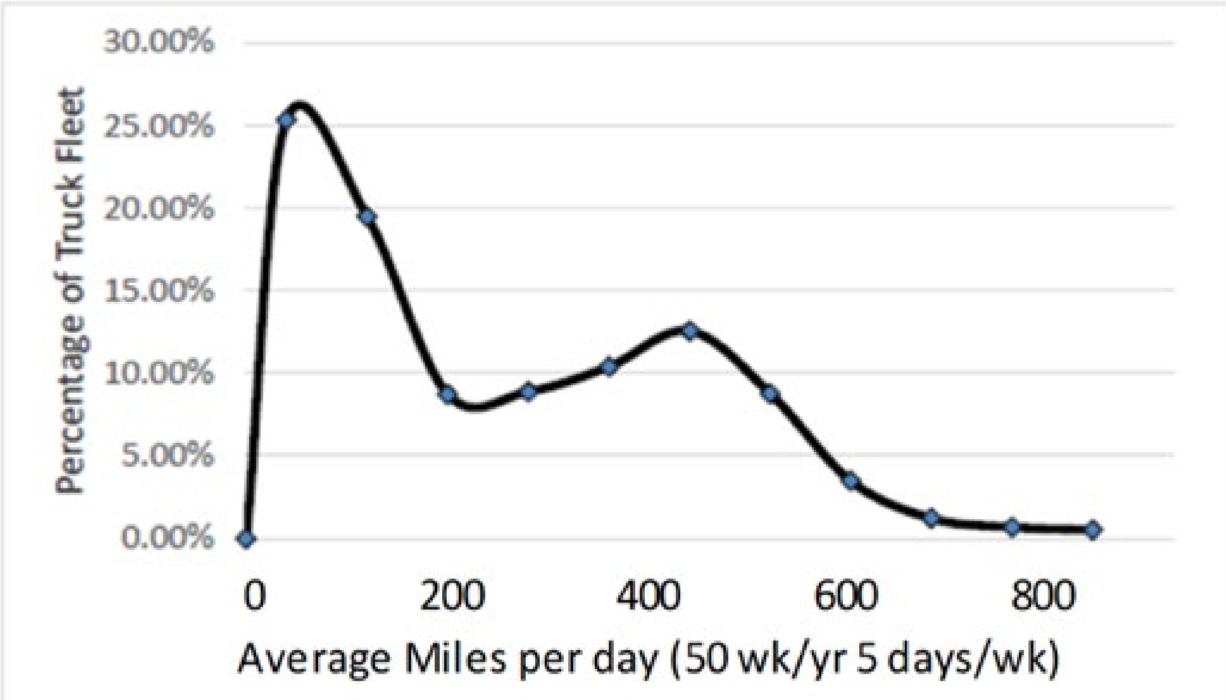


Figure 22. Estimated Miles per Day (NACFE/EIA)

The U.S. Bureau of Transportation Statistics provides the data in Figure 23 showing ~50% of freight tonnage is moved less than 100 miles per day and 67% is less than 240 miles per day. [26]

Distance band (miles)	Value (millions of 2012 $)	Percent of value	Cumulative percent of value	Tons (thousands)	Percent of tons	Cumulative percent of tons	Ton-miles (millions)	Percent of ton-miles	Cumulative percent of ton-miles
Below 100	6,736,740	35.6%	35.6%	9,401,764	50.5%	50.5%	275,901	5.3%	5.3%
100 - 240	3,062,384	16.2%	51.8%	3,097,303	16.6%	67.1%	537,538	10.2%	15.5%
250 - 499	3,319,931	17.6%	69.4%	2,986,761	16.0%	83.2%	1,046,958	19.9%	35.4%
500 - 749	1,520,917	8.0%	77.4%	1,120,608	6.0%	89.2%	672,048	12.8%	48.2%
750 - 999	1,100,209	5.8%	83.2%	608,201	3.3%	92.5%	522,604	10.0%	58.2%
1,000 - 1,499	1,360,279	7.2%	90.4%	825,488	4.4%	96.9%	992,118	18.9%	77.1%
1,500 - 2,000	754,531	4.0%	94.4%	331,759	1.8%	98.7%	573,414	10.9%	88.0%
Over 2,000	1,052,264	5.6%	100.0%	244,172	1.3%	100.0%	630,088	12.0%	100.0%

Note: Percents may not add to 100 due to rounding.
Source: U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework, version 4.5.1, 2019,

Figure 23. Freight by distance band

National Renewable Energy Laboratory (NREL), in a report on the feasibility of ZEVs in March 2022, quoted the graph from Bourlaug et al published in Nature shown in Figure 24. [104][105] NREL concluded that “approximately 10% of heavy-duty trucks have an operating range of 500 miles or more, whereas approximately 70% operate primarily within 100 miles.”

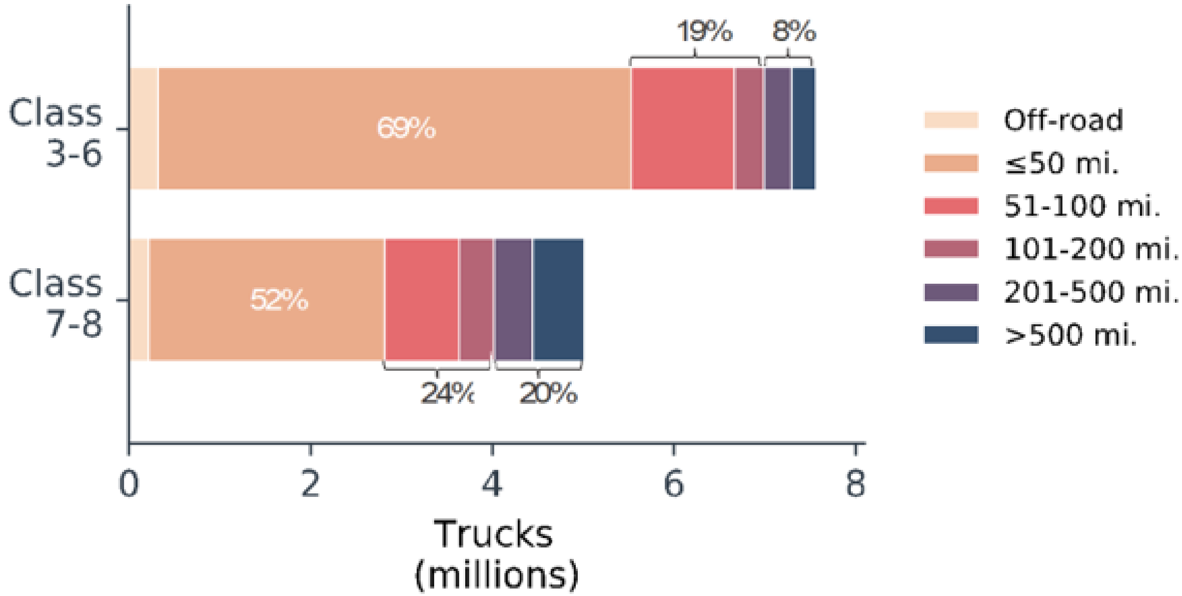


Figure 24. Truck population by range (Borlaug et al)

Fleets and drivers in surveys feel that more routes are moving to regional haul from long haul. A survey conducted by *Overdrive* of owner-operators highlights the opinion that length of haul has been decreasing for 31% of those surveyed as shown in Figure 25. [76] Only 12% felt their route lengths had increased.

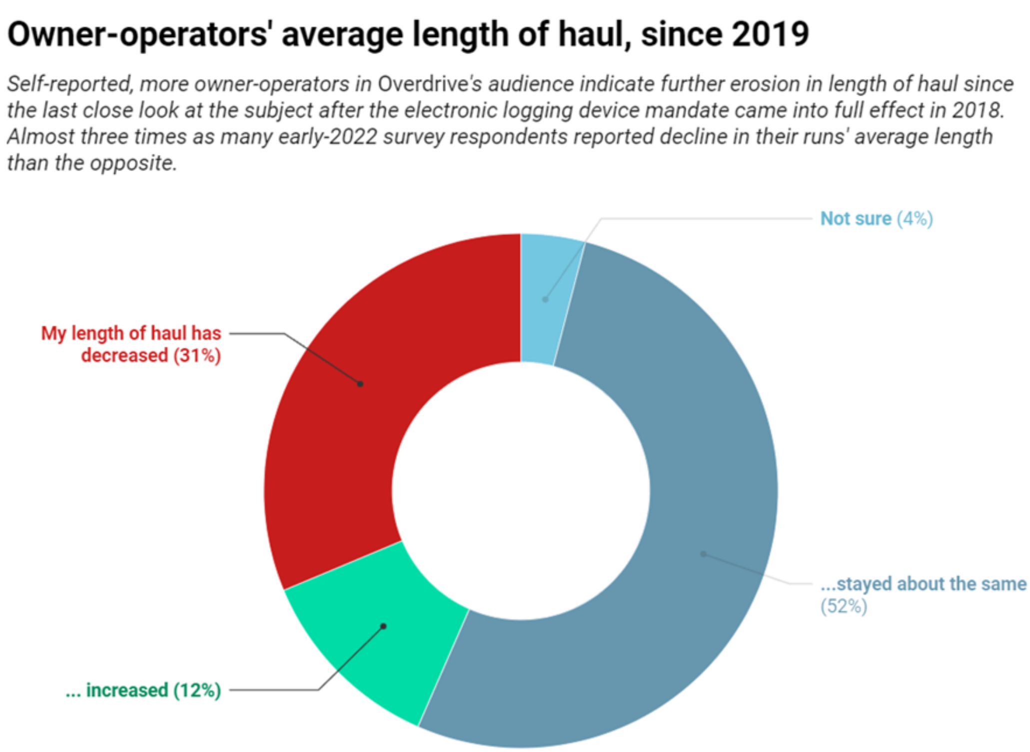


Figure 25. Decreasing length of haul opinions

The report asked owner-operators what haul lengths they preferred and results are shown in Figure 26. [76]

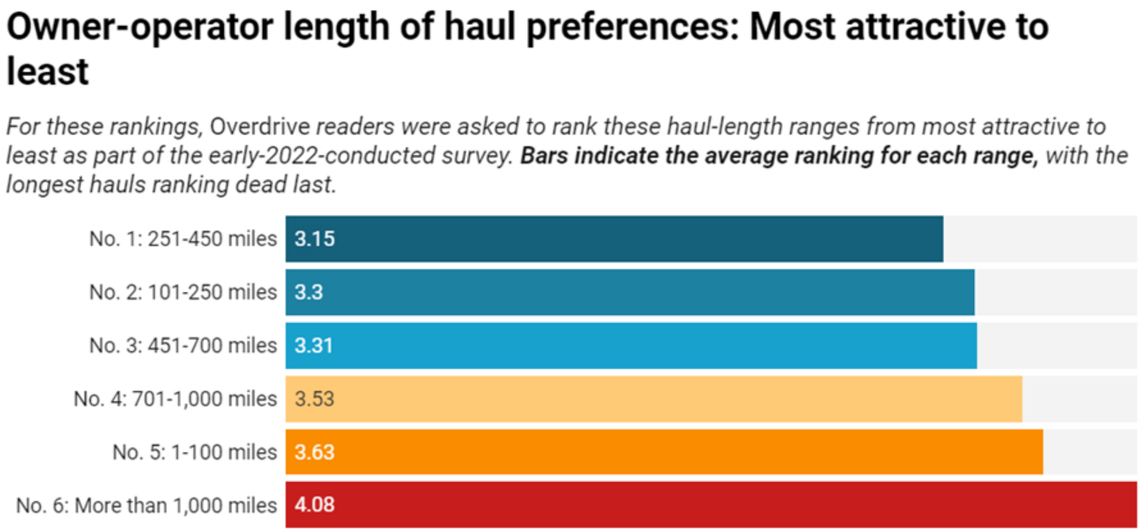


Figure 26. Length of haul preferences (Overdrive)

“Today's owner-operators show only a slim plurality of preference for hauls between 250 and 450 miles, a trip within whose range sit runs that can be completed in a day (some with the return included). From there, preferences swing between short and long, with the shortest and longest ranges — 1 to 100 miles and more than 1,000 miles — ending up dead last in ranked preferences.” [76]

DAT tracks industry trends through digital load boards. Median length of haul from DAT's datasets is plotted (in Figure 27) in miles between pickup and delivery week by week between the beginning of 2020, just pre-COVID pandemic, and the most recent full week in February 2022. Reefer haul length over that time shows a 15% increase in the median haul, the center number in the dataset, to 666 miles. Dry van's median haul rose approximately 14% over the same period to 477 miles. Flatbed stayed fairly level yet showed much more variability over the roughly two-year period. [76]

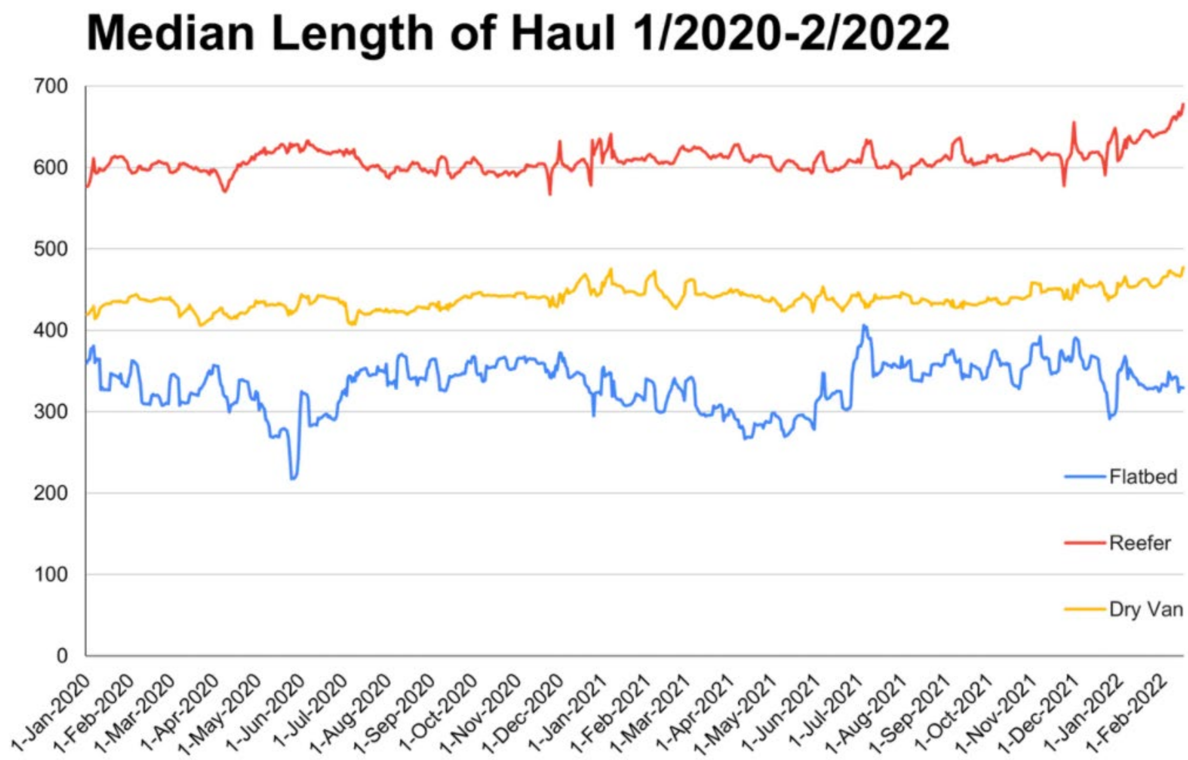


Figure 27. DAT data on length of haul (DAT)

Avery Vise, vice president, trucking at FTR, concluded that a “big shift in trucking employment has been migration from big carriers with locked-up contracts with shippers to tens of thousands of new small carriers that scoop up opportunities across the haul-length spectrum on the spot freight market, with those big carriers eventually hiring on more drivers for shorter, regional hauls.” [76]

The trend toward more regional haul was highlighted in a 2019 *Overdrive* article that showed spot market data, also from DAT, in Figure 28. [77]

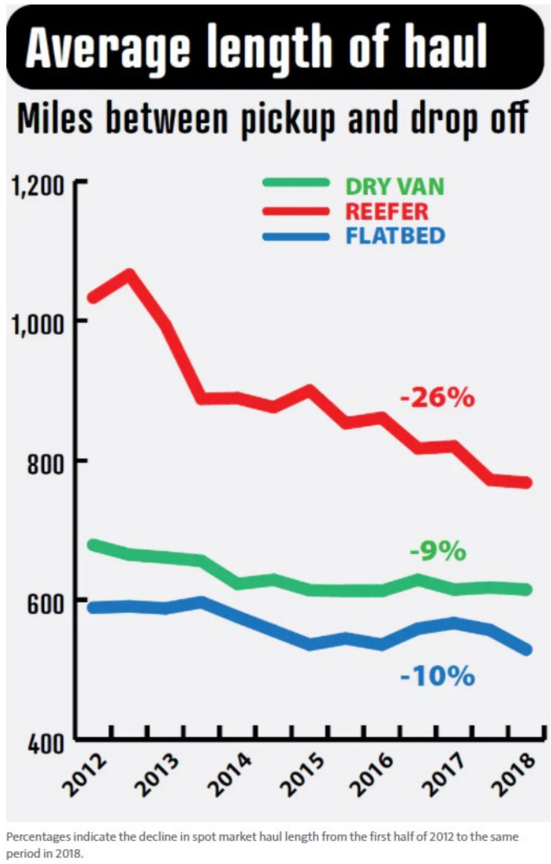


Figure 28. Spot market trends on length of haul (DAT)

In summary, Class 7 and 8 heavy-duty tractors are used in a wide range of duty cycles. Battery electric vehicles are not a solution today to replace every diesel, but the segment hauling below 200 miles per day is a significant portion of the market, and BEVs are capable today in that range, even with heavy loads. Figure 29 compares a diesel day cab tractor to a current production BEV for a 200-mile daily range duty cycle. This example estimates maximum freight weight as 49,500 lbs. based on a diesel tractor tare weight of 17,000 lbs. and a trailer tare weight of 13,500 lbs. for a combined tare weight of 30,500 lbs. The maximum permissible gross vehicle weight rating for this vehicle is 80,000 lbs. The BEV maximum freight weight is estimated as 45,500 lbs. based on recent production measurements and independently verified tractor tare weight of 22,500 lbs. and the same trailer tare weight of 13,500 lbs. for a total tare weight of 36,000 lbs. Just as with diesels, some OEM models are heavier than others.

NACFE has identified a range of OEM BEV tare weights from 22,500 lbs. to 29,000 lbs. depending on battery pack capacity and model. Fleets that regularly see heavy loads on long routes such as hauling paper, chemicals, liquids, etc. likely have very lightweight day cab tractors as their baseline, perhaps as low as 14,000 lbs. Electrifying those fleets will have to wait for advances in battery energy density or alternatives such as hydrogen fuel cells for a viable zero-emission solution.

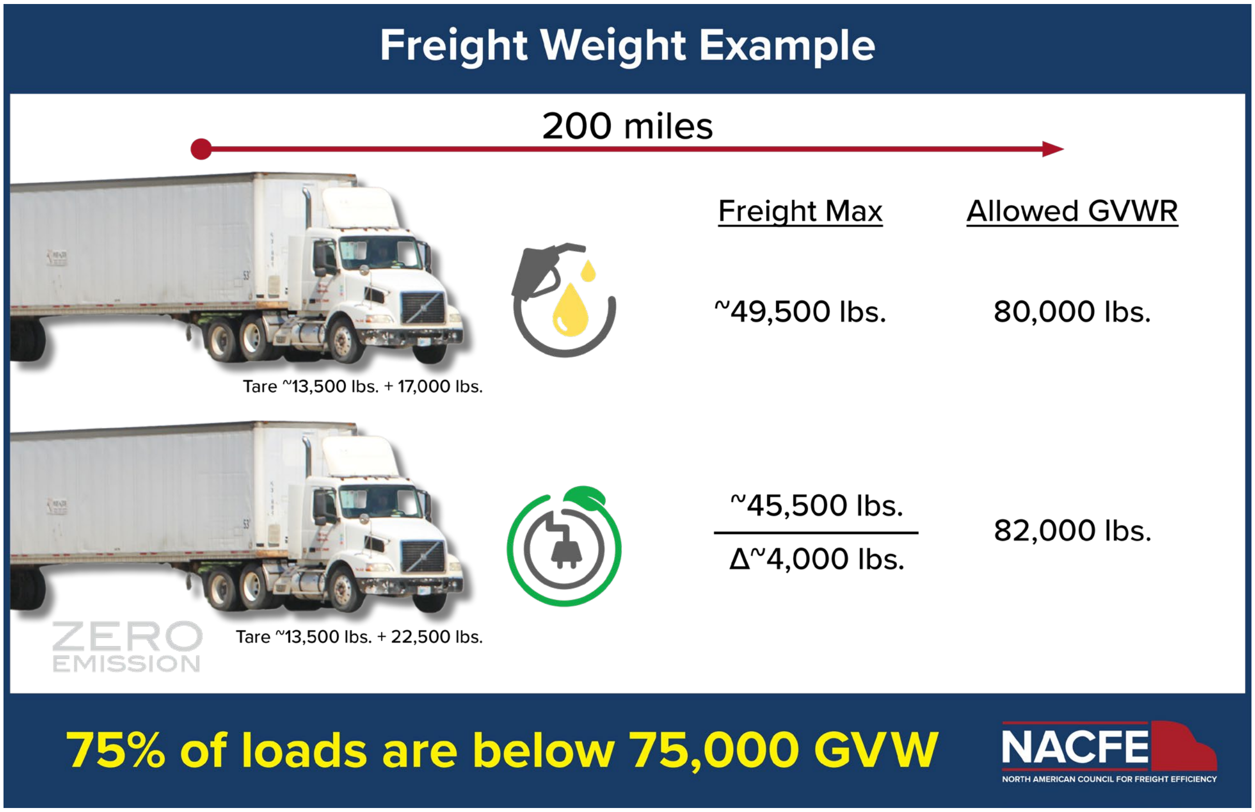


Figure 29. Freight weight example comparison

3.4 Vehicle Type and Duty Cycles

Regional haul vehicles today are a mix of day cabs and sleeper cabs. Regional haul fundamentally implies the truck and driver return to base daily. That suggests that the preferred vehicle for regional haul would be a day cab. In those instances where an overnight stay is required, many fleets operating day cabs support the driver using a hotel.

However, sleeper cabs also are used in regional haul. In some cases, a fleet will choose to purchase diesel sleeper cabs so they have the flexibility of using them on short-, medium- and long-haul routes. The market demand can be fluid requiring this flexibility. In other cases, vehicles and drivers may see very long wait times at facilities. A sleeper allows the driver to relax and avoid the wait time from impacting hours of service. In still other cases, the vehicle was purchased on the used market and the sleeper was what was available. Yet another reason may be that sleeper cabs depreciate less than day cabs and a fleet may be thinking downstream about trade-in value.

The majority of Class 7 and 8 BEVs as of early 2022 are Class 8 day cabs to optimize the vehicles for weight and wheelbase. BEVs tend to weigh more than their diesel counterparts, and packaging battery packs may make wheelbases somewhat longer than the diesels.

The market for day cabs versus diesels has traditionally been a 40/60 or 50/50 split depending on the year, as shown in Figure 30. [28] While the trend toward more regional haul where drivers get home daily is supported, a comparable trend toward more day cabs has not been seen yet.

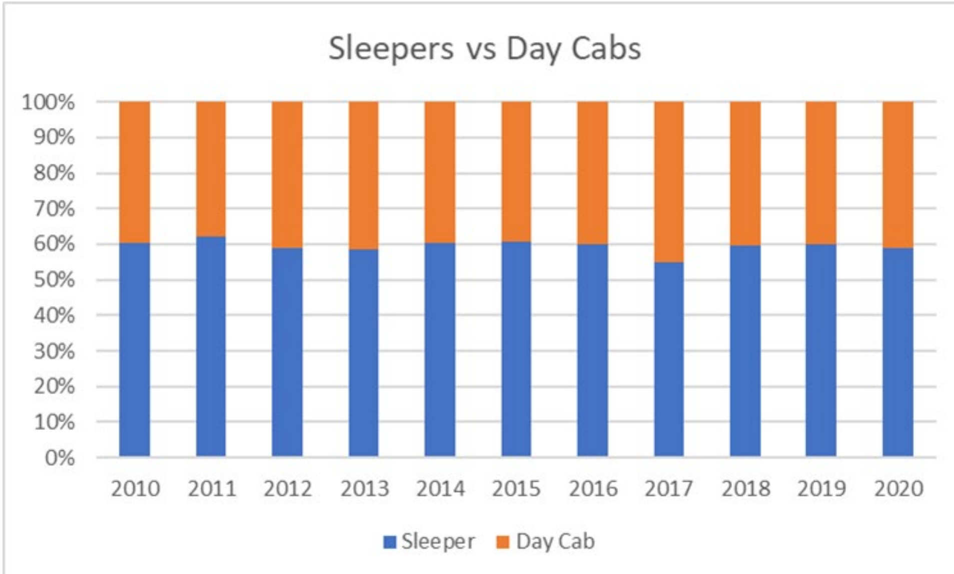


Figure 30. New sleepers vs. day cabs market share (ACT Research/NACFE)

Class 7 4x2 BEVs are likely to enter the marketplace as an additional move toward purpose-built vehicles. Already today, many urban tractors are 4x2 configuration, and even on-highway where fleets have determined their loads are cubing out, some fleets have opted for 4x2s. Examples of 4x2s are shown in Figure 31.

Figure 31. Examples of 4x2 diesel trucks (Mihelic)

3.5 Market Size

The market for heavy-duty trucks is very cyclical as seen in data on percent of build mix from ACT Research in Figure 32 and in data from Oakridge National Laboratory (ORNL) that is focused on Class 7 and 8 sales, shown in Figure 33. [28][106] These sales numbers reflect not just what the factories can produce, but also what the marketplace can absorb, or demand, each year.

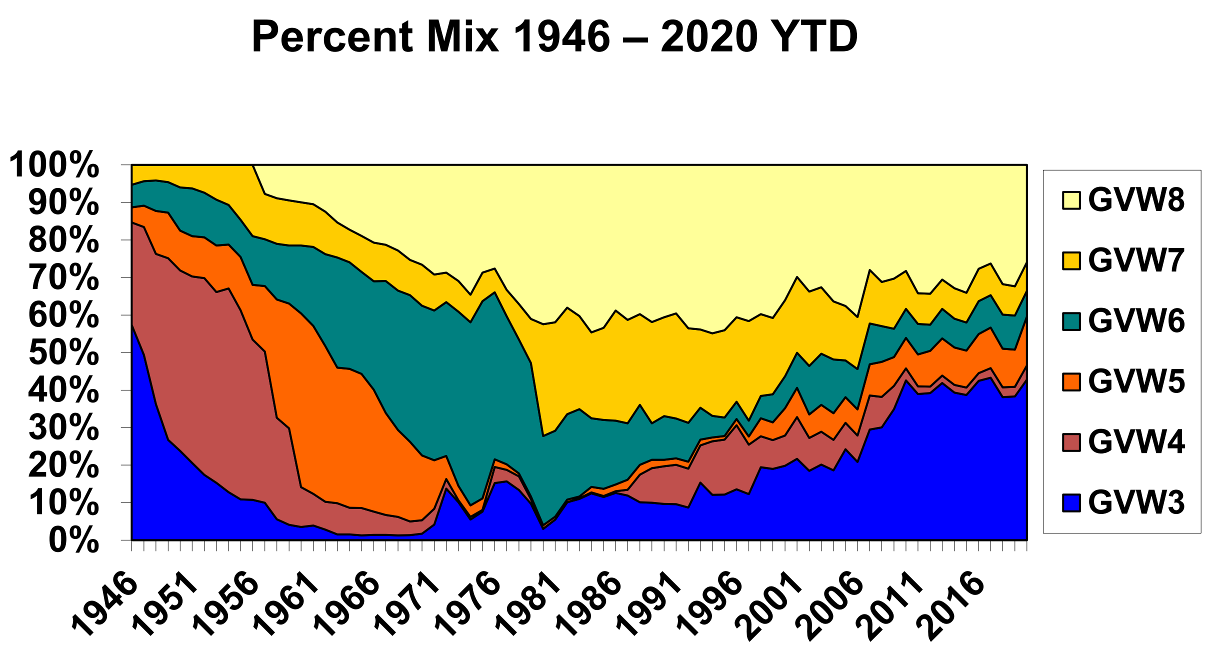


Figure 32. Truck production by class

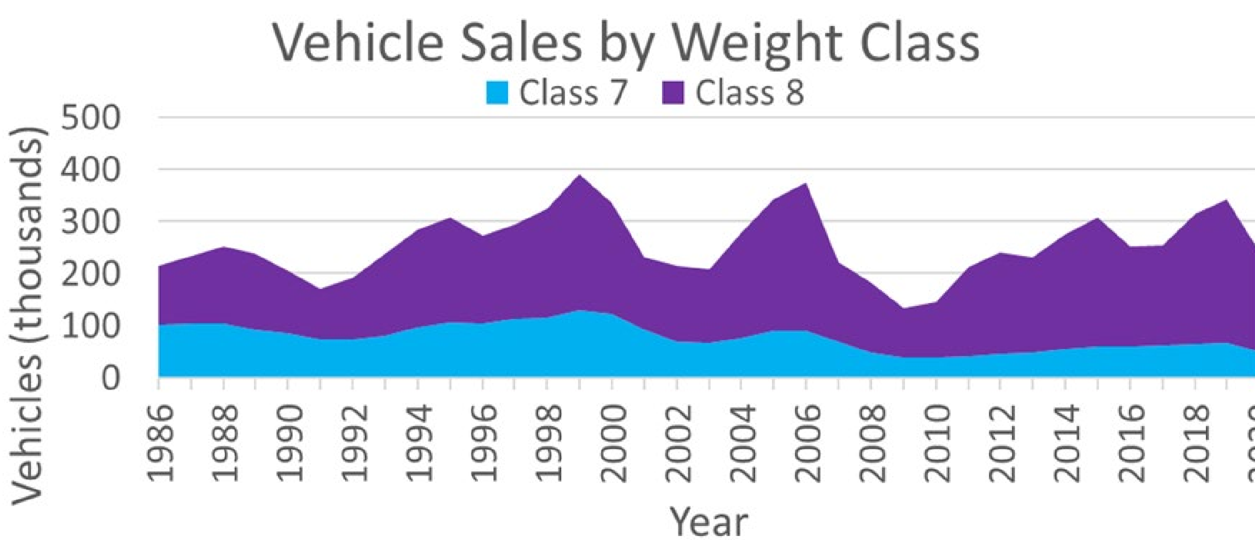


Figure 33. Vehicle sales by weight class (ORNL/NACFE)

ACT Research provided NACFE the graph in Figure 34 showing their projected growth in sales of BEV day cabs and overall day cab sales projections through 2030. Their 2021 forecast shows 24.2% of all day cabs to be BEVs in 2030, 43.7% by 2035 and 46.1% in 2040. Note that there are a significant number of assumptions built into any sales projection. For example, Advanced Clean Truck state rules, national emissions rules, fuel price fluctuations from political factors, etc. all play into supply and demand factors. Announcements from major OEMs on schedules for reducing diesel truck builds and moving to near-zero and zero-emission products also may accelerate adoption of BEVs.

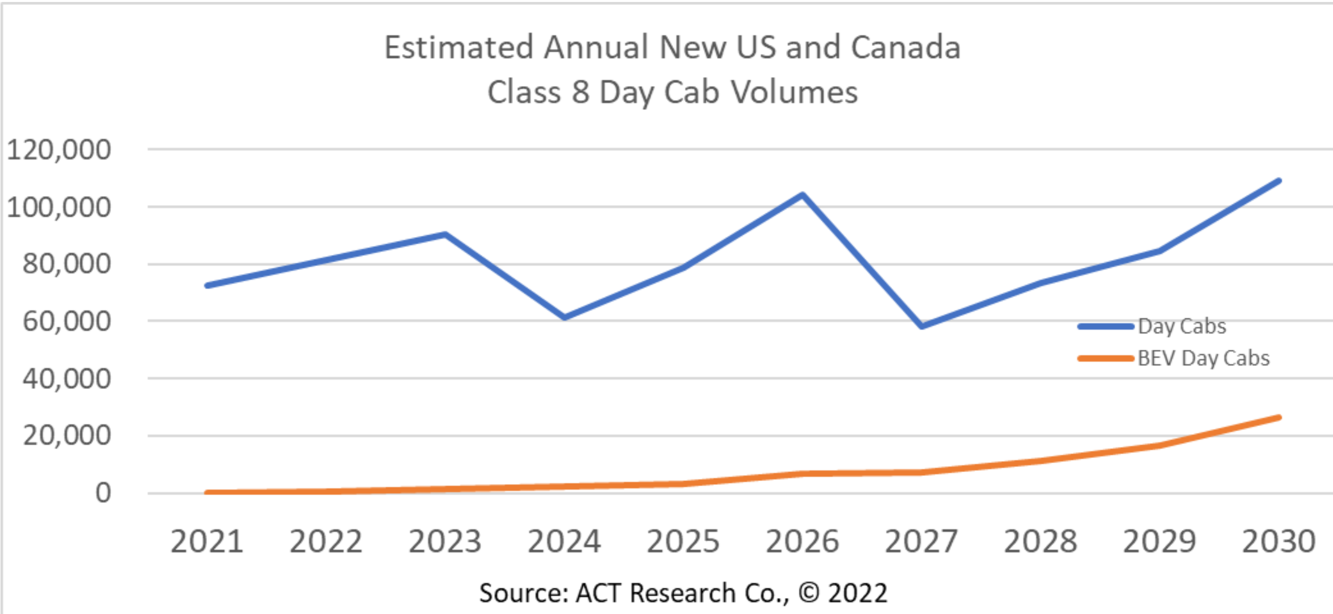


Figure 34. Projected Class 8 day cab sales

A very good production year is approximately 300,000 Class 8 tractors, and roughly 50% of those are day cabs. If the market is split between approximately 10 Class 8 manufacturers, the average annual build per manufacturer would be 15,000 day cabs a year. Minimum factory builds for models tend to be on the order of 1,000 per year. There is a potential to ramp up BEV day cab production quickly if the market demand is there.

3.6 Fuel Cost vs. Electricity Cost Volatility

Transportation fuel pricing is often described as “volatile” meaning it can change dramatically from day to day. Fossil fuel pricing fluctuates based on actual supply and demand, and also opinions about both supply and demand, often called speculation. For example, look at on-highway diesel pricing between May 2021 and March 2022 shown in Figure 35 reported by the DOE Energy Information Administration (EIA). Pricing increased in all regions, jumping 67% from a national average of $3.14/gal on May 3, 2021, to $5.25/gal on March 14, 2022, with most of the change occurring in the first quarter of 2022 due to a variety of international and national factors, although the underlying production for the US had not changed significantly. [30]

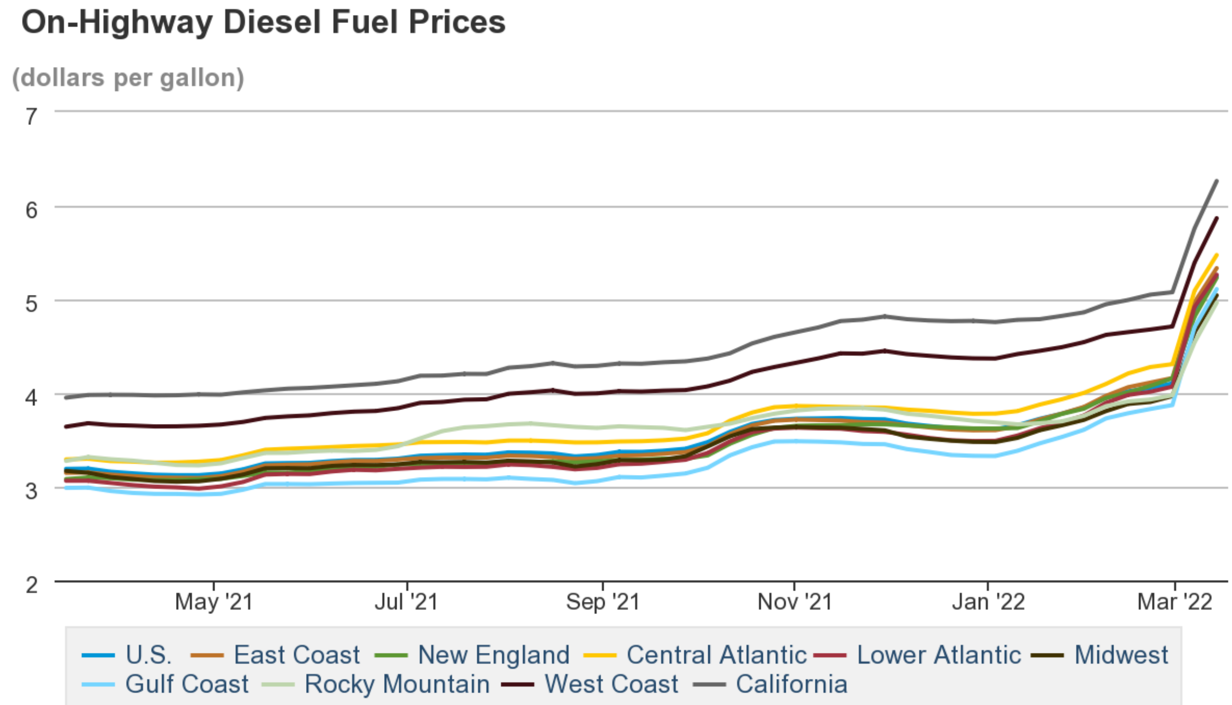


Figure 35. On-highway fuel prices by region May '21 through Mar '22

The comparison of fossil fuel pricing to electricity pricing shown by the AFDC in Figure 36 illustrates the stability of electricity costs over time versus diesel costs over time. The graph for electricity pricing spans from January 2011 through October 2021, encompassing many significant national and international events. Electricity pricing across this span is in large part stable and predictable in comparison to diesel fuel costs. [29] CNG also has been fairly stable across this same time span. The graph does not yet reflect the significant increase in diesel pricing seen in the first quarter of 2022 shown previously in Figure 35. [30]

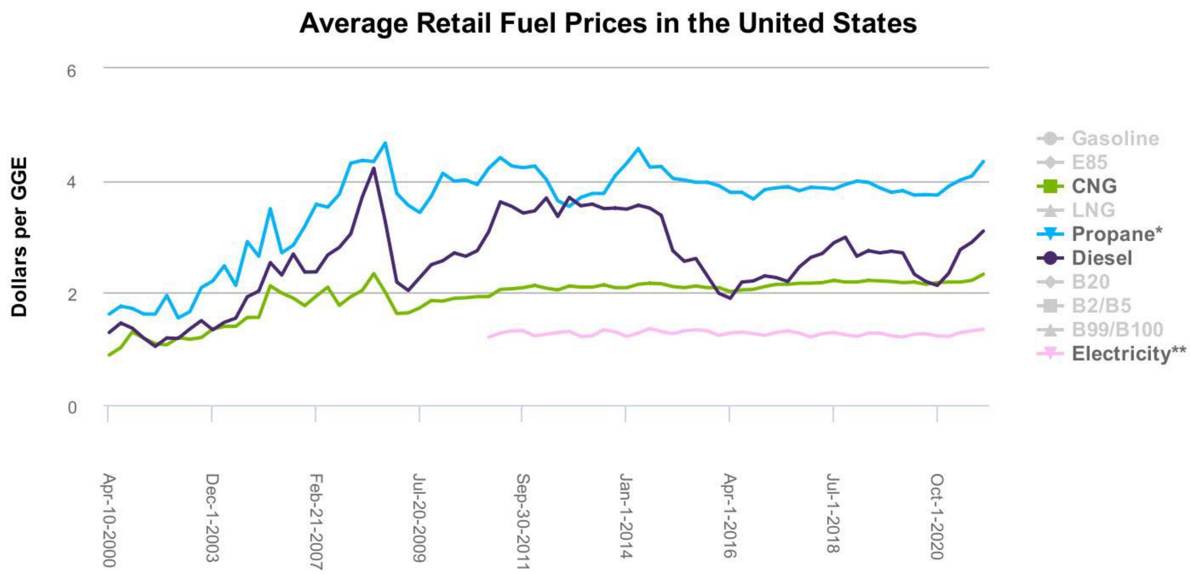


Figure 36. Retail pricing of fuels (AFDC)

The reason for the stability of electricity pricing is likely that electricity can be produced through multiple methods and from multiple energy sources. This tends to have a stabilizing effect on prices as market fluctuations in one energy type can be offset by others. A major influence also is from the stability of CNG pricing which fuels a significant portion of power generation.

3.7 Efficiency

While the focus of this report is on electrification as a viable zero-emission alternative to Class 7 and 8 diesel trucks, there are efficiency improvements relevant to both. For example, low rolling resistance tires, lightweighting options such as aluminum wheels, aerodynamic devices on both the tractor and trailer, driver incentive programs tied to energy efficiency improvement, cruise control use, etc. are examples of improvement areas pertinent to both diesels and BEVs.

Specifying a truck fundamentally doesn't change, irrespective of powertrain choice.

- Know your business using metrics
- Specify features required to do the job
- Focus on efficiency improvement opportunities

RUN ON LESS ELECTRIC

Lesson Learned

Be clear on range metrics: per shift, per day, per charge cycle, etc.

Figure 37 from NACFE's Run on Less 2017 demonstration highlights many of these common opportunities for efficiency improvements. Improving efficiency means using less energy to move down the road, and for BEVs that translates to range extension, smaller batteries, shorter recharge times and/or lower costs for electricity. [31] Figure 38 highlights common opportunity areas for efficiency improvement on a tractor trailer. [79]

Figure 37. Factors for efficiency improvement of diesels, many applicable to BEVs
(Click here for a larger version of this graphic.)

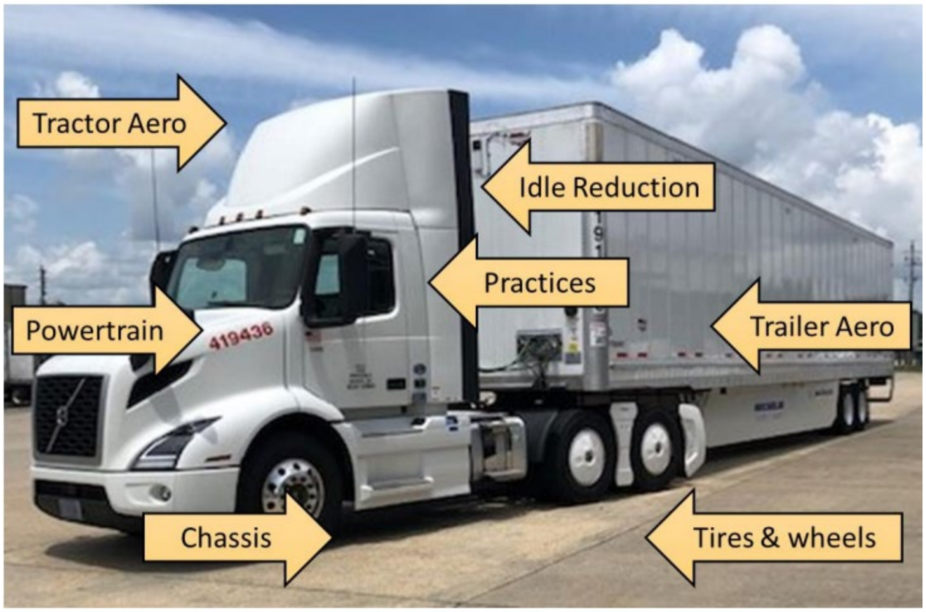


Figure 38. Efficiency areas relevant to range extension (NACFE)

Lesson Learned

Specify efficiency technologies, as you have for diesel MPG, to gain range without adding batteries.

3.8 Regulations

Duty cycles need to be considered with respect to regulations. Drivers' hours of service requirements are examples of regulations that factor into duty cycles. Noise reduction zones and idle restrictions are other examples where regulations can impact duty cycles by preventing or restricting operations in specific locations or regions. Regulations are constantly evolving.

3.8.1 Advanced Clean Truck (ACT) Rule

The Advanced Clean Truck (ACT) rule created in California in 2020 — but adopted in Oregon, Washington, New Jersey, New York and Massachusetts as of March 2022 — is summarized by Transport Topics as "requiring a growing percentage of all medium- and heavy-duty trucks sold to be zero emission starting in 2025. Manufacturers must increase their zero-emission truck sales in those states to 30% to 50% by 2030, and 40% to 75% by 2035." [34]

The International Council on Clean Transportation (ICCT) summarizes the rule, "The ACT rule requires the sale of zero-emission or near zero-emission [heavy-duty trucks] starting with the manufacturer-designated model year 2024. Sales requirements are defined separately for three vehicle groups: Class 2b to 3 trucks and vans, Class 4 to 8 rigid trucks, and Class 7 to 8 tractor trucks. The regulation is structured as a credit and deficit accounting system. A manufacturer accrues deficits based on the total volume of on-road [heavy-duty trucks] sales within California in a given model year. These deficits must be offset with credits generated by the sale of zero-emission vehicles (ZEVs) or near zero-emission vehicles (NZEVs).” [35] The phase-in for California is graphed in Figure 39. [35]

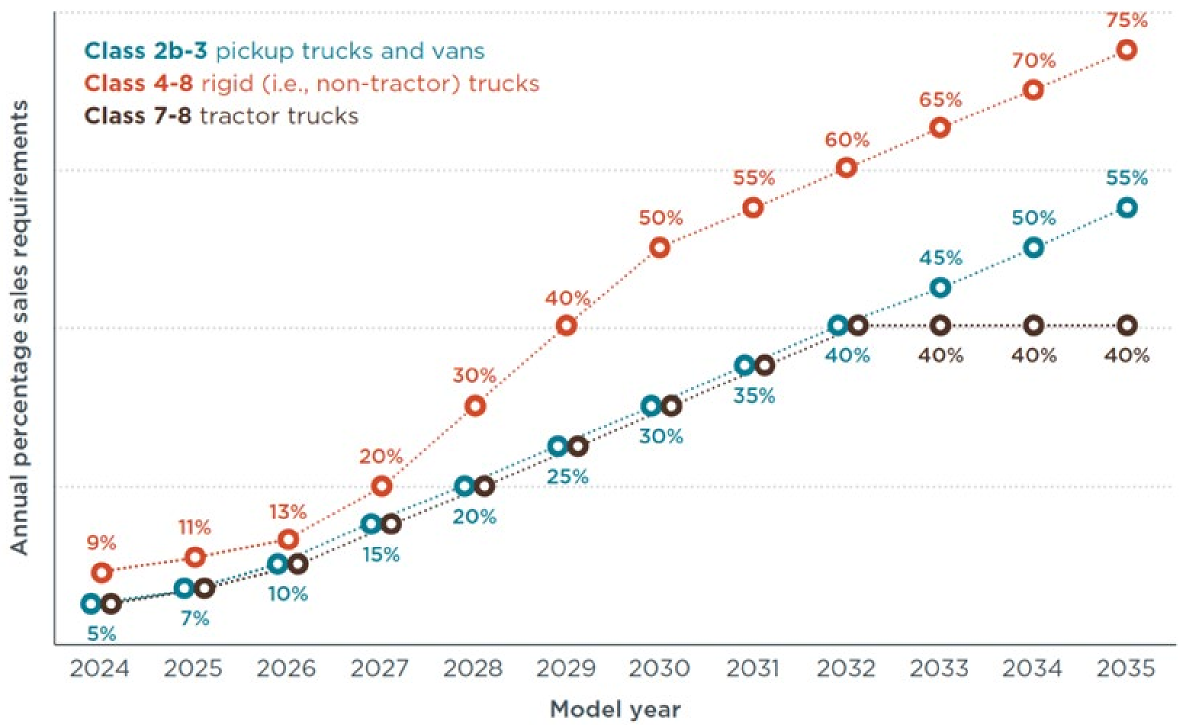


Figure 39. California ACT Rule targets (ICCT)

3.8.2 Advanced Clean Fleets Rule

The ACT Rule applies to the manufacturers of the vehicles by regulating the market mix of vehicles sold. This can impact a fleet’s choice of vehicles to buy for specific regions. Rules governing the operation of fleet vehicles in regions may follow. California is developing an Advanced Clean Fleets (ACF) rule, describing that “California Air Resources Board (CARB) is developing a medium- and heavy-duty zero-emission fleet regulation with the goal of achieving a zero-emission truck and bus California fleet by 2045 everywhere feasible and significantly earlier for certain market segments such as last mile delivery and drayage applications. The initial focus would be on high-priority fleets with vehicles that are suitable for early electrification, their subhaulers, and entities that hire them. The goal of this effort is to accelerate the number of medium- and heavy-duty zero-emission vehicle purchases to achieve a full transition to zero-emission vehicles in California as soon as possible.” [36] Southern California Edison projected that the ACF rule has an expected implementation in 2023 with a phase-in of zero-emission trucks and buses (over 8,500 lbs. GVWR) to 2045. Drayage trucks required to be zero emission by 2035.” [46]

3.8.3 Heavy-Duty Low NOx Omnibus Rule

Regulations governing nitrous oxides (NOx) and particulates emissions (PM) are being tightened under the CARB Heavy-Duty Low NOx Omnibus Rule. This rule is being adopted by other states such as Oregon.

The Omnibus rule lowers NOx and PM2.5 standards for new truck engines, extends the useful life and warranty periods, and has other elements such as additional testing requirements. Daimler summarized the Omnibus Rule elements and timing in Figure 40. [37]

CARB Omnibus Overview

2024

- Lower tail pipe NOx and PM
- New low load cycle (LLC)
- Lower Idle standard
- New in use testing on any "commercially available" fuel

2027

- Longer warranty (HD: 450k/7 year)
- Longer useful life (HD: 600k/11 year)
- Lower tail pipe NOx
- Lower low load cycle
- Lower idle standard

2031

- Longer warranty (HD: 600k/10 year)
- Longer useful life (HD: 800k/12 year)

	Today	MY24	MY27	MY31
Nox: FTP, RMC	0.2 g/hp-hr	0.05[1] g/hp-hr	0.02[1] g/hp-hr	
PM: FTP, RMC	0.01 g/hp-hr	0.005 g/hp-hr	0.005 g/hp-hr	
LLC Nox	N/A	0.05 g/hp-hr	0.02 g/hp-hr	
Idling	30 g/h	10 g/h	5 g/h	
HDIUT	NTE Procedure CF: 1.5	3-bin MAW CF: 2.0		3-bin MAW CF: 1.5 [2]
	Customer route	All routes	All routes + Cold start	
Useful Life	HHD: 435k mi / 10 years		HD: 600k mi / 11 years	HD: 800k mi / 12 years
Warranty	HHD: 100k mi/ 5 years	HHD: 350k mi/ 5 years	HD: 450k mi/ 7 years	HD: 600k mi/ 10 years
DF	50% UL: Option for 35% UL	FUL: 9800 h or 50% UL + 600h DAAAC	FUL: DAAAC for 1900 h + in-use data	

This affects new commercial vehicles registered for use in California and CARB Opt in states

[1] At 435k miles, additional allowance at proposed extended FUL
[2] CF change to 1.5 in 2030

Figure 40. CARB Omnibus Rule overview

The Oregon Department of Environmental Quality (DEQ) summarized Omnibus Rule changes from the warranty requirements as shown in Figure 41. [38]

Model Year	Warranty (miles)			
	LHDD	MHDD	HHDD	HDO
June 2018 Step 1 Warranty 2022-2026	110,000 5 years	150,000 5 years	350,000 5 years	50,000* 5 years
2027-2030	150,000 7 years/ 7,000 hours	220,000 7 years/ 11,000 hours	450,000 7 years/ 22,000 hours	110,000 7 years/ 6,000 hours
2031 and Subsequent	210,000 10 years/ 10,000 hours	280,000 10 years/ 14,000 hours	600,000 10 years/ 30,000 hours	160,000 10 years/ 8,000 hours

* Not included under Step 1 Warranty, but current periods are shown here for completeness.

LHDD = Light Heavy-Duty Diesel 14,001-19,500 lb. GVWR
MHDD = Medium Heavy-Duty Diesel 19,501-33,000 lb. GVWR
HHDD = Heavy Heavy-Duty Diesel >33,000 lb. GVWR
HDO = Heavy-Duty Otto-Cycle > 10,000 lb. GVWR

Figure 41. Current and proposed warranty requirements

The extensions to warranty and product life expectancy applies to diesel vehicles. These extensions may result in higher prices for diesel trucks, which may influence fleet decisions on future vehicle technology choices. BEVs are considered to have zero emissions so are not subject to these diesel requirements.

3.8.4 Federal Emissions Rules

In March 2022, the EPA announced a new proposed rule titled "Proposed Rule and Related Materials for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards." [39] The rules would, "Set new, more stringent standards to reduce pollution from heavy-duty vehicles and engines starting in model year (MY) 2027." A fact sheet published by EPA states, "This proposed rule would reduce NOx from heavy-duty vehicles over a wide range of operating conditions, with significant emissions reductions at low speeds, idling, and in stop-and-go traffic. EPA is proposing longer useful life periods to ensure engines would meet emission standards for more of their operational lives and prompt engine manufacturers to design and build durable engines and emission controls. EPA also is proposing longer emissions warranty periods which would increase the number of useful life miles covered under warranty. Longer warranty periods may make it less likely for owners to tamper with emissions controls, and more likely that owners will make needed repairs." [40] Daimler's timeline of regulations — presented in 2021 — suggested this new rule was expected as shown in Figure 42. [37] The EPA proposed the Clean Trucks Plan in March 2022. [101][102]

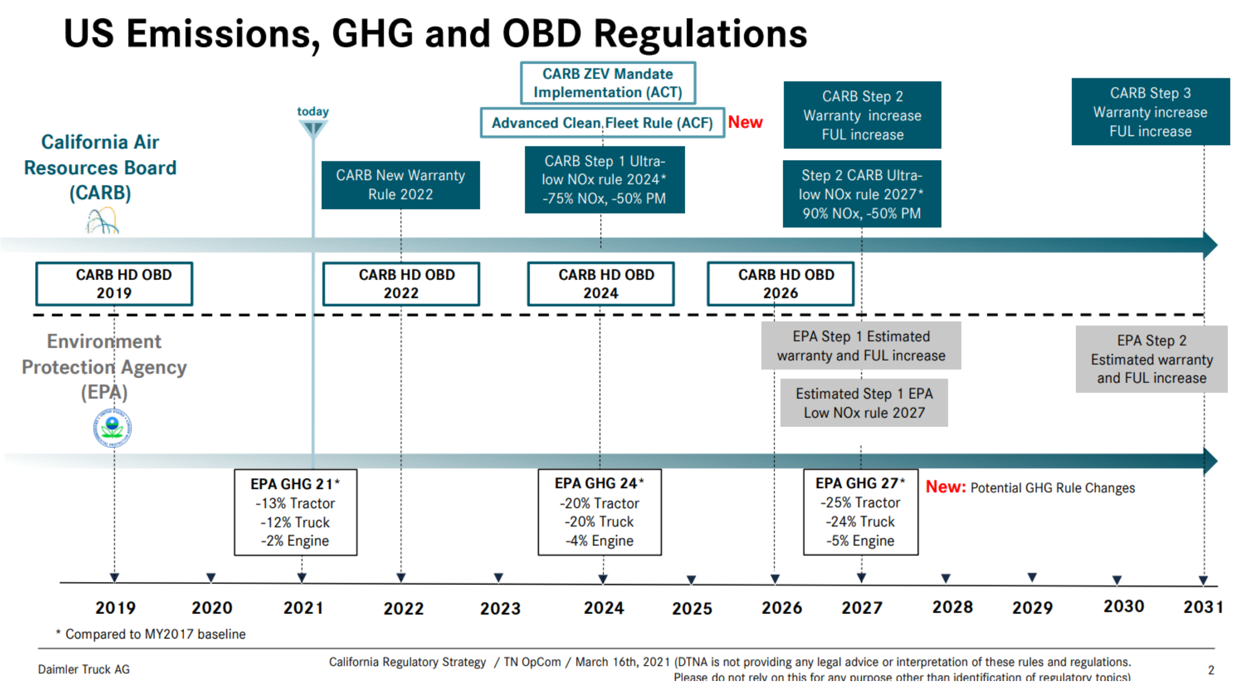


Figure 42. US Emissions, GHG and OBD regulations (Daimler)

The federal level regulations in concert with the state and regional ones likely will increase the cost of diesel engine vehicles in the future, somewhat closing the gap with BEV pricing. These regulations may impact technology choices for fleets for specific duty cycles.

3.8.5 Warehouse Indirect Source Rule (ISR)

A new rule for warehouses operating in the greater Los Angeles area requires warehouse operators to track and offset emissions of Class 2b to 8 vehicles that visit their warehouses. The South Coast Air Quality Management District (SCAQMD) Rule 2305 Warehouse Indirect Source Rule – Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program phases in as shown in Figure 43. [32] "The purpose of this rule is to reduce local and regional emissions of nitrogen oxides and particulate matter, and to facilitate local and regional emission reductions associated with warehouses and the mobile sources attracted to warehouses in order to assist in meeting state and federal air quality standards for ozone and fine particulate matter." [32]

The DLA Piper group summarizes the rule, "Warehouse operators must earn a specific number of points (called WAIRE Points) to offset the number of truck trips to and from warehouses under their control. Warehouse operators incur their WAIRE Points obligations on a weighted basis, with, until 2026, larger obligations for larger warehouse facilities, and for warehouses hosting larger vehicles (e.g., tractors or tractor-trailers). WAIRE Points are earned through emissions-reducing activities or payment of mitigation fees. Both owners and operators of such warehouses must also comply with significant new information gathering and reporting obligations under the Rule." [33]

Phase	Warehouse Size (square feet)	Initial Reporting Date (Annual WAIRE Report)	Initial Compliance Period
1	≥ 250,000	January 31, 2023	January 1, 2022 to December 31, 2022
2	≥ 150,000-<250,000	January 31, 2024	January 1, 2023 to December 31, 2023
3	≥ 100,000-<150,000	January 31, 2025	January 1, 2024 to December 31, 2024

Figure 43. ISR Rule phase in (SCAQMD)

This ISR could modify a fleet's choice of vehicles that visit specific facilities at the request or demand of the warehouse operators. This rule is considered a novel approach moving beyond regulating the fleet operators to now include the shippers and receivers operating warehouses.

3.8.6 Electric Thermal Refrigerated Units

Trailers also are a factor in future electrification. California is developing regulations requiring use of electric thermal refrigerated units (eTRU) on trailers. New regulations were released in March 2022 affecting TRU use on straight trucks. [44] Those rules state, "Zero-emission truck TRU requirement — Beginning December 31, 2023, TRU owners shall turnover at least 15% of their truck TRU fleet (defined as truck TRUs operating in California) to ZE technology each year (for seven years). All truck TRUs operating in California shall be ZE by December 31, 2029." CARB plans "to start the development of a second rulemaking to transition non-truck TRUs to ZE technology in 2022. This second rulemaking is anticipated for Board consideration in 2025." These include semi-trailer TRUs.

Zero-emission technologies outlined by CARB include battery-electric TRUs, cold plate TRUs, and indirect cryogenic TRUs. [44] TRU companies and trailer manufacturers already are working on ZE trailer development.

TMC drafted a Future Truck Position Paper 2022-2 titled *Trailer Energy Harvesting: Regenerative Braking Systems for Trailer Applications.* [45] The document includes the table provided by Great Dane on eTRU energy demands shown in Figure 44.

TABLE 1: eTRU ENERGY REQUIREMENTS FOR TRAILER APPLICATIONS			
OPERATION	TRIP LENGTH	kWH REQUIRED	
	Hours	Pull Down	Total
Long Haul (-20°F) 53'	10	52	70.02
Long Haul (0°F) 53'	10	22	65.62
Food Service (2 - 38°F / ambient temperature)	10	46	76.12
Dairy (35°F)	10	27	58.35
Grocery (35°F)	10	16	46.46
Produce (35°F)	10	16	52.86
			Source: Great Dane, LLC

Figure 44. eTRU energy demands for trailer applications (Great Dane/TMC)

Semi-trucks generally are designed to pull multiple trailer types, so a diesel tractor may be pulling an eTRU-equipped trailer in the future. However, future technologies may develop that transfer electrical energy either direction between the tractor and trailer. Those technologies may develop in parallel to adoption of BEV tractors and eTRU trailers. Rules such as the SCAQMD ISR also may expand beyond greater Los Angeles such that warehouses will require refrigerated deliveries to be made with BEVs pulling eTRU trailers.

3.8.7 SEC Reporting Rule

In March 2022, the SEC announced a proposed rule titled Enhancement and Standardization of Climate-Related Disclosures for Investors. [41] A fact sheet describes the primary new reporting requirements with respect to climate-related information including:

- Climate-related risks and their actual or likely material impacts on the registrant's business, strategy, and outlook;
- The registrant's governance of climate-related risks and relevant risk management processes;
- The registrant's greenhouse gas (GHG) emissions, which, for accelerated and large accelerated filers and with respect to certain emissions, would be subject to assurance;
- Certain climate-related financial statement metrics and related disclosures in a note to its audited financial statements; and
- Information about climate-related targets and goals, and transition plan, if any.

The rules are proposed to phase-in over several years beginning with elements in 2024. [41]

One of the foundations of improvement is a need to measure the baseline. These new SEC rules may provide that foundation for shippers and fleets with respect to GHG emissions from vehicles under their direction referred to as Scope 1, 2 and 3 emissions disclosures.

3.8.8 Canadian Regulations

Canada signed the COP26 Memorandum of Understanding (MOU) setting targets of 100% new sales of zero-emission medium- and heavy-duty trucks by 2040 and 30% new sales by 2030 [48]. The MOU was proposed by CALSTART. Carolyn Kim, national transportation director at Pembina Institute, said, "For commercial vehicles such as trucks and buses, it has been a challenge to electrify these fleets because they are still part of emerging technology and energy systems. There is also a lack of infrastructure in Canada to support them. But moving forward, the federal government will need to take up leadership and create a national zero-emission vehicles strategy for medium- and heavy-duty vehicles." [48]

Canada issued new regulations as reported in TruckNews in March 2022 with a target that "zero-emission vehicles will need to account for 35% of Canada's medium- and heavy-duty truck sales as early as 2030, under a series of sales targets and incentives unveiled in a new federal emissions reduction plan." [99][100] *TruckNews* said the rules come with financial assistance, with "details around $547.5 million in purchase incentives for medium- and heavy-duty zero-emission vehicles, along with eligibility dates, are to be unveiled in the coming federal budget. Another $199.6 million will be invested to retrofit large trucks already on the road. And $33.8 million will be available for projects that demonstrate hydrogen-electric trucks, to address barriers such as technical standards that apply to long haul trucks."

4 Charging Considerations

Charging and infrastructure are perhaps the most challenging aspect of heavy-duty BEVs. The story on charging is not just about the size of the battery pack, but also about the size of the charger.

4.1 The Battery Pack Size

Light- and medium-duty trucks with battery packs between 50 and 150 kWh can suffice with inexpensive low power Level 2 chargers during long overnight dwell times. Those low power chargers can operate below the typical 19.7 kW A/C charger level used by cars at home. Heavy-duty BEVs have significantly larger battery packs, 200 kWh to perhaps 1,000 kWh in size. Recharging battery packs of these sizes in an overnight dwell period requires much higher power levels. The table in Figure 45 summarizes production BEV data from California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP) and OEM websites. [48][49][50][51] One OEM states that the ~400 kWh battery pack takes three hours to charge from a 120 kW DC charger while the same battery takes 36 hours connected to a 240 VAC charger.

BEV	Battery Pack
BYD 8TT	435 kWh
Freightliner eCascadia	475 kWh
Kenworth T680E	396 kWh
Lion Electric Lion8T	653 kWh
Nikola TRE	753 kWh
Peterbilt 579e	396 kWh
SEA Cascadia EV	220 kWh
Tesla Semi	600 kWh & 1,000 kWh*
Volvo VNR	375 kWh & 565 kWh

* Estimated from OEM specification

Figure 45. Battery pack sizes

4.2 The Charger Size

Charging systems come in many levels as shown in Figure 46. The actual power ratings can vary in each level, so for example a Level 2 charger could be rated from 7.2 kW to as high as 19.7 kW. A DC fast charger (DCFC) can be anywhere from 50 kW to as high as 350 kW. Some references indicate DCFC could be as high as 1 MW but the primary SAE CCS1 connector used with these chargers is limited to 350 kW. The descriptor "fast" can have many interpretations. The higher rate megawatt charging systems (MCS) are just being defined at this time. They may similarly vary in capability ranging higher than 2 MW. A detailed overview of connectors and charging can be found in the NACFE report *Amping Up: Charging Infrastructure for Electric Trucks.* [52]

Description	Level
Level 1	Charging at 120V AC
Level 2	Charging at 240 volts AC
DCFC ("Level 3")	Direct Current (DC) Fast Charger
MCS	Megawatt Charging System

Figure 46. Charger Levels

Mike Rowand, director engineering and technical services at eTransEnergy, a Duke Energy Company, concludes that, "Maximum kW (demand) is a major contributor to infrastructure and energy costs." The energy demand is defined as power used over time. So, for example, a 19.7 kW Level 2 charger operating at peak power for one hour uses 19.7 kWh of energy. But the same amount of energy can be provided over 10 hours, in which case the charger is only operating at 1.97 kW to provide the same total energy of 19.7 kWh. That 1.97 kW is roughly equivalent to running a hair dryer continuously.

A mistake often made in estimating electricity costs is assuming the maximum power rating of the charger is what the charger will operate at. To illustrate this, Rowand provides the following example of three scenarios for charging a fleet of trucks. Assume each truck has a 100-kWh battery pack, and consumes energy at 0.9 kWh/mi. These trucks average 75 miles per day of operation. So, in this simple example that ignores energy losses, each day each truck uses 68 kWh of energy. The fleet of 50 would then need 3,400 kWh per day as shown in Figure 47. [98]

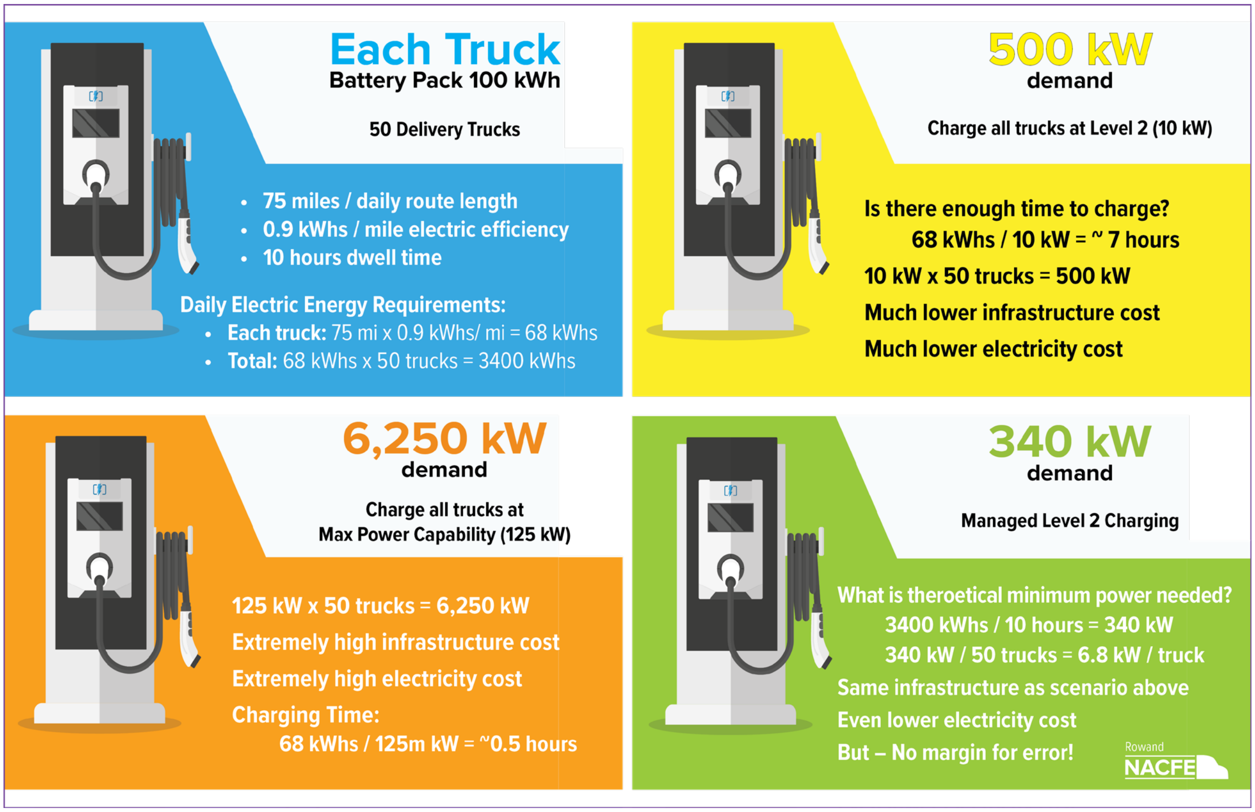


Figure 47. Example of charging energy scenarios

The first scenario charges the trucks as fast as the charger permits, at 125 kW. The entire fleet would charge in 30 minutes and the power demand would be 6,250 kW, using 3,400 kWh of energy.

The second scenario stretches out charging by limiting power to 10 kW charging level occurring over 6.8 hours of available dwell period. The net power demand is then 500 kW, and still uses 3,400 kWh of energy.

The third scenario uses managed Level 2 charging, stretching out charging over the full 10 hours of available dwell time. Each truck is charging at a very reasonable 6.8 kW. The total power demand here is then 340 kW, and still uses 3,400 kWh of energy.

While the charger may be rated at 125 kW, the actual demand by the vehicle can be as low as 6.8 kW in this example. The level of power demand determines the capacity of the entire system delivering energy to the vehicle, i.e., the worst-case sizes the system as shown in Figure 48. [98] Demand level directly impacts the cost of the infrastructure. Higher demand power levels mean much more expensive infrastructure. Higher demand also translates into higher electricity costs, the $/kWh rate paid to the utility. Think of demand as if it was a pipe carrying liquid. Higher demand means a bigger pipe and all that goes with that.

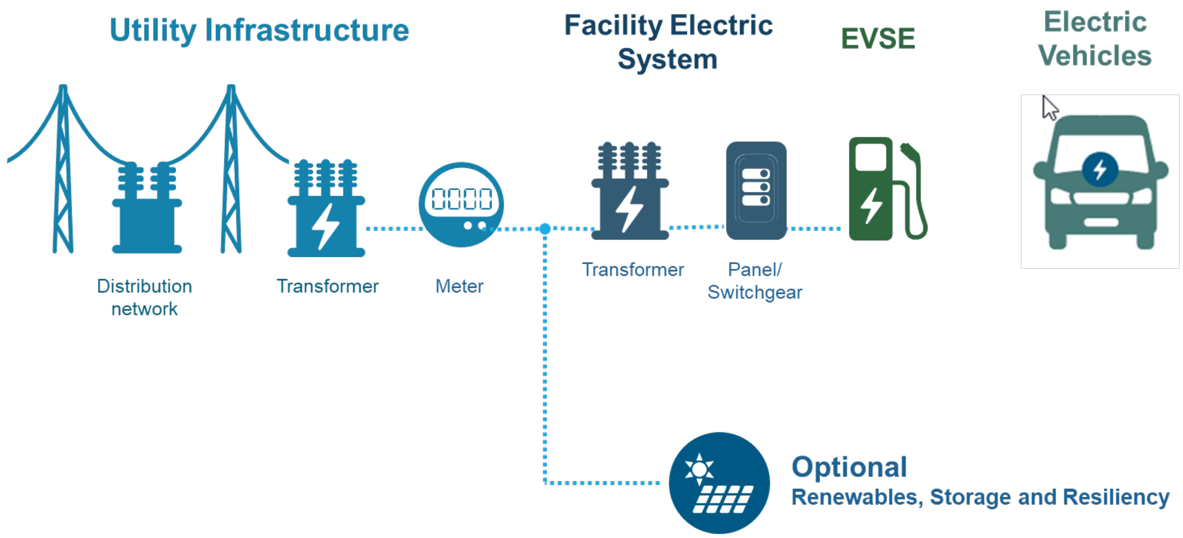


Figure 48. Power demand sizes the infrastructure (Rowand)

4.3 Connectors

These are early days in terms of rolling out BEVs to fleets. Many alternative charging connectors were being discussed and used on prototypes, but the industry understands that standard connectors are needed. The primary connector now being deployed for Level 1 and Level 2 chargers is the SAE J1772 connector shown in Figure 49. [52] These originated for automobiles. The exception is Tesla, which has a proprietary connector which can be connected to SAE J1772 ports with an adapter.

Figure 49. Level 1 and 2 standard connector

DC fast charging has standardized on the combined charging system 1 (CCS 1) connector, often referred to as the combo connector. This connector is based on the SAE J1772 connector with the addition of two DC power connections as shown in Figure 50. [53]

Figure 50. CCS 1 standard DCFC connector (The Driven)

The megawatt charging system (MCS) has been in development for some years through the industry consortium CharIn. [55] An example MCS connector being tested is shown in Figure 51. [55] The standard connectors have been in testing with the DOE. The expectation is that the preliminary standard will be out in 2022. [54]

Figure 51. NREL testing MCS connector (NREL)

NREL is not just looking at connectors, it is researching a 1+ MW level charging facility for heavy-duty trucks. According to NREL, "NREL is working with other national labs to develop a megawatt-scale charging system for medium- and heavy-duty electric vehicles, enabling drivers to charge in less than 30 minutes at reasonable cost." [56] The entire system from grid to vehicle is being considered as shown in Figure 52. [56]

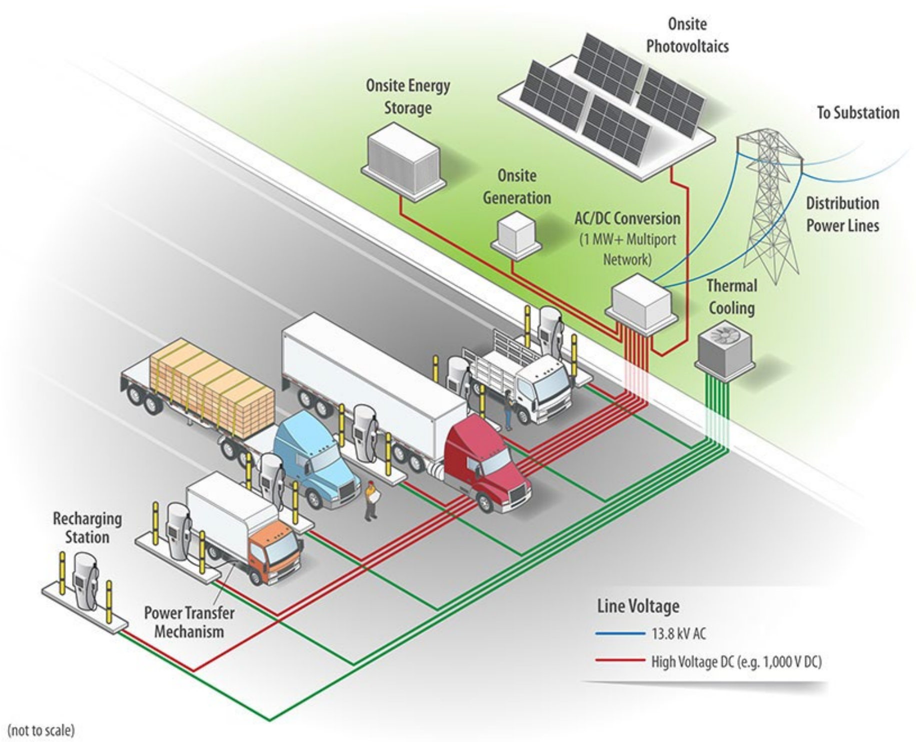


Figure 52. NREL project for fast heavy-duty vehicle charging

High power wireless charging also is being investigated. A DOE funded project titled Long-Range Battery Electric Vehicle with Megawatt Wireless Charging was near completion at the end of 2021. [59] The project lead is Kenworth with UPS as a fleet partner. The project is installing 1 MW level charging systems at one location in Seattle and one in Portland, with BEVs shuttling between the two sites as shown in Figure 53. [59]

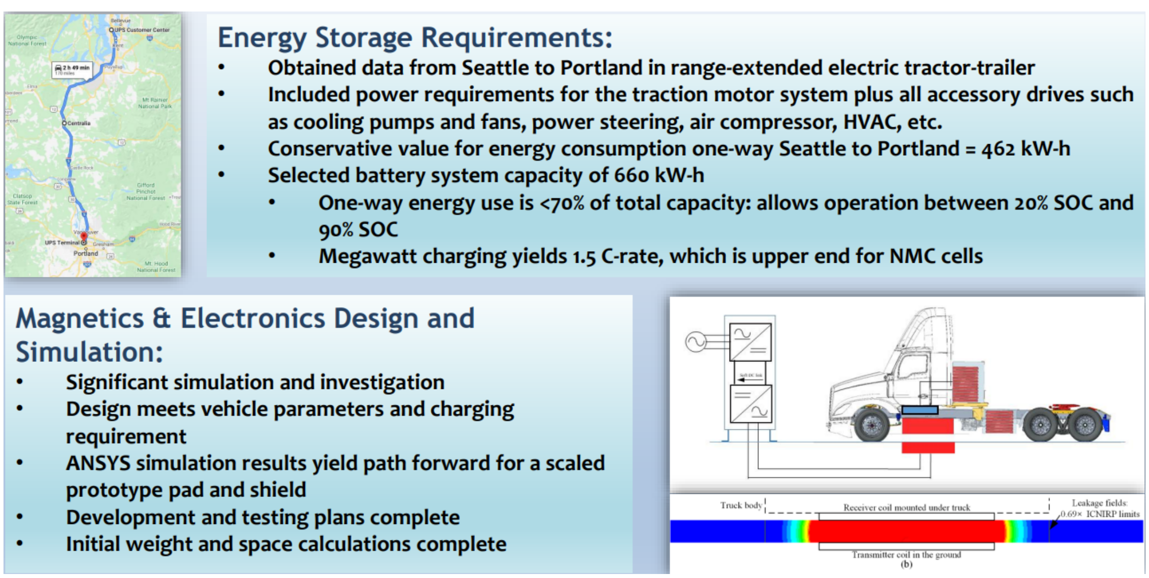


Figure 53. Long range BEV Megawatt Wireless Charging (Kenworth/DOE)

Wireless charging has been shown to work on bus systems and cars. The costs and benefits need to be analyzed once production level systems are available.

One other charging method that is being tried uses overhead or under pavement charging systems while the vehicle is in motion. These are similar to the pantograph systems used in some metropolitan bus systems as in San Francisco and on some east coast train systems like the Amtrak Acela. One project in Carson, CA is funded by the DOE and used the system shown in Figure 54. [60]

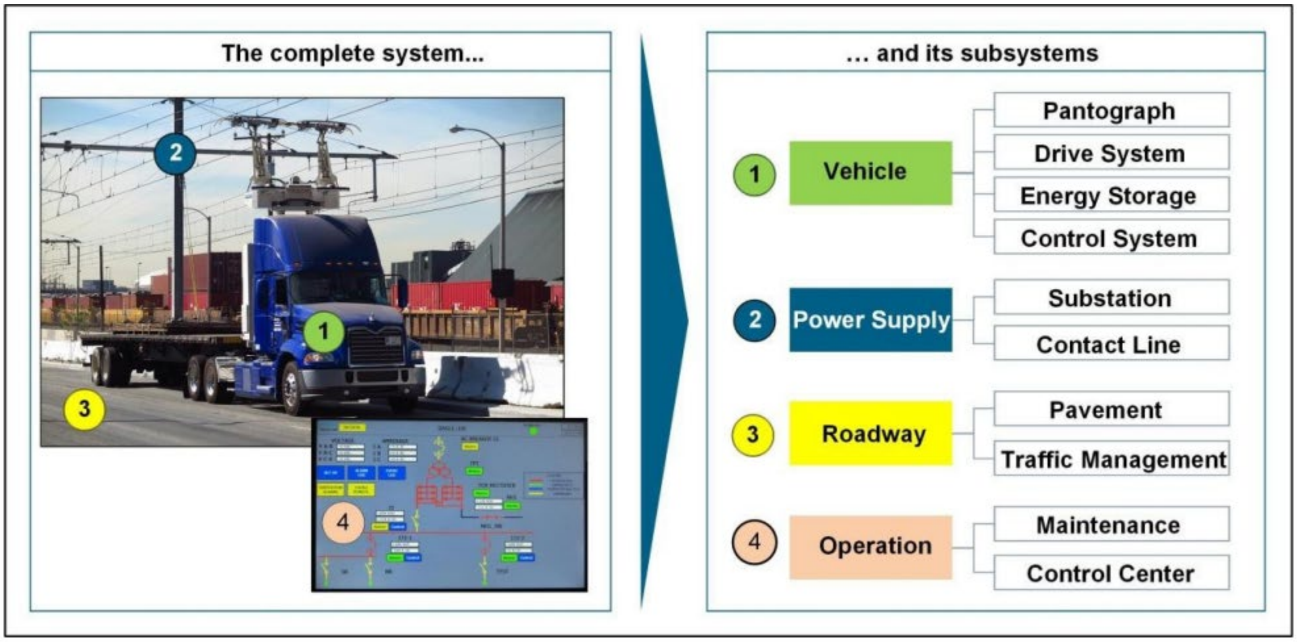


Figure 54. Subsystems and components of the eHighway System (Siemens)

"The key to success and major objectives of the project were the integration of an advanced pantograph into three Class 8 trucks to allow full electric operation on the catenary infrastructure built for this project. The catenary system was built in both directions on a one-mile stretch of Alameda Street in Carson, CA, which is a major truck route heavily used by trucks serving the ports of Long Beach and Los Angeles." [60] Other overhead or under pavement prototype projects are occurring in Europe.

The attractiveness of this system stems from minimizing a major concern of BEVs, specifically that the batteries weigh too much. The pantograph systems allow for minimal battery sizing, providing all the emissions reduction of typical BEVs but with much greater freight capacity. The argument can be made that the infrastructure costs for installing overhead catenary wires would be on par or less than installing depot charging at all the warehouses for BEV charging. Siemens estimates that overall, the well-to-wheel reductions are as shown in Figure 55. [60]

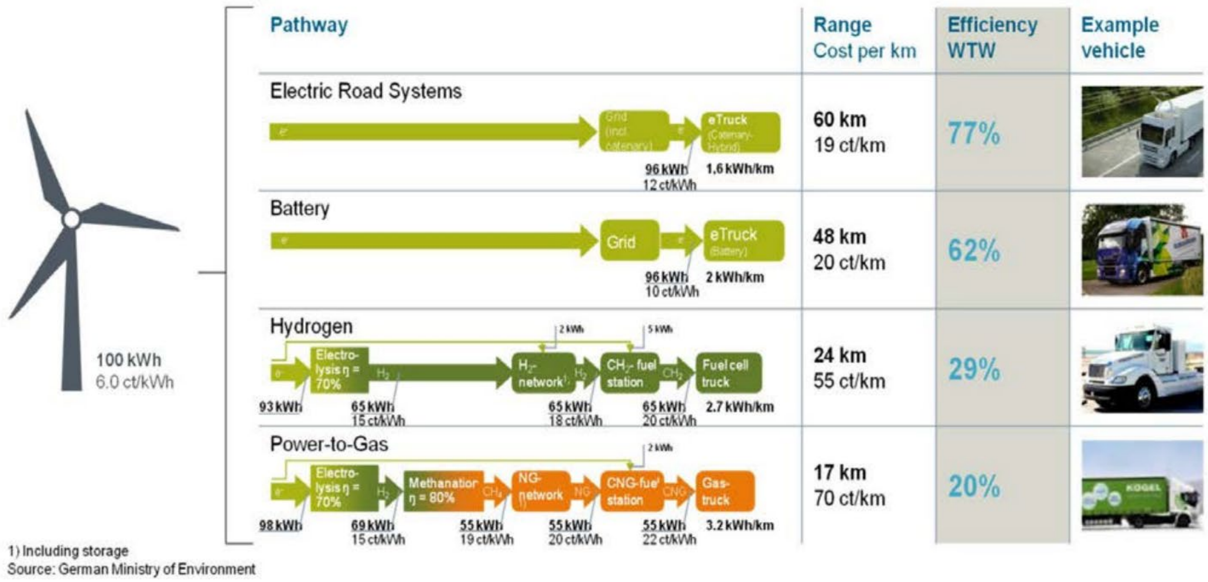


Figure 55. Well-to-wheel efficiencies of decarbonized road freight options

4.4 VEHICLE POWER LEVELS AND FUTUREPROOFING

Each vehicle has a power level maximum. Just because a charger can go to a certain level doesn't mean that the vehicle is capable of that. As previously stated, the power demand level has a major influence on the cost of the components. Manufacturers may choose not to enable future higher-level charging in their current vehicle designs in order to reduce the cost of the vehicle. This means that a vehicle that has a maximum charging level of 150 kW will not be able to take advantage of a 350-kW charger at a later date. It still will be limited to a maximum of 150 kW. Similarly, a vehicle capable of 350 kW charging will be limited to 150 kW by a charger with a maximum power of 150 kW. Ultimately the maximum power level is limited by the weakest link in the system.

This reality has implications on futureproofing fleet purchases of vehicles and infrastructure. Whether or not these vehicles can be or should be rebuilt at a later date to take advantage of newer, more capable systems is one industry concern. An analogy would be looking at a 1990's traditional non-aerodynamic truck and asking if it make sense to rebuild it as a modern aerodynamic one. Certainly, elements of the vehicle might be reused, but many parts would need to be scrapped. The cost of remanufacturing might exceed the cost of simply buying a new vehicle.

RUN ON LESS ELECTRIC

Lesson Learned

Plan ahead for initial infrastructure to make future scaling easier.

The charging limitations of the vehicles are likely to improve over subsequent model years, but the infrastructure at a facility likely will evolve more slowly. Capital investment by the utilities, the facilities and anyone else tied to installing and maintaining charging infrastructure will have longer investment life spans than the trucks at the facility. Those trucks may be resold to other fleets after a few years of use, while the infrastructure will stay in place.

This is where facility planning is critical, to take steps to help futureproof the infrastructure. For example, installing trenches for power cables in a way that can be updated easily at a later date. Or installing charging systems that are rated higher than the current vehicles, so that future higher power, more capable vehicles can be taken advantage of. Planning to create future on-site storage and power generation is another futureproofing activity, as those assets can reduce the cost of electricity from the grid. Those regions that have low carbon fuel standard credit systems, such as California, also offer additional options for offsetting the cost of electricity.

Planning ahead on infrastructure helps minimize downstream work, costs, and delays in scaling BEV use. One charging system company outlined factors to consider to allow either adding chargers, or increasing the power level at each or some, or some combination of the two.

1. Pre-configure the site for adding future charging dispensers to serve future vehicles including:
   - Oversize the electrical switchgear for future demand loads;
   - Allocate additional space on equipment pads to allow for additional power cabinets;
   - Install underground conduits to future locations to minimize future site disruptions.
2. Add capacity to allow converting, for example, 150kW Dispensers to 350kW including adding conduits from existing dispensers to future power cabinets.
3. Install underground conduits from the switchgear to future battery energy storage systems (BESS).
4. Factor in potential future microgrid distributed generation from solar panels or other sources.

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.

4.5 Charger Cost

Charging infrastructure, what is termed electric vehicle supply equipment (EVSE), is new to fleets. Diesel truck operators often rely on public fueling stations, so there is no thought of all the steps involved in getting the fuel to the truck. Some fleets have their own on-site diesel fueling facilities, and they likely are more aware of the complexity of that enterprise. Adding depot-based electric vehicle charging to a fleet's facility requires looking at the facility as a complete system. NACFE's report *Amping Up: Charging Infrastructure for Electric Trucks* can provide insights on this system's perspective. [52]

Looking at costs, RMI illustrates in Figure 56 the many cost factors involved in setting up charging infrastructure, equating EVSE costs to an iceberg, where many cost factors are unseen below the surface. [57]

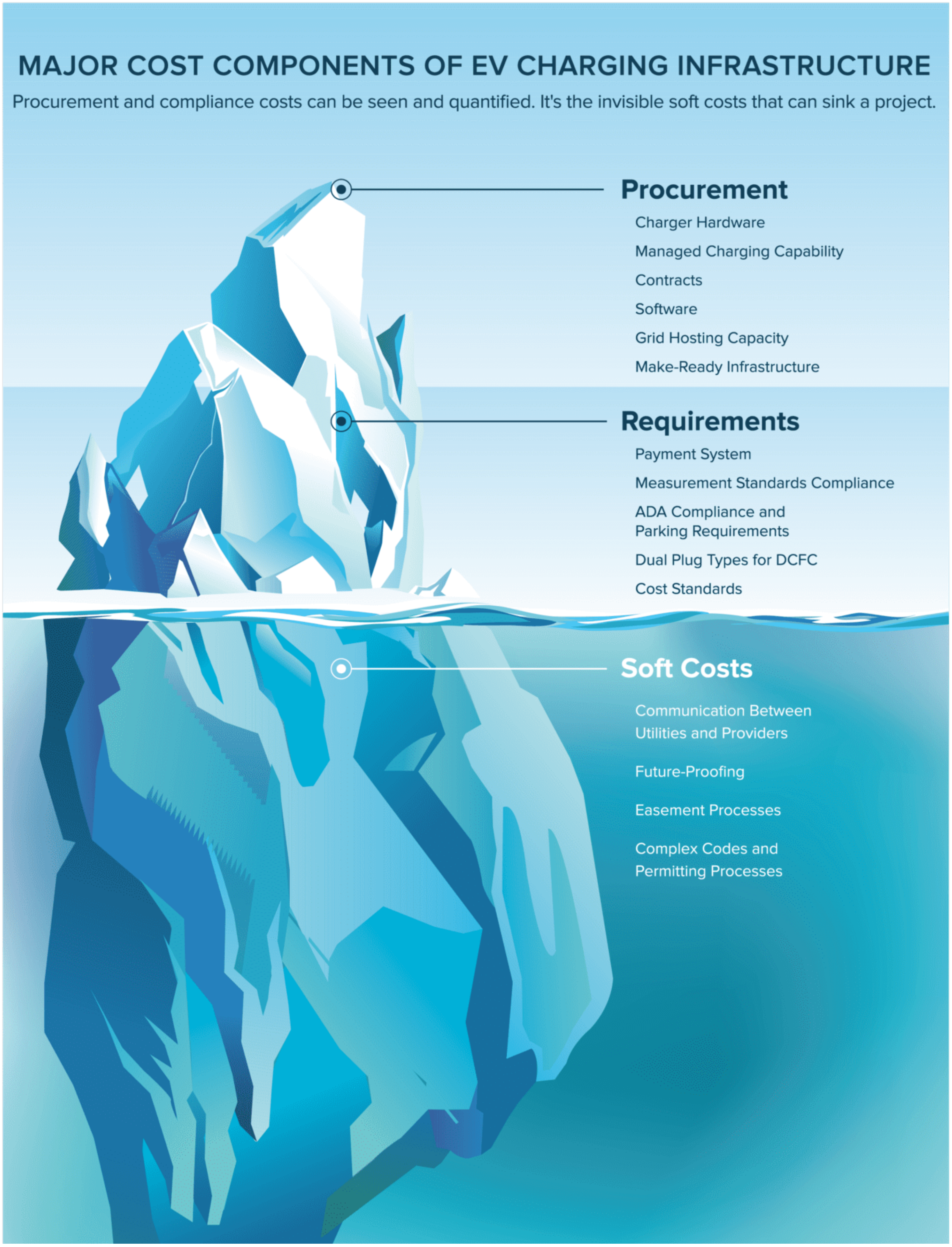


Figure 56. Cost factors for EVSE

The chargers themselves vary in cost based on their capabilities. ICCT published Figure 57 in 2019 reflecting that EVSE costs increase as power levels increase. [58]

Level	Type	Chargers per pedestal	Per-charger cost
Level 1	Non-networked	One	$813
Level 1	Non-networked	Two	$596
Level 2	Non-networked	One	$1,182
Level 2	Non-networked	Two	$938
Level 2	Networked	One	$3,127
Level 2	Networked	Two	$2,793
DC fast	Networked 50 kW	One	$28,401
DC fast	Networked 150 kW	One	$75,000
DC fast	Networked 350 kW	One	$140,000

Figure 57. Per charger public and workplace charger hardware cost (ICCT)

RMI estimated EVSE costs in Figure 58 in its 2019 report, *Reducing EV Charging Infrastructure Costs*. [57]

COST ELEMENT	LOWEST COST	HIGHEST COST
Level 2 residential charger	$380 (2.9 kW)	$689 (7.7 kW)
Level 2 commercial charger	$2,500 (7.7 kW)	$4,900 (16.8 kW); outlier: $7,210 (14.4 kW)
DCFC (50 kW)	$20,000	$35,800
DCFC (150 kW)	$75,600	$100,000
DCFC (350 kW)	$128,000	$150,000
Transformer (150–300 kVA)	$35,000	$53,000
Transformer (500–750 kVA)	$44,000	$69,600
Transformer (1,000+ kVA)	$66,000	$173,000
Data contracts	$84/year/charger	$240/year/charger
Network contracts	$200/year/charger	$250/year/charger
Credit card reader	$325	$1,000
Cable cost	$1,500	$3,500

Note: DCFC denotes direct-current fast chargers.

Figure 58. Cost ranges for charging infrastructure components (RMI)

RMI estimated the range for DCFC charger costs in Figure 59. [57]

Figure 59. Range of DCFC costs

Megawatt level charging is expected to increase EVSE costs significantly. Accurate cost estimates are yet to be determined since the systems are just in the prototype stage. Daimler has installed an electric island in Portland, a proving ground for investigating charging systems for heavy-duty trucks as shown in Figure 60. [61] The facility is designed to be upgradable over time as technologies advance. Green Cat Reports summarized Daimler futureproofing the site stating, "Through some incremental transformer upgrades, the Electric Island site is set up for 5 MW of power, potentially within a couple of years. The site can accommodate up to 16 dispensers (some potentially with two connectors). And although the highest power of the hardware at Electric Island is currently 150 kw, the hardware there can deliver up to 350 kw. [61]

Figure 60. Electric island charging facility

4.6 Scaling

Scaling BEV deployments is currently being done with two large scale projects announced in August 2021 under the Joint Electric Truck Scaling Initiative (JETSI), Project Scaling with fleets NFI and Schneider and OEMs Volvo and Daimler as outlined in Figure 61. [62]

Vehicles/Equipment Funded

100 Commercial CARB certified Class 8 battery electric trucks (BETs) and infrastructure deployed at freight handling facilities:

- 50 BETs each at NFI (Ontario) and Schneider (South El Monte)
- 34 175/350 kW DC fast chargers at NFI and 16 175/350 kW DC fast chargers at Schneider
- 1 MW solar, 5 MWh battery energy storage, BET maintenance facility at NFI

Featured innovations:

- Multiple truck configurations to meet drayage/regional haul applications and range
- Increased energy density battery chemistry for later model year BETs
- Solar, energy storage, and second life batteries to mitigate grid impacts and energy costs
- Networked chargers with fleet management software
- EPRI to develop fleet uptime software to maximize charger utilization/uptime

Figure 61. JETSI BEV scaling project (CARB)

These two sites represent a significant step forward in demonstrating large scale deployments of BEVs along with the required infrastructure to charge and maintain the vehicles. Both operations focus on drayage duty cycles compatible with BEVs. CARB describes these BEVs this way: This project will have a minimum daily range of at least 150 to 200 miles on a single charge and most trucks will be in drayage service, with some in short regional haul service.” [62] Funding is estimated at $63,052,220 with the projects being fully operational by spring 2025.

Another scaling activity is in process with WattEV in Bakersfield, CA, where an EV truck stop is being built. [63] See Figure 62. WattEV is a truck-as-a-service (TaaS) business model providing shippers and carriers access to BEVs at a per-mile rate, including charging. The company believes its model will have parity with operating diesel trucks. WattEV’s first public truck charging depots will be in Bakersfield, San Bernardino, and near the Port of Long Beach, and will feature 250 kW CCS chargers that will provide the Volvo VNR Electric trucks an 80% charge in 90 minutes for the six-battery packs.

According to WattEV’s website, “As WattEV’s public charging network expands nationwide, the company plans to scale its depots to provide 1.2 MW charging capability for ultra-fast charging.” [63] According to Jerry Hirsch of Trucks.com, “WattEV Inc. said it has secured a $5 million grant from the California Energy Commission to build the state’s first solar-powered truck stop for heavy-duty electric trucks and expects to break ground on the project in late October 2021.” [64] Work is underway on this project as of the writing of this report.

Figure 62. WattEV electric truck stop

5 Benefits of BEVs in Regional Haul Market Segment

BEVs offer the potential for significant operating cost reductions, extended service intervals, less maintenance, improved ability to attract and keep drivers, better driver morale, and improved brand image.

5.1 Emissions

Battery electric Class 7 and 8 tractors have 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 BEV are “moved” from the location where the tractor operates to where the power is generated. 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.

5.2 Maintenance and Downtime

BEVs are both simpler and more complex than their diesel counterparts. It’s often stated that there are far fewer parts in an electric vehicle. That is somewhat misleading because part counts depend on what level of assembly is being considered. A circuit board, for example, has a significant number of parts, but it also is considered a single part number as an assembly. A diesel engine might just as easily be considered one part number when delivered to the truck factory. While there are fewer moving parts in a BEV, an electric vehicle generally has more software — more lines of code — than a diesel. The greater use of software to control the vehicle allows for automating aspects of troubleshooting. However, while each line of code is not considered a part number, the greater complexity of the software is something to consider in terms of troubleshooting time during repairs.

5.2.1 Part Count

What is accurate is that there are far fewer moving parts in a BEV than a diesel. This means there are fewer friction and vibration sources to cause heat, wear and failure. Figure 63 shows an example diesel drivetrain photographed at a truck show. Fewer moving parts means there is less need for lubricants and greases and less need for pumping and filtering systems to keep the fluids moving and free of particles. A diesel engine also requires air handling systems, both air intake and exhaust. Diesels also have complex emission systems. These systems have significant maintenance aspects which are not present with a BEV. Transmissions and mechanical drivetrains also are greatly simplified on BEVs.

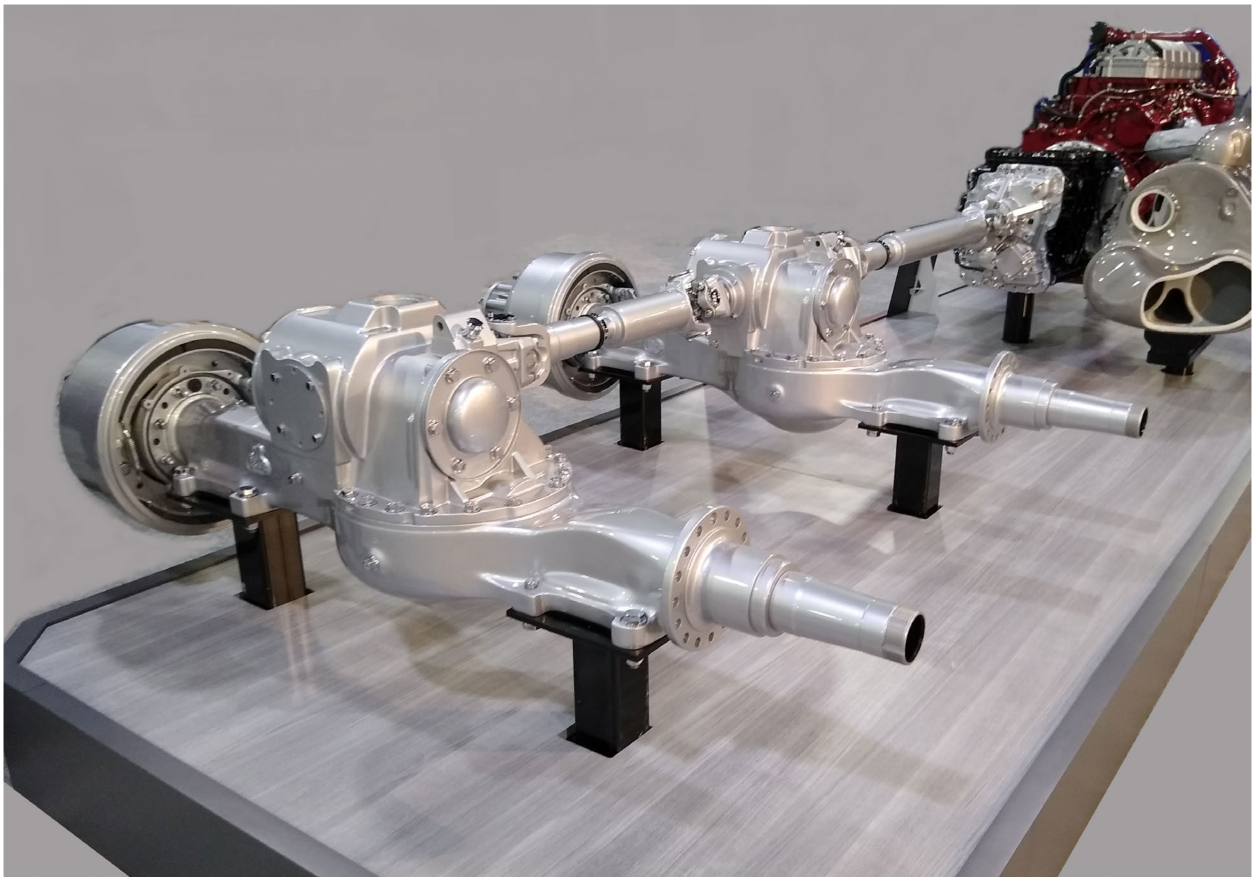


Figure 63. Example diesel drivetrain (Mack/Mihelic)

5.2.2 Fluids

NACFE estimated the weight of Class 8 tractor fluids in Figure 64 from the report *Electric Trucks – Where They Make Sense.* [2] Fluids for diesel trucks account for anywhere between 877 lbs. to 2,411 lbs. based on how much fuel is on board. While BEVs will have some of these same needs, things like fuel, diesel exhaust fluid (DEF) and engine oil are not required. Coolant, and some amount of other lubricants likely will still be required for a BEV. Eliminating engine oil changes goes beyond just the truck. Proper handling and disposing of waste engine oil requires infrastructure and incurs costs.

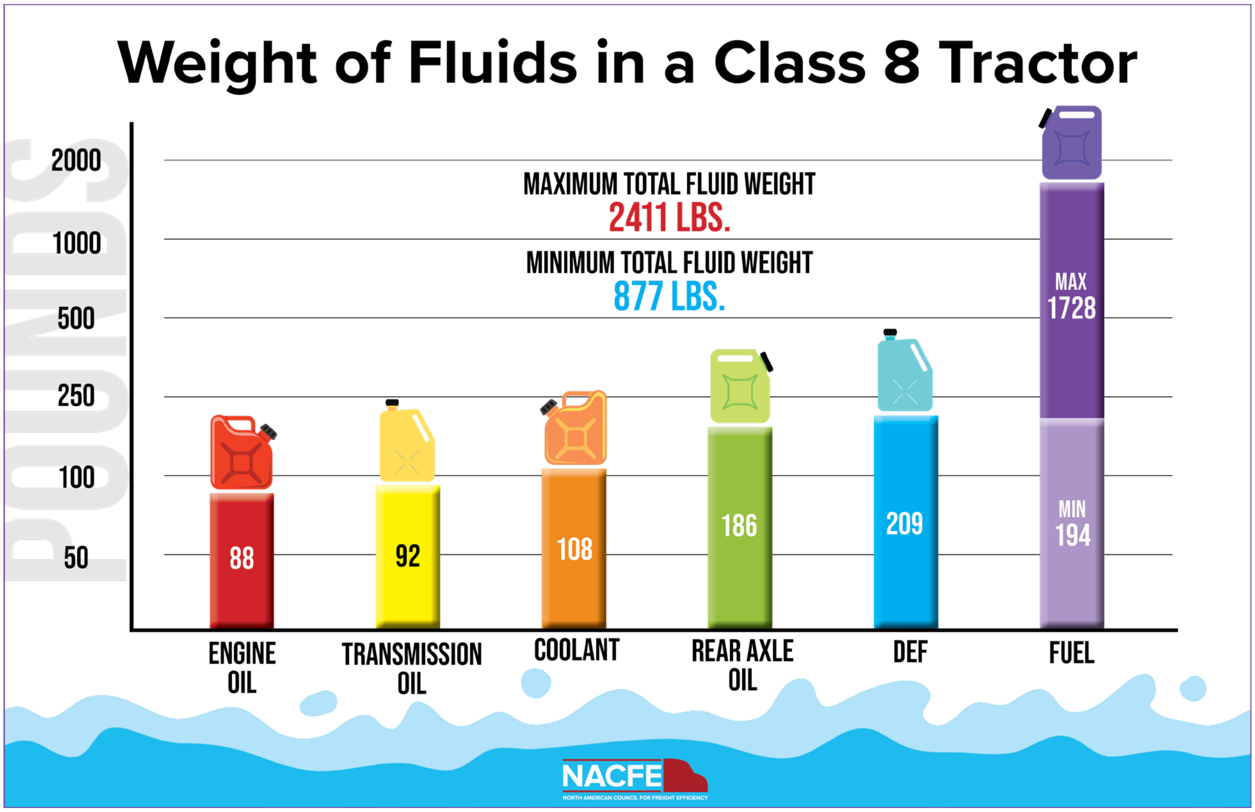


Figure 64. Example weight of fluids in a Class 8 tractor

5.2.3 Emission Systems

There are no emission systems or exhaust systems on a BEV. Emissions systems on diesels are a significant downtime and maintenance repair item for fleets.

5.2.4 Cooling Systems

Diesels have a significant need for cooling systems to maintain proper conditions for the engine to operate. These all require radiators, ducting, sensors, pumps, filters, etc. BEVs also require thermal management systems, but there are fewer components. The comparison in Figure 65 shows all the hoses, pipes, cooling package, filters, etc. for a diesel compared to a recent production BEV. Both vehicles are seen to have pink coolant and blue windshield washer fluid reservoirs. Absent on the BEV are the large air intake pipes and air filter, charge air cooler, turbocharger, coolant lines, oil pan, oil filter, belts, belt driven accessories, etc.

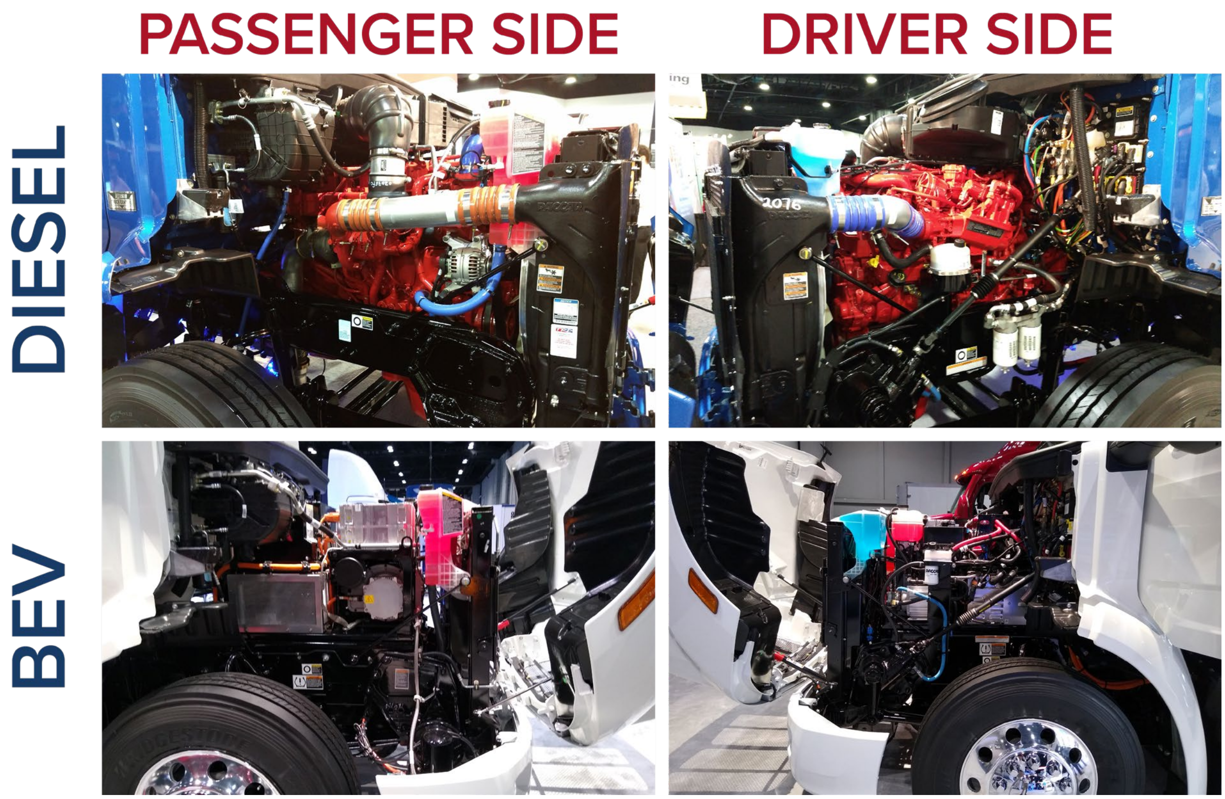


Figure 65. Diesel vs BEV under hood (Mihelic)

5.2.5 Brakes

Diesel truck brakes see significant wear and need regular servicing. The same air brake systems are on Class 8 BEV tractors, but they are greatly supplemented by regenerative braking, essentially using the motors that drive the wheels to act in reverse as electrical generators while slowing the vehicle. Regenerative braking greatly extends the life and service intervals for the friction material on air brake systems.

5.2.6 Tires

Reliable data on heavy-duty BEV tire wear versus diesels is not yet available because the lack of significant numbers of operational production Class 7 and 8 battery electric tractors. There are arguments on both sides of the question of whether BEVs will accelerate or extend tire replacement cycles.

One argument is that the faster acceleration possible with BEVs versus diesels will mean drivers are prone to jack rabbit starts that wear tires faster. However, the experience seen in Run on Less – Electric is that drivers drive responsibly, with smooth accelerations. BEV acceleration is controlled by software. The software can be tuned by the fleet and OEM to minimize tire acceleration wear, while still providing drivers better acceleration than possible with a diesel.

Another tire argument is that regenerative braking will wear tires faster than seen with diesels. Energy recovery during deceleration using regenerative braking is best with long slowdowns. Very little energy is recoverable with quick stops. This suggests that tire wear may be on par with diesels or perhaps even better during stopping. One-pedal driving is the term used to describe BEV acceleration and deceleration. Taking the driver's foot off the accelerator pedal engages energy recovery by the regenerative braking system. The greatest recovery would be, for example, lifting the foot when first entering an exit ramp, and then coasting to the stop at the end of the exit, applying the foundation brakes at the end if required. One-pedal driving may maintain tires better through more uniform wear. One BEV school bus district operator interviewed by NACFE indicated that their tire wear for BEVs was better, extending replacement cycles by a year or more.

A third argument is that BEVs are significantly heavier than diesels so will wear tires more quickly. It is true that the tare weight of BEVs is more than comparable diesels by 3,000 lbs. to as much as 14,000 lbs. The front axle ratings are not necessarily any different. That means the weight on the steer axles may be similar. The drive axles will see the additional weight. NACFE estimates for three of the lighter current production OEM BEVs, the added weight per tire is approximately 1,000 lbs. per super single, or 500 lbs. per tire in a dual arrangement. The heavier new BEV models could add two to three times more weight to the steer and drive tires.

Research on tire life as a function of load obtained from a truck tire manufacturer indicates that going from an 80,000 lbs. truck to an 82,000 lbs. truck — a 2.5% change in load — would decrease tire life by approximately 5%. An automotive tire manufacturer stated that tire life tests with similar vehicles showed that EVs can reduce tire life mileage by up to a quarter. However, the manufacturer indicated that in some cases with four-wheel drives, the EV tires lasted 10% longer.

5.2.7 Transmissions and Drivetrains

Transmissions for diesels tend to have many gears to provide the best torque to the wheels at different speeds. Multi-speed transmissions have been the standard choice whether manual, automated-manual or fully automated. BEV electric motors can deliver the same torque across nearly all speeds, requiring few if any gears. The complexity reduction is significant. The example shown in Figure 66 is a diesel Allison TC 10-speed transmission on the left, and on the right a BEV Meritor Integrated ePowertrain multi-speed transmission with either two or three speeds.

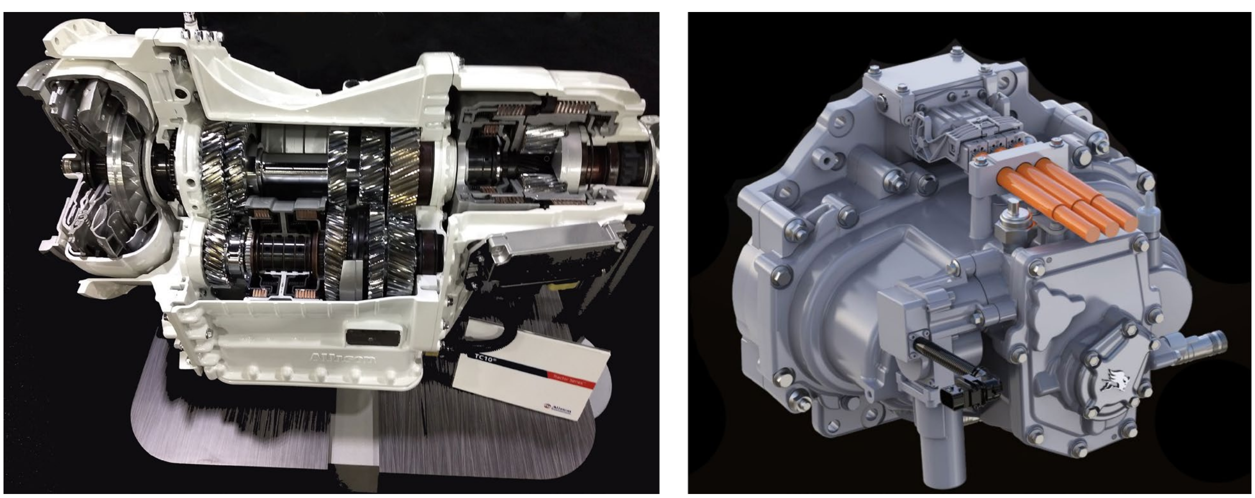


Figure 66. Example diesel transmission (Mihelic/Allison/Meritor)

5.2.8 12V Batteries

BEVs have high voltage batteries and traditional 12-volt ones. The 12V batteries in diesels have to provide starting power in all conditions and also power for deep cycling during vehicle hoteling when the engine is off. The 12V batteries in BEVs no longer have to provide starting power since there is no engine to start. The remaining demands on the 12V battery of powering door locks, radios, interior lights, etc. still exist with BEVs. The majority, if not all, regional haul BEVs will be day cab versions so there is no sleeper power demand, no refrigerator, no microwave, no television, etc.

12V batteries for diesels are a maintenance a repair item. According to Vicki Hall, director of transportation technical solutions at Enersys, 12V batteries tend to be damaged by extreme heat conditions, then fail to provide enough starting power in cold conditions, leading to stranded loads, road service calls and downtime. [66] BEV 12V batteries are subject to the same failure modes, but the demands are no longer split between needing high cranking power and deep cycling. Only the deep cycling is there, allowing 12V batteries to be tuned to that need and possibly extending their service life.

5.2.9 Electric Cables, High Voltage, etc.

Electric cables and their connectors always have been an issue for diesel trucks. Class 8 trucks see very severe environments that often induce abrasion in cables as the chassis flexes, harsh chemicals and significant water pressure from truck washes, and significant temperature extremes in the seasons. BEVs bring additional high voltage cables to the vehicle but eliminate or simplify other existing cables. Examples of high voltage cables are shown in Figure 67.

The high voltage cables are required to be very robust with thick insulation and stringent connector requirements to ensure safety. These cables will be less prone to abrasion. They also are not going to be repaired in the field but most likely will be replaced with new cables when they fail. This also will reduce failures from improper field repairs or modifications that can occur with diesels. High voltage cables will be an area of focus as production trucks arrive in the field in significant numbers moving forward.

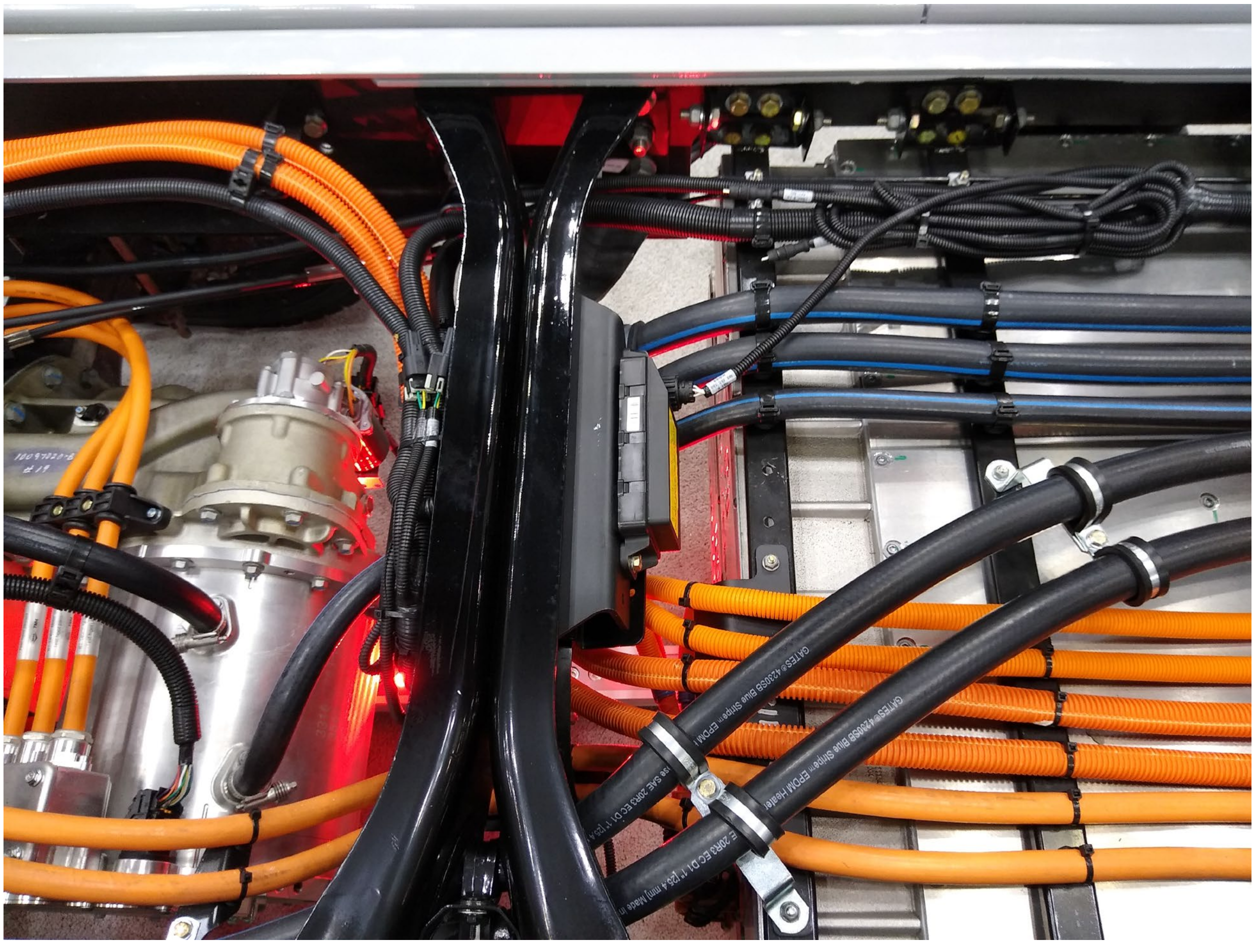


Figure 67. Example of high voltage cabling (orange) on a medium duty truck (Mihelic)

5.2.10 Accessories

BEV accessories will not be powered by belt drives off a diesel engine. There are no belts on a BEV. Vibration and heat are hard on belt-driven accessories. Electrifying accessories eliminates a significant number of failure-prone mechanical moving parts. For example, cab heaters no longer need to be fluid based. Most heaters in electric automobiles are electric resistive heaters. A resistive heater has no pump or liquid and none of the associated failure modes or maintenance issues. There is no belt-driven alternator, fuel pump, oil pump, or DEF pump. All of these systems are failure modes and maintenance and repair items on diesels. See an example diesel engine with belt-driven accessories, oil pan and multiple filters in Figure 68.

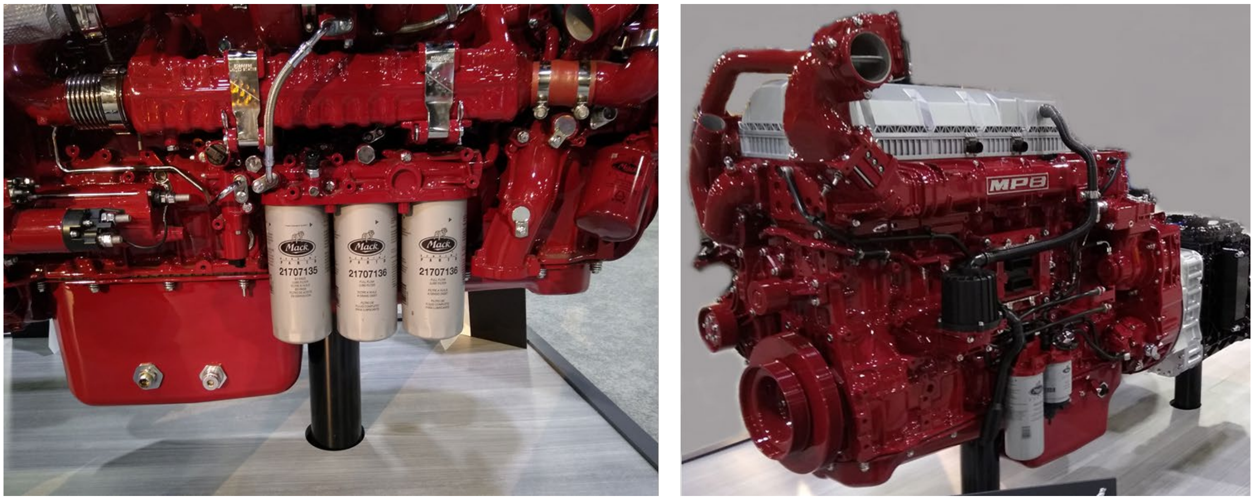


Figure 68. BEVs do not have oil pans, filters, pumps unlike this diesel (Mihelic)

5.2.11 Shop Equipment

Equipping a shop for BEVs will focus on safety. And, of course, personal safety equipment will be required in shops. There are no fumes with BEVs, so no expensive exhaust systems are needed. Personal safety equipment and strict adherence to safety protocols will be required in shops. Rubber gloves and face shields will be required when servicing high voltage systems. Lockout-tagout procedures will need to be followed. High voltage batteries stored at a facility will need to be protected properly in locked storage rooms only accessible by trained technicians. Fire suppression systems and training will be needed as battery packs may require special suppression methods.

Professor John Kelly at Weber State, which has an EV technician training program, posted a video, *EV and Hybrid Training Shop Tour.* [67] What is remarkable going through the entire shop, there is very little in the way of new equipment needed to service BEVs. However, the high voltage nature of the power systems requires insulated tools, such as the Wiha tools displayed in Figure 69. [67][68]

Figure 69. Examples of insulated tools (Weber State)

The primary service tool for BEVs likely is already in a diesel shop: the laptop computer. Much of the servicing of BEVs will be based on using OEM service software and the computer to identify and troubleshoot the BEV. Kelly's tour of the EV automotive shop includes only two other pieces of equipment not found in a diesel garage, a smoke tester and a battery cell balancer. The smoke tester shown in Figure 70 is described as a tool needed to verify that the covers of components are sealed to keep moisture out. [67]

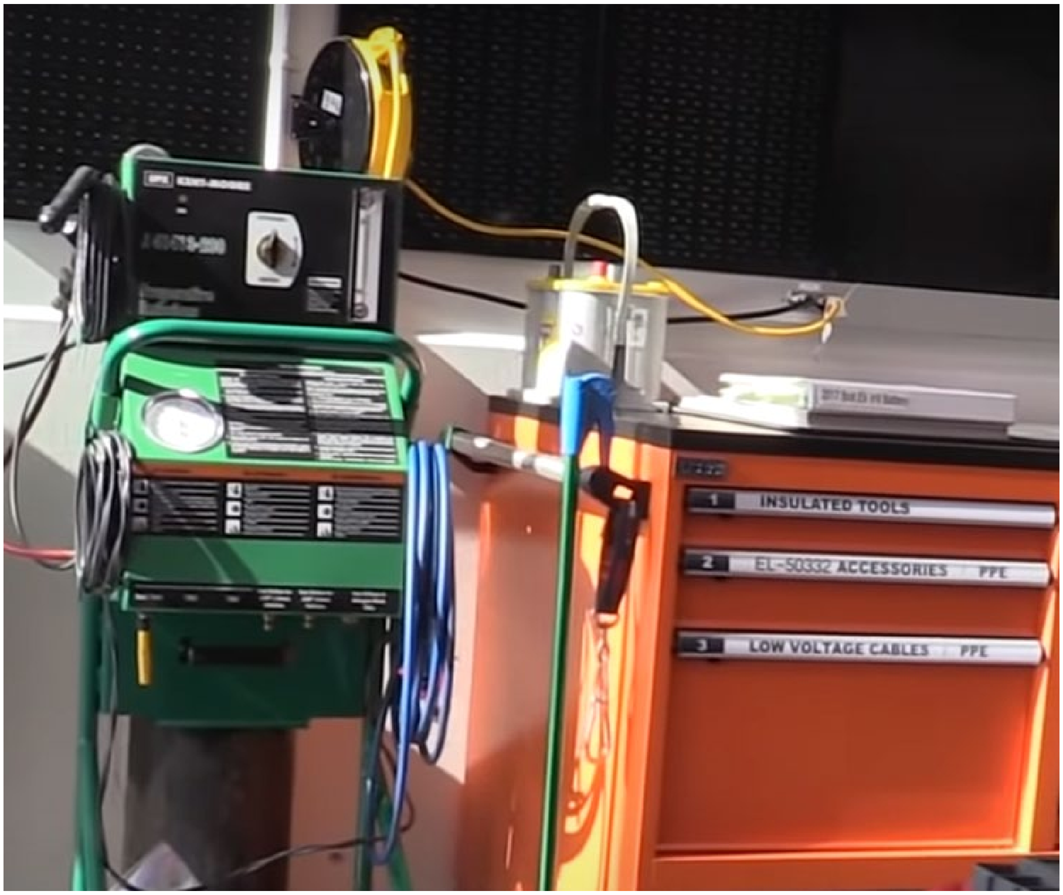


Figure 70. Smoke tester to check sealing (Weber State)

The battery cell balancer seen in Weber State's shop shown on the left of Figure 71 is a battery discharge/load leveling tool. [67] A GM-50332 is shown on the right of Figure 71 and is described by GM Tools and Equipment this way: "Volt battery pack consists of three cell group sections. Replacement sections will ship from a GM warehouse at 30% SOC (state of charge). This electronic device is required when the Volt battery pack is serviced internally to replace a bad section. The tool can either charge the new section to match the SOC of the other two sections or discharge the new section to match the SOC of the two original sections." [69]

Heavy-duty trucks will have larger and more complex battery packs likely to be serviced by specialists in the early years of BEV deployment. Servicing the internal components of the battery pack or any of the high voltage components likely will be done by OEM or supplier technicians, or they simply will be replaced with the failed units being returned to the vendors for servicing. In the long run, large shops likely will begin to migrate high-voltage component servicing in-house or hire trained and certified third parties to perform that work on site at their facilities.

Figure 71. Left, battery cell levelling tool in cabinet (Weber State). Right, example battery discharge/load levelling tool (GM).

5.2.12 Maintenance Costs

The Class 8 BEV industry has not had sufficient time with production level BEVs in the field to accurately assess long-term maintenance reductions of BEVs versus diesels. There has been more experience with EVs in automotive and commercial bus applications where the anecdotal feedback is that there is significantly less maintenance. Whether this translates to significantly less downtime for BEVs is hard to verify, as much of the maintenance data is proprietary. All new technologies generally experience early learning curves where field experience finds problems not experienced in OEM testing. The natural process of fleet feedback, warranty claims and continuous improvement tends to eliminate these issues over the course of the first few model years. Limited published information from public bus agencies operating battery electric buses shows improvement in uptime over the first few years of production vehicles. NACFE expects that Class 8 battery electric production trucks will see similar experience.

Over-the-air (OTA) update capability is often touted as an advantage of BEVs over diesels. The BEVs, as previously noted, are more software intensive vehicles, lending themselves more to having problems corrected via OTA software updates, but modern diesels also get OTA updates. The benefit of OTA updating is that a problem discovered on one vehicle can be resolved remotely and then that solution can be applied remotely to all the other fleet vehicles in one quick update.

This also highlights a significant fleet risk in that a bad update can then affect the entire fleet at the same time. Software engineers are not perfect, and often their solutions cannot be fully vetted in the test lab before being placed in fleet use. Fleets essentially become beta testers for the software. This is nothing new, it's been going on with software updating for personal computers and cell phones for decades. It does, however, highlight that OTA updates may need to be staged to smaller groups of vehicles over a period of time to gain confidence in the update to make sure an entire fleet is not disabled at one time.

TMC, working with FleetNet America, tracks and reports on the frequency of roadside repairs for Class 8 diesel-powered vehicles across three groups — Less-Than-Truckload (LTL), Tank and Truckload (TL), and Dry Van. Their first quarter 2021 report states, "Truckload carriers averaged 21,856 miles between breakdowns." The data is based on the Vehicle Maintenance Reporting Standards (VRMS) system which allows looking at which systems are causing the issues.

FleetNet's report for Q2 2021 shows the most frequently repaired systems in road service as shown in Figure 72. [70] The data highlights that brakes, exhaust systems, power plant and cranking systems are typical roadside repairs. In the comparison between diesels and Class 8 battery electric tractors, BEVs do not have cranking systems, the powerplant has essentially no moving parts, accessories are electrified, and the brakes see much less use due to regenerative braking. This data supports the argument that BEVs will have fewer issues.

Most Frequently Repaired Systems by Miles/Repair

FleetNet America/ATATMC 2021 Q2

VRMS Group	LTL	TL	Tank
Cranking System (032)	1,103,141		621,762
Lighting System (034)	823,968		557,663
Trailer Frame (077)		342,338	
Power Plant (045)	516,726	367,346	
Exhaust System (043)			517,639
Mechanical Refrigeration (082)		136,160	
Brakes (013)	330,074	166,976	222,606
Tires, Tubes, etc. (017)	114,666	59,249	36,243

Figure 72. Most frequently repaired systems

NACFE's interviews with Run on Less – Electric participants showed substantial belief that BEV maintenance costs would be significantly less and that vehicle uptime would be comparable or better than diesels.

To learn more about maintaining electric vehicles, listen to the replay of NACFE's Electric Truck Bootcamp training session, Maintenance, Training & Safety.

5.3 Drivers

The experience from the RoL-E interviews with drivers and their management teams is that drivers love electric trucks. Drivers universally stated the electric vehicles were better driving experiences versus diesels. There were several factors contributing to this conclusion including reduced noise levels inside the cab, better acceleration, ease of operation, ease of charging, the fact that there are no emissions during idling, the fact that BEVs emit no fumes, and drivers find them less tiring to drive. In addition, there is a novelty factor about driving a BEV and they portray a positive brand image for the fleet. NACFE's report, *Electric Trucks Have Arrived: Documenting A Real-World Trucking Demonstration*, contains more details on what drivers think about BEVs.

NACFE firmly believes that BEVs will be an asset to fleets in attracting and keeping drivers. This applies to all age groups, ethnicities, genders, and experience levels. The competition for new drivers has never been more challenging, and Class 8 BEVs have the potential of attracting new entrants in their 20s. The RoL-E interviews of older drivers also found that some previously considering retirement felt the BEVs were enough reason to stay in service. Between those extremes in ages, there is a large group of drivers that switch companies frequently. Driver turnover has been an issue that fleets try to address with having newer equipment, better pay structures, more regional haul operations to allow reliable time at home with the family, etc. BEVs will be an advantage, especially in the early years where production quantities are limited. The fleets that have BEVs will have a distinct advantage over those that do not. The corporate image also will be greatly enhanced in the driver pool.

To learn more about drivers, listen to the replay of NACFE's Electric Truck Bootcamp training, Drivers and Electric Trucks.

5.4 Fuel Costs

ATRI annually reports on the operational cost of vehicles. [43] NACFE has summarized ATRI data in the graph in Figure 73. Fuel, which includes the cost of DEF, over the past decade generally has represented about one-third the cost of operating a vehicle. In more recent years, fuel prices have been more depressed and driver wages have seen significant growth. The 2020 data shows fuel as 19% of the cost per mile. However, fuel prices have been rising in the latter half of 2021 and early 2022, not yet included in Figure 73.

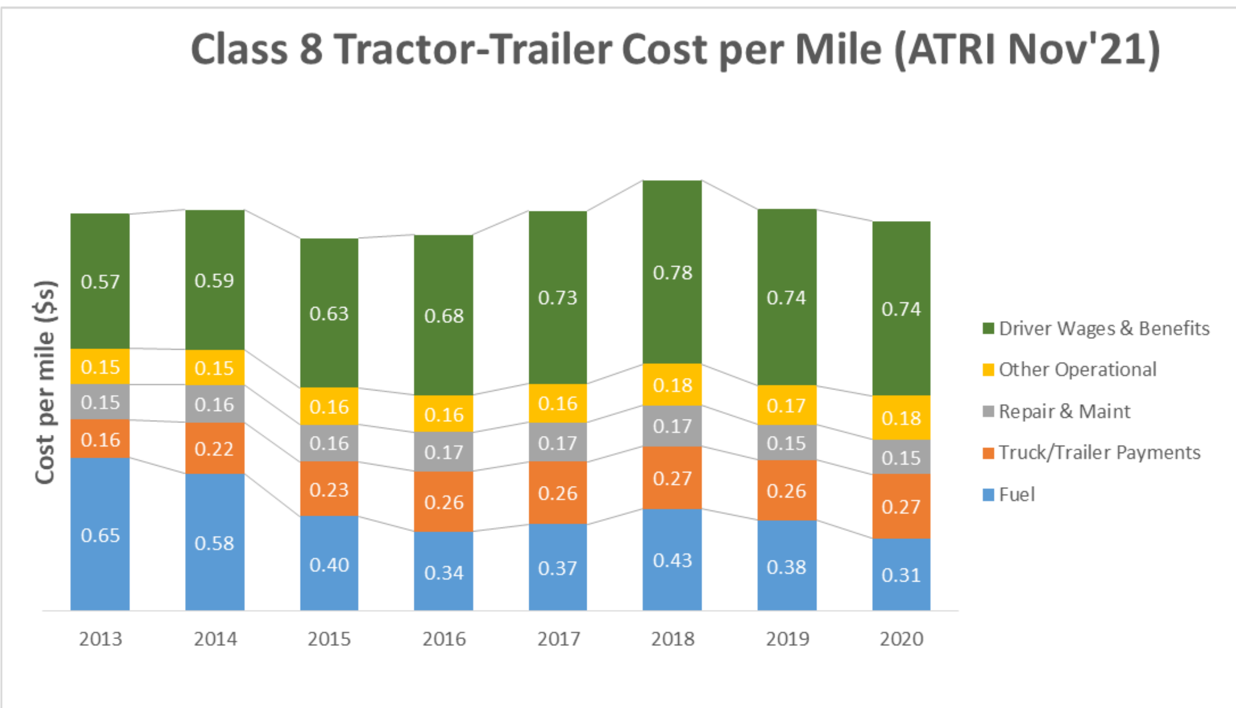


Figure 73. Operating costs per mile over time (ATRI/NACFE)

5.4.1 Fuel Cost Comparison

Actual BEV cost per mile data from fleets using production level trucks is not yet publicly available, and the majority of experience to date for Class 8 trucks involves prototypes and early production units which likely is not representative of production vehicle operational use. However, just looking at energy efficiency, current data supports that Class 8 BEVs can operate at 0.5 mi/kWh. Recent diesels in regional haul are capable of 8.0 mpg based on NACFE's 2019 Run on Less Regional demonstration where nine diesels achieved 8.7 mpg in regional haul operations. [16] Average US diesel fuel costs for all of 2021 per the DOE Energy Information Administration data was $3.28/gal. [30]

The 2021 average US cost for electricity, averaged over all sectors according to EIA is $0.112/kWh. [42] Comparing a Class 8 diesel to a BEV for a 200-mile daily range over a year shows a fuel costs savings of $9,300 as seen in Figure 74. This is before any consideration of cost of DEF fluid for the diesel or low carbon fuel standard credits or other fuel cost benefits the BEV might have. Diesel fuel costs for 2022 are expected to be significantly higher than 2021. EIA reports the average price of diesel reached $5.25/gal the week of March 14, 2022, while electricity prices remained fairly unchanged from 2021.

Fuel Cost Comparison Between Diesel and Electric Class 8 Tractors

Diesel	
Average Miles per Gallon	8.0
Average Gallons per Mile	0.125
Price per Gallon of Gasoline	$3.28*
Daily Range (mi)	200
Operational Days	250
Gallons Burned per Day	25
Cost of Fuel per Day	$82.00
Estimated Annual Fuel Cost	**$20,500**

* 2021 average weekly U.S. price per EIA

Electric	
Miles per Kilowatt Hour (kWh)	0.5
Kilowatt Hour per Mile	2.0
Price of Electricity per kWh	$0.112*
Daily Range (mi)	200
Operational Days	250
Electricity Consumed Per Day (kWh)	400
Cost of Electricity Per Day	$44.80
Estimated Annual Electricity Cost	**$11,200**

* 2021 average U.S. price of electricity – all sectors per EIA

Approximate Annual Fuel Savings per Vehicle:
$9,300

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Figure 74. Comparison ICE vs BEV on fuel costs

5.4.2 Driver Fill Time

Time is also a factor with fueling BEVs and diesels. There is significant commentary in the media on how fueling time is so critical and that BEVs are just not competitive because they must fuel overnight. That is a poor argument. Diesel fueling takes up valuable driver time because the driver is required to find a fueling station and fill the tanks. That time is not spent driving and can conservatively take 10 to 20 minutes or more away from driving plus add out-of-route miles to find a place to fuel. Some fleets fill their tanks daily to ensure there are no issues in making deliveries. Others carry excessive amounts of heavy fuel onboard to avoid having to make more frequent fuel stops. The BEV in regional haul, however, is fueled overnight at the end of shift. The driver's time is less than one minute in connecting the truck to a charger at the base of operations. There are no out-of-route miles and no lost driving time. Drivers are not subject to fumes or spills. The BEV is an advantage in fueling. Figure 75 captures fueling vs. charging from the driver's perspective.

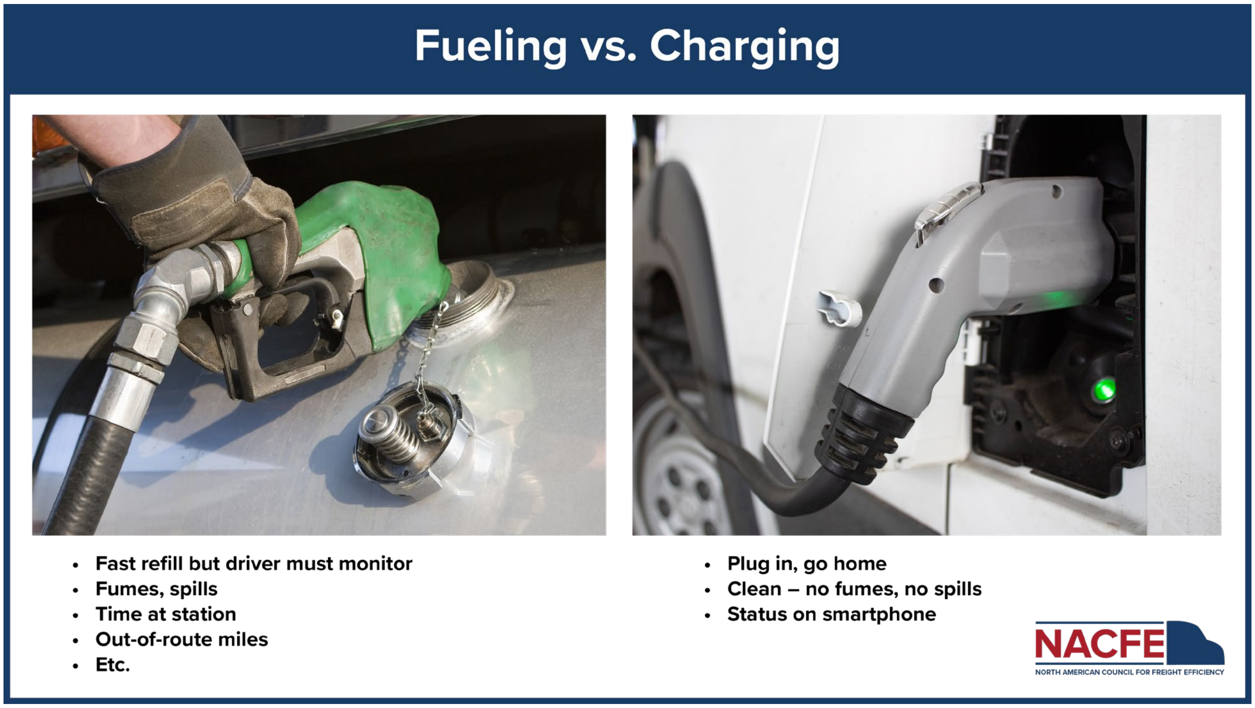


Figure 75. Fueling vs charging from driver perspective

5.5 Capital Cost Grants, Incentives and Credits

Capital costs for both the BEV and its charging infrastructure are generally greater than that for diesels. Production pricing is not yet public knowledge and in these early days, it likely will be subject to significant changes in the competitive BEV business climate. There are several offsets available for the foreseeable future in the way of credits, grants, tax advantages, and other mechanisms. All these mechanisms are intended to reduce the premium associated with the new BEV technology so that the net out-the-door cost is similar to the diesel it is replacing. These incentives will be in place for some years in order to get high volumes of BEVs into the marketplace. Over time, as production volumes increase and later models are subject to the forces of cost reduction and newer technology evolves, the list costs of these vehicles and infrastructure is expected to fall.

The Low Carbon Fuel Standard (LCFS) is a major mechanism for providing fleets with ongoing positive cash flow for owning and operating BEVs that has no counterpart with diesel operations. [81] Mike Saxton, managing director clean transportation at SREC Trade, summarized the LCFS as a supply-and-demand-based market where petroleum and oil refiners have a growing need for credits that are provided by clean fuel generation unit owners (EV charging infrastructure, biofuel, ethanol, CNG, etc.) as illustrated in Figure 76. [80] Essentially, the petroleum fuel producers that keep producing carbon-based fuels in their businesses have to offset that carbon by purchasing credits from clean fuel providers. What this means to a facility that operates BEVs and has on-site charging infrastructure, is that they have a positive cash flow each year from operating the equipment.

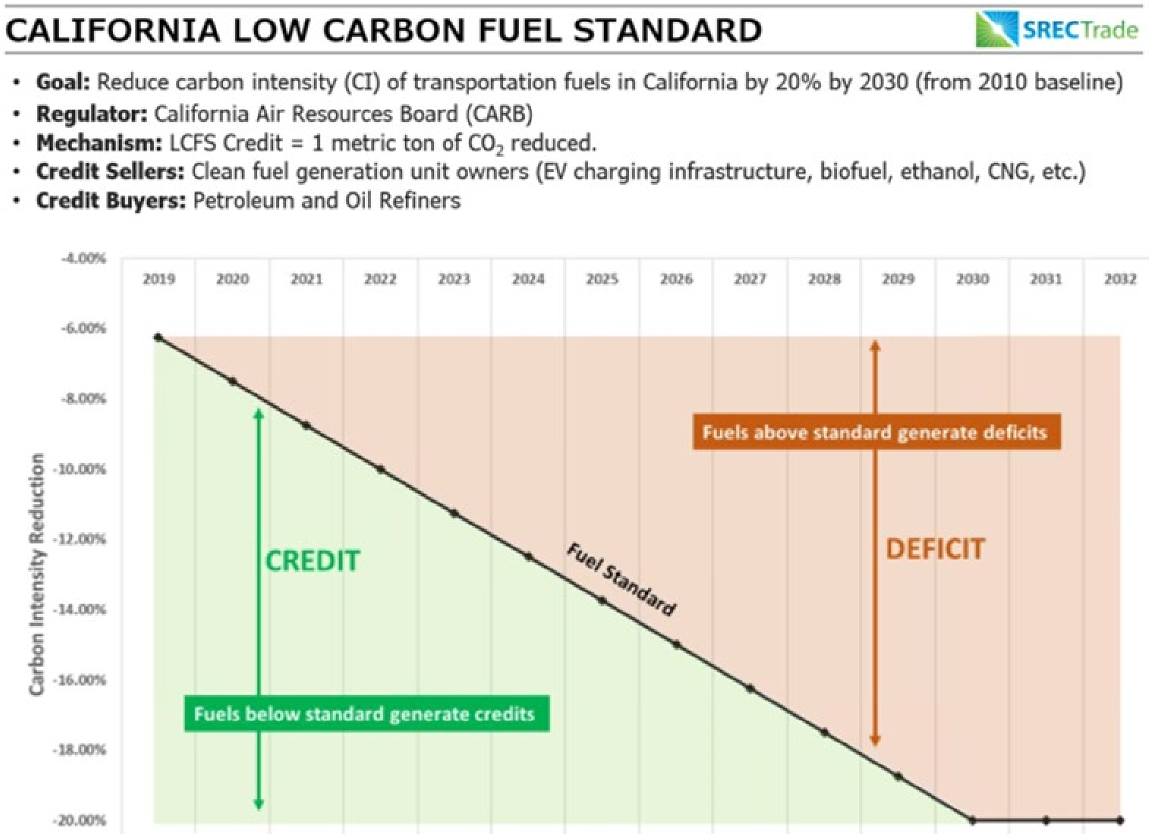


Figure 76. LCFS market (SREC Trade)

California's (HVIP) program is an example program which provides $120,000 vouchers to help purchase new vehicles as shown in Figure 77. [49]

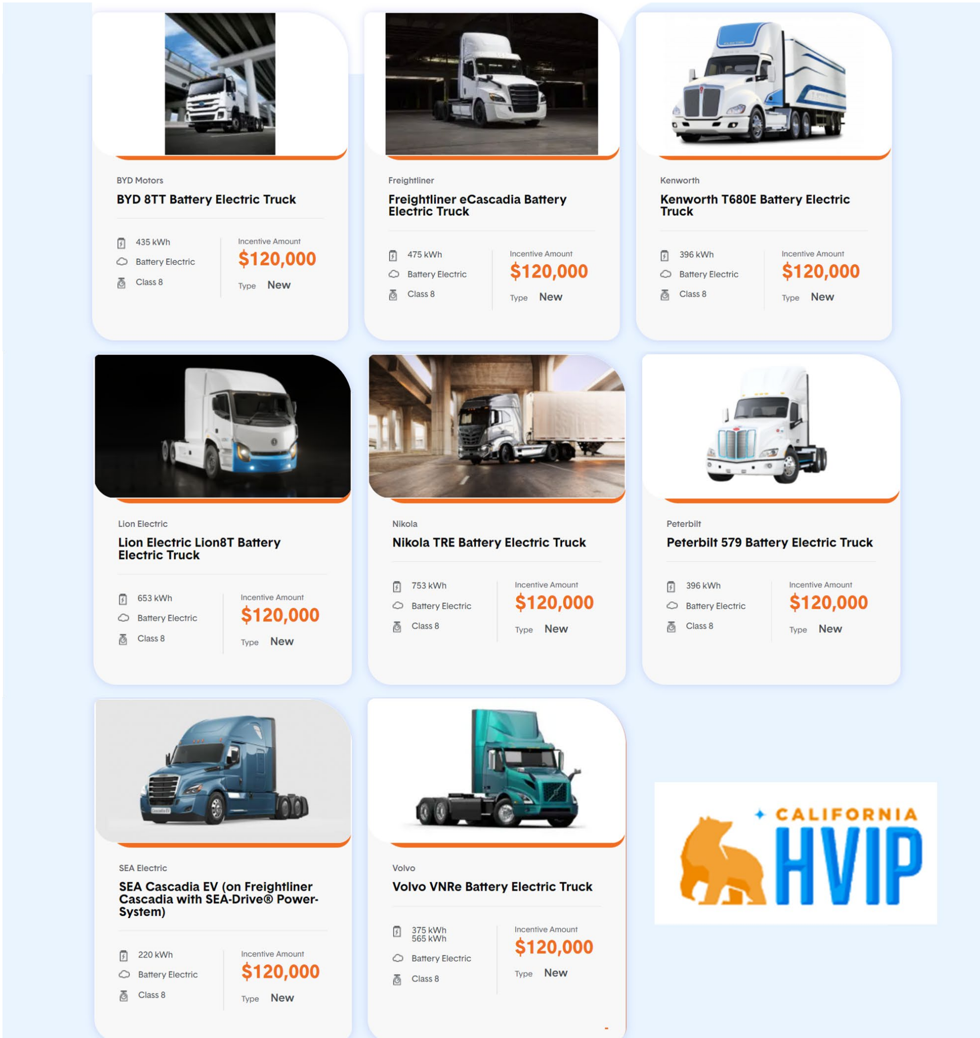


Figure 77. Example of incentives

Grants and incentives are available for the charging infrastructure as well as the trucks. An example is the Clean Transportation Program in California. [83] Federal funding programs also exist and can be found through the U.S. DOT Federal Funding Programs website. [84]

Many of the OEMs have established marketing and sales groups to assist fleets in finding sources of funding to help with purchasing vehicles and infrastructure. There are multiple third-party groups also operating in this space to facilitate purchasing vehicles and infrastructure. NACFE's report *Amping Up: Charging Infrastructure for Electric Trucks* is a good resource with many references to assist in planning facilities and operations.

To learn more about funding electric vehicles, listen to replays of NACFE's Electric Truck Bootcamp training, Incentives for Electrification and Financing the Transition & Innovative Business Models.

The Clean Cities Coalition is a consortium of government and industry groups helping "to foster the nation's economic, environmental, and energy security by working locally to advance affordable, domestic transportation fuels, energy efficient mobility systems, and other fuel-saving technologies and practices." [97] There are more than 75 active coalitions located in the US as shown in Figure 78. [97] These groups are available to help fleets and utilities navigate the new world of electric vehicles.

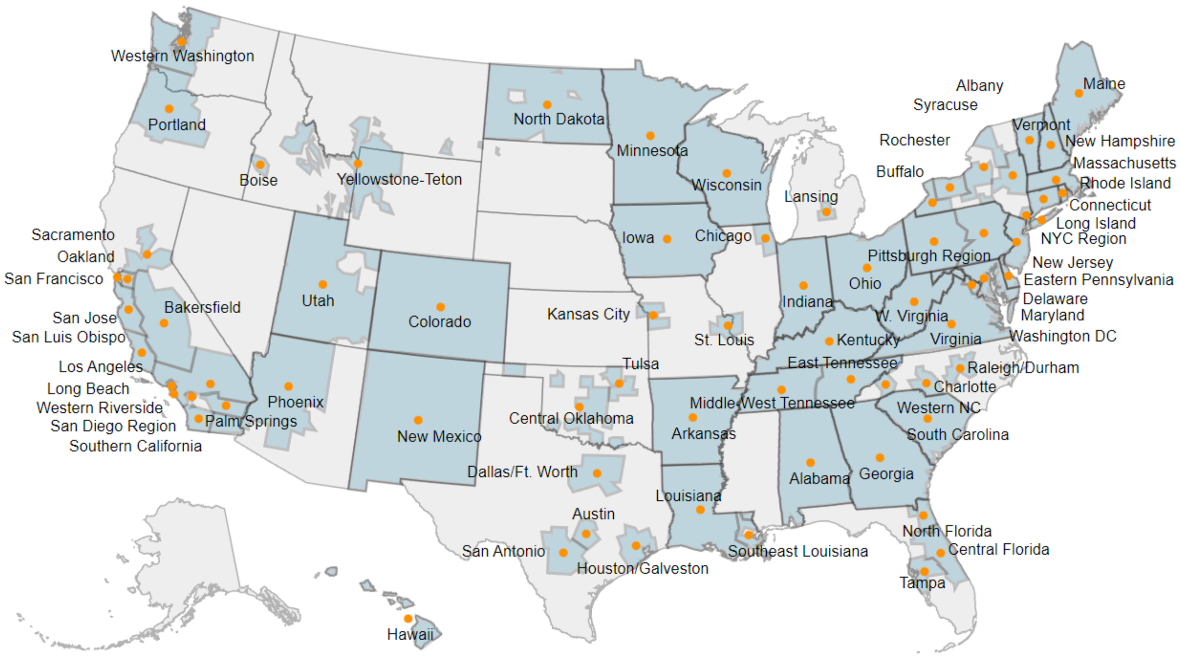


Figure 78. Clean Cities Coalitions in the U.S. (DOE)

5.6 Moving Fuel Around

The diesel fuel used to move a fleet's truck has already moved a significant number of miles before getting into the truck's tank. Buried in the price of fuel is the cost of delivering the oil to the refinery and then distributing the fuel from the refinery to the fueling station, but there are a lot of ramifications to moving liquid fuel versus transferring electricity by wires.

The U.S. Bureau of Transportation Statistics developed the Freight Analysis Framework (FAF) creating a "comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation." [71] This data can be used to benchmark transport of fuel between the extensive origin-destination pairs in FAF for the US. For 2020, the FAF estimates 621,410,400 tons of fuel oils were transported in the US by truck. [72] The "fuel oils" group includes diesel, bunker C, and biodiesel. [73]

Another source on how much diesel is transported is EIA tracking sales and deliveries of ultra-low sulfur diesel since its introduction in 2007 shown in Figure 79. The graph shows that more than 150,000,000 gallons of diesel are sold each day. That fuel had to get from the refineries shown in Figure 80 to the fuel pump by pipeline, by truck, by train or other modes. [74]

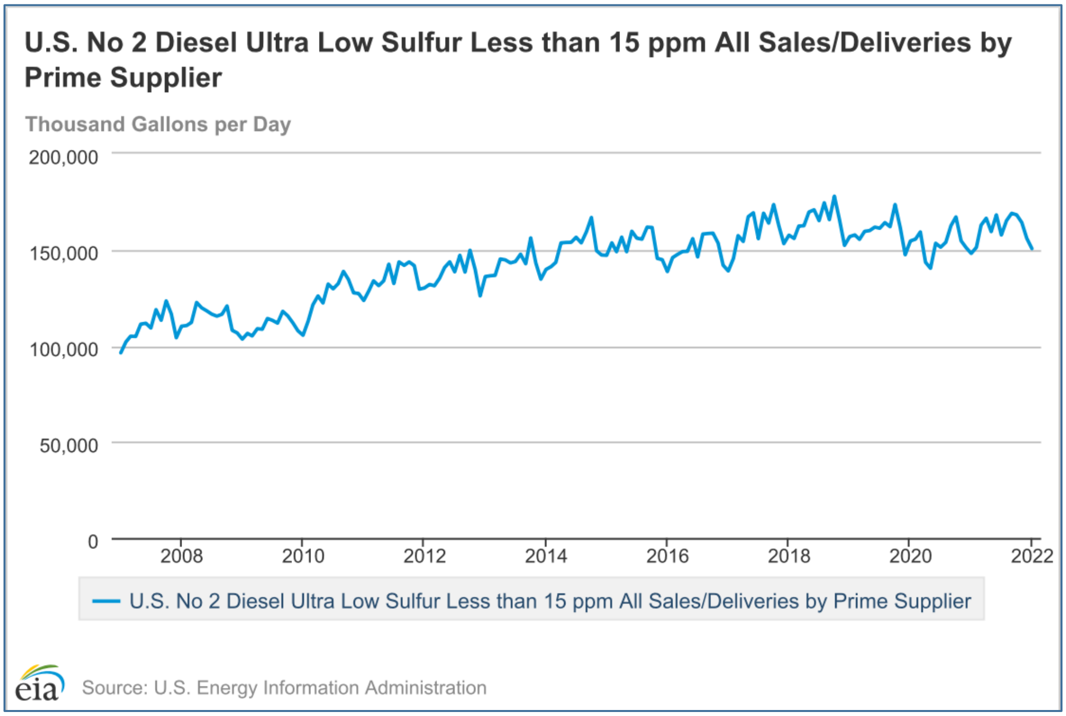


Figure 79. Daily diesel sales/deliveries

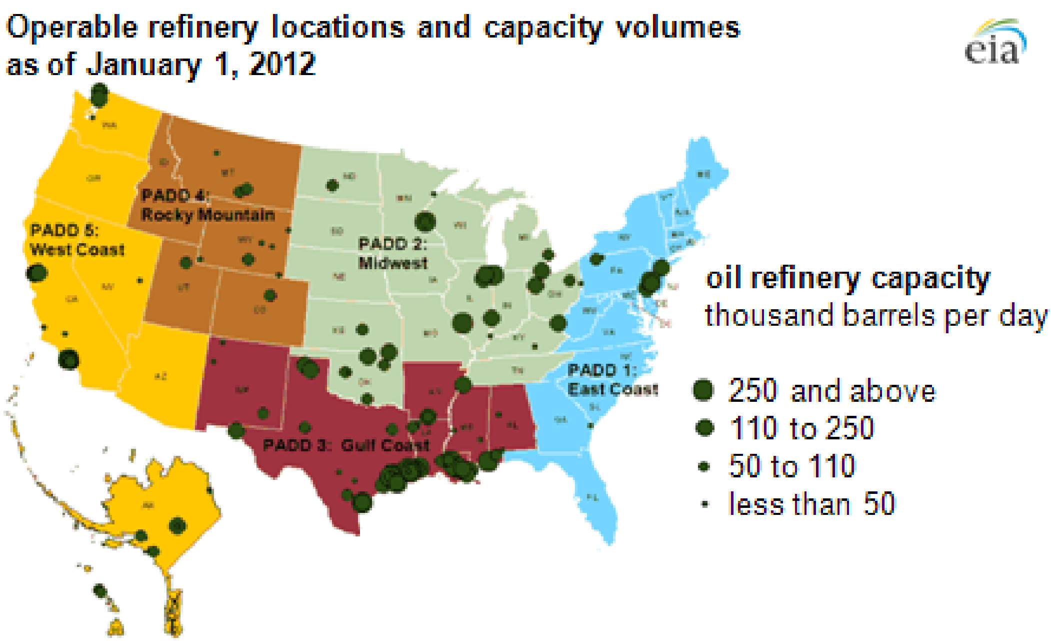


Figure 80. Where refineries are located (EIA)

What is different about delivering electrical energy is that there is no mass transfer required in distributing the energy. Electrical power is delivered from the power plant to the end user by wires. Consider the ramifications of moving less fuel across the US. There would be fewer fuel trucks on the road, fewer opportunities for accidents, less traffic, less emissions, less demand for tires, less road maintenance required, etc. The downside deals with employment loss potential from both fuel fleet haulers and the infrastructure jobs they support, such as truck stops.

6 Challenges of EVs in This Market Segment

BEVs are not the solution for replacing every diesel truck in every duty cycle. BEVs for regional haul are best fits for shorter daily routes. The shorter the daily route for a BEV, the heavier the possible payload because of the trade-off between range and payload weight for batteries. These BEVs need to have access to charging points for long dwell times. Multi-driver, multi-shift operations can use BEVs, but the additional shifts require that daily net mileage is kept below the 150-to-200-mile range that the battery packs of these tractors are typically capable of. Dwell times, even with higher rate DC fast chargers on the order of 240kW, still require three or more hours to recharge the vehicle. The availability of MCS is still in development and any trucks purchased today will not have been designed to take advantage of that capability.

Operating costs are expected to decrease significantly for BEVs versus diesel tractors. BEVs are two to three times more efficient at translating energy into motion. Electricity costs significantly less than diesel fuel per mile. BEV maintenance costs are less due to fewer moving parts, minimal vibration, and friction. However, BEVs do add cost factors into the total cost of ownership equation.

6.1 Purchase Price

There is a significant amount of confusion on what the list price of BEVs will be due to the confusion around Tesla's 2017 proclamation that it was feasible to build a Class 8 BEV semi capable of 300 miles and sell it at a base price of $150,000 and one capable of a 500-mile range for $180,000. [86][88] This claim continues into 2022 with Tesla's website still listing the same prices as shown in Figure 81 (image modified from Tesla website to fit available space and current as of April 2022). [50] Note that *Car & Driver* shows the 2022 Tesla Model S all-wheel drive automobile starting at $101,440 for a 4,561 lbs. curb weight vehicle with a 412-mile estimated range. [87]

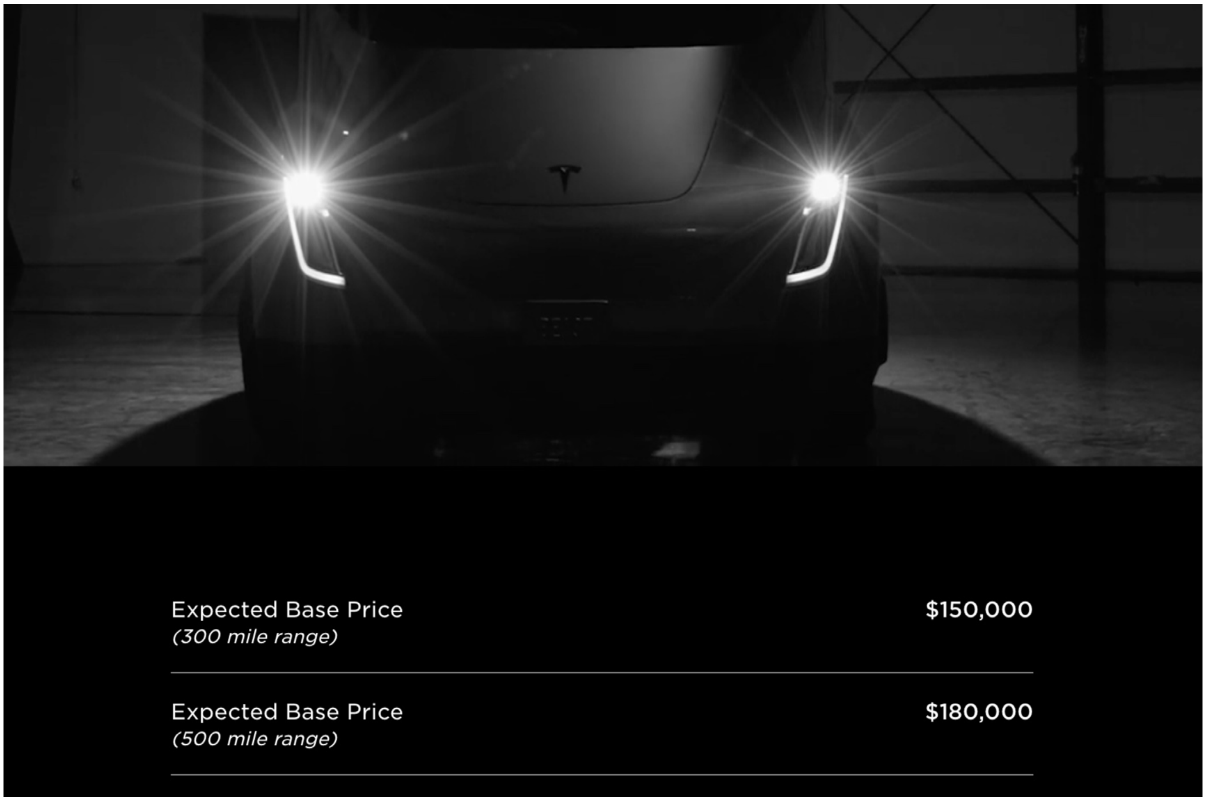


Figure 81. Tesla Semi base pricing

Actual pricing of the prototype Class 8 semi trucks in use today is not meaningful information. Pricing of series production tractors is just now being documented on various purchase orders. Claire Buysee of ICCT documented several of these prices but admitted that backing out the cost of the trucks from a bulk purchase order required a lot of guesswork. [84] Two examples found were the Port of Oakland purchasing in 2022 a total of 10 Peterbilt 579EVs at a cost of $510,000 per truck, and a 2020 order for 50 Lion Electric 8T trucks that worked out to $400,000 per truck.

ICCT took another approach and attempted to estimate the cost of a battery electric tractor doing a bottoms-up method from public research as summarized in Figure 82. [84] These costs are before grants, credits, fees, or other offsetting factors. The summary is the expected list price that is two to three times that of a diesel.

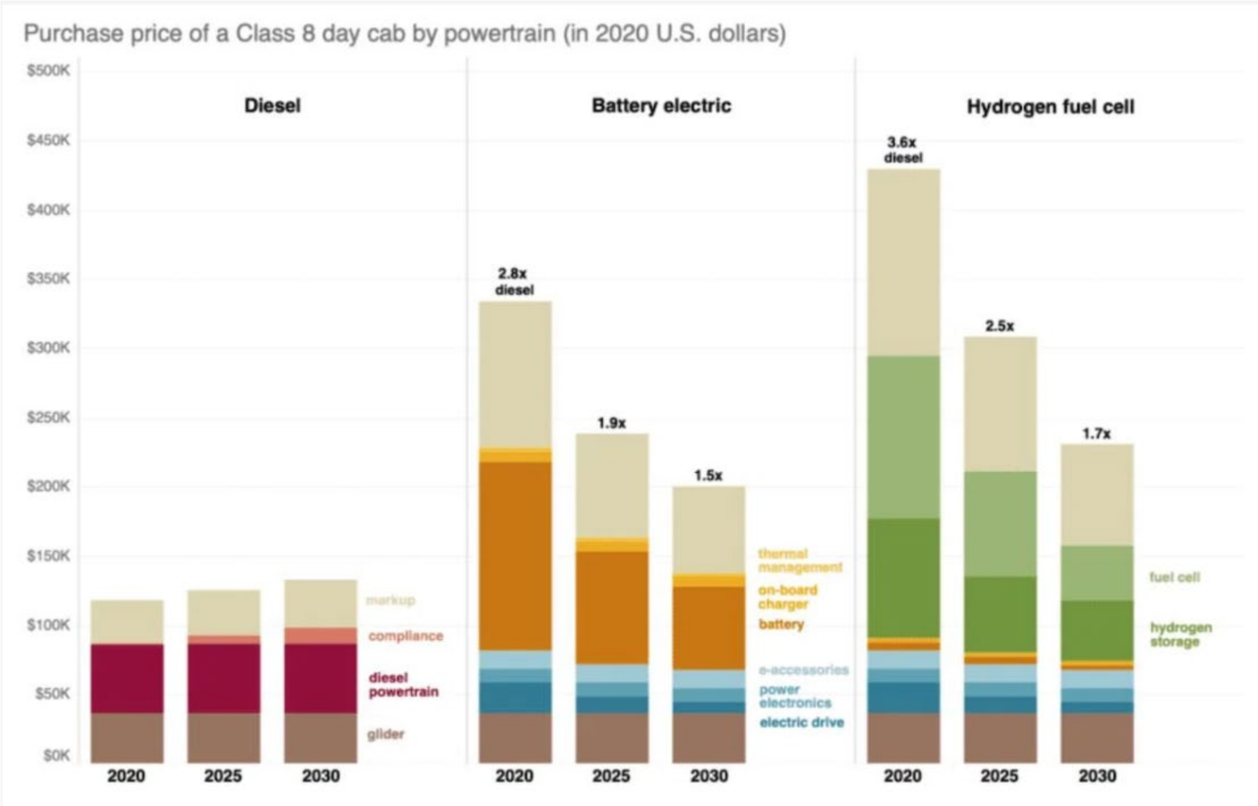


Figure 82. Purchase price of a Class 8 day cab in 2020 dollars (EV News)

Factoring other offsetting cost items such as credits like an HVIP voucher program drops the effective 2025 out-the-door price of the BEV to roughly comparable to that of diesel. Considering operational cost savings in the total cost of ownership over time, ICCT estimates the BEV five-year operating cost improvement needed to reach cost parity with the diesel is only 15%. Since maintenance and fuel costs savings are projected to be higher than 15% for BEVs versus diesels, the TCO is expected to be less over a five-year period.

While the list price of a BEV is two to three times higher than a comparable diesel, the out-the-door price with help of credits, grants or other incentives may be similar, and the actual TCO over a five-year period of ownership will show the BEV is better.

6.2 Charging Time

BEV 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 BEV.

For example, let's imagine a BEV with a gross battery capacity of 400 kWh. To recharge from 20% SOC (SOC = 80 kWh) to 80% (SOC = 320 kWh) requires 240 kWh of energy. Charging the last 20% to full SOC can take twice as long as charging from 20% to 80% as described in NACFE's report *Medium-Duty Electric Trucks Cost of Ownership*. [90] Figure 83 outlines the estimated times required based on the power level applied by the charger.

Charging Times

Charging Power (kW)	Charge Time 20% - 80% (hrs)	Charge Time 20% to 100% (hrs)
20	12.0	36.0
40	6.0	18.0
60	4.0	12.0
80	3.0	9.0
100	2.4	7.2
120	2.0	6.0
140	1.7	5.1
160	1.5	4.5
180	1.3	4.0
200	1.2	3.6
220	1.1	3.3
240	1.0	3.0

Figure 83. Charging times

6.3 Chargers

Diesel fueling stations are everywhere. Fleets and drivers generally don't need to maintain or purchase them. There are capital and operating expenses for fuelers. Regional haul BEVs are most likely going to be charged at their depot. This places the charging equipment, the EVSE, on-site and the responsibility of the site.

Fleet depots are not necessarily owned by the fleets. It is common for these to be leased by the fleet operator from the site owner. EVSE tends to be a long-term capital investment at a site, with an expected life of 10 or more years. This places the burden of capital investment on the site owner. The fleet operator of the facility may play a part in the owner's decision-making process, as there are potential costs and benefits tied to who actually owns the EVSE.

RUN ON LESS ELECTRIC

Lesson Learned

Many companies that need the charging infrastructure do not own the site, requiring new lease contract terms.

The EVSE likely is going to be operated and maintained under contract to a service provider such as ChargePoint. The cost of maintenance will then be rolled into the cost of using the charger, just as the cost of maintaining a diesel fuel pump at a truck stop is rolled into the cost of the fuel purchased by a driver.

Mike Terreri, EV product manager at Asset Works, reinforced that while BEV maintenance is expected to be less than that of diesels, some maintenance is required. Terreri presented this at NTEA's Work Truck Week 2022 in a presentation titled "Yes, EVs (and Chargers) Need Maintenance, Too." [88] Chargers are complex devices that operate with software and sensors. They communicate digitally with the cloud and also with each truck. They also must make physical connections to the truck. All those software and hardware interfaces have the potential to fail.

A damaged charger means the vehicles that need to use it are not going to be recharged for the next shift, causing lost revenue for the fleet and the charger service provider. This also can impact the acceptance of the technology. Terreri believes that most organizations have not planned for the long-term maintenance needs of chargers. This is a growing concern area for BEV adoption.

Terreri cited a 2019 study by Avista Corporation in Spokane, WA looking at 439 EVSE charging ports installed at residential, workplace, fleets and apartments, including seven DC fast chargers over a three-year period. [89] The results are summarized in Figure 84. [89] The report analyzed more than 53,000 charging sessions. These are primarily used by autos and light trucks, so not directly reflective of heavy-duty truck data, but it provides insights into operating chargers.

	Installation cost per port	Annual O&M per port	% uptime	% online
Residential AC Level 2 - networked	$2,445	$370	98%	66%
Commercial AC Level 2 - networked	$6,035	$600	86% - 93%	76% - 86%
DC fast charging site	$128,084	$1,550	87%	87%
Residential AC Level 2 – non-networked	$1,766	$5	100%	NA
Commercial AC Level 2 – non-networked	$4,472	$185	99%	NA

Figure 84. Average EVSE installation cost, O&M expenses and performance

A key takeaway from the Avista Corp. study was that "Networked EVSE reliability, uptime, costs, and customer experience are all important opportunities for improvement, reinforcing the importance of utilizing interoperable networked EVSE. Non-networked EVSE are very reliable and cost effective, and should be utilized wherever possible unless data collection, user fee transactions, remote monitoring, or other requirements necessitate the use of networked EVSE." [89] Managed charging systems, which offer the lowest cost of electricity, require networked EVSE.

Lesson Learned

Chargers need management and maintenance.

Uptime for a single diesel fuel pump is probably not a factor for fleets since another working pump is probably nearby at a truck stop. However, a disabled BEV charger at a depot likely has a greater chance of impacting fleet uptime as there will not likely be an overabundance of open chargers at a site due to their expense.

6.4 EVSE Installation Time

Heavy-duty BEVs require larger chargers than do electric automobiles. The power demand for these larger vehicles requires engaging local utility experts very early in the planning process for a fleet considering BEVs. Planning, permitting, procuring and installing utilities to support chargers can take months to perhaps a couple years to complete. Early communication between the fleet, the utility, the OEM, permitting agencies, and others is necessary to streamline the time frames for installation. As NFI's Bliem said during RoL-E, "Getting the trucks can be much quicker than getting the EVSE."

To learn more about installing chargers, listen to replays of NACFE's Electric Truck Bootcamp trainings, Charging 101 — Planning and Buildout; Charging 202 — Power Management and Resilience; and Working with Your Utility.

6.5 High Voltage Cables and Connectors

Thick, orange high voltage cables and connectors replace many of the mechanical drive components for a BEV versus a diesel. These cables do not bend well or easily and can be damaged if kinked or abraded. Installing the connectors and crimps requires special equipment not likely to be found in a service bay. Shorted cables can trip large capacity circuit breakers in the batteries to prevent injuries or further damage. Cables will be expensive to replace, but when damaged they likely will be required to be replaced rather than repaired because of their high voltage. Due to their high cost, it is unlikely that service centers will stock spares. So, a speedy part ordering and delivery system will be necessary to get the trucks back on the road.

Cables and connectors are a common failure mode in diesels. BEVs are subject to the same harsh environment that diesels operate in and are exposed to similar chemicals and liquids whether directly or indirectly through co-location with diesels. The cables are heavily shielded to prevent damage, but the real world can find ways to damage anything. Cables and connectors will be a major focus for maintenance monitoring as BEVs gain market share.

6.6 Battery Life

Batteries are likely the single most expensive part on the BEV. They tend to lose capacity over years as documented in more detail in NACFE's reports *Electric Trucks: Where They Make Sense* and *Medium-Duty Electric Trucks Cost of Ownership*. At some point, when maximum state of recharge is at perhaps

80% of the original new battery, the battery is considered no longer useful for transportation use and needs to be replaced or repaired. The failure mode inside batteries is statistical in nature; one cell might be fine and the next not. The lowest performing cell controls the output of the battery. Servicing battery packs requires some sophistication in both design and maintenance operations. Batteries will need to be able, through software and sensors, to determine which cells are not performing well and need to be replaced. Batteries need to be designed to be serviceable. Maintenance centers will need to be equipped to do this specialty work with high voltage batteries.

In these early days of BEVs, fleets are looking to their OEMs and dealers to handle high voltage component servicing. Batteries likely will be replaced rather than serviced to get the truck back on the road quickly. The expense of these batteries is so steep that dealerships are unlikely to have much, if any, inventory of batteries on site. Expedited ordering and delivery of these high-cost components will be critical to rapid servicing. The failed units likely will return to the factory or a specialty service center for repair and then used as a factory refurbished unit.

Batteries are one of the greatest concerns fleets have. Their durability — their expected life spans — are critical to estimating future costs, choosing duty cycles for the vehicles, and determining residual value. Fleets should plan to track battery factors closely in monitoring BEV costs.

To learn more about the battery life cycle, listen to the replay of NACFE's Electric Truck Bootcamp training, Sustainable Supply Chains & End of Life.

6.7 Battery Cost

The BEV battery cost is a constant topic with BEV advocates citing a decade of data showing that battery costs have been falling as technology improves. Opponents of BEVs cite that raw material availability and costs have been increasing in recent years, so that battery pack prices have increased. Both are right. Accurately predicting the future cost of technologies is only possible in retrospect once you are there. There are many uncontrolled factors in modeling the costs of any technology. Supply and demand are not alone in driving pricing. Global and regional politics, import and export tariffs, conflicts, natural disasters, faulty sourcing strategies, innovation, accidents, speculators, regulations, market forces, and many other factors impact the fundamental market price for battery packs.

A goal for battery pack price is $100/kWh. Current estimates from consulting firm Roland Berger are that 2021 prices ended the year at approximately $130/kWh. [92] Martin Daum, former CEO of Daimler Trucks North America, in an interview with *The Financial Times* stated that the cost of electric trucks will "forever be higher" than their combustion engine cousins. [91] "If you take the entirety of engine, transmission, axle, tank system, cooling...we have a maximum of about €25,000 (~$27,700) (of material in a combustion engine truck)." *The Motley Fool* quoted Bloomberg, "The prices of key battery raw materials like cobalt, lithium, and nickel exploded last year, driving battery pack prices to an average $132 per kilowatt-hour in 2021 with projections to remain above $100 through 2024." [91] The vehicles listed on the California HVIP site as being in production have battery packs ranging in size from 396 kWh to 753 kWh. At $130/kWh, the battery packs alone for those vehicles are estimated to cost $51,480 to $97,890.

Pricing for battery packs and other key components of the BEVs will be hard to accurately predict until sufficient volumes of trucks are in mass production over several years, and true costs can be audited.

For the foreseeable near-term future, battery pack pricing is not expected to decrease, and pricing may have bottomed out for the current version of BEV battery technology.

6.8 Training

Safety training is critical for BEVs including training of drivers, technicians, first responders, and other fleet personnel that might come near the vehicle. Safety protocols need to be second nature to operating around BEVs. OEMs design the vehicles to industry safety standards, but those standards expect that personnel follow their training guidelines.

Driver training appears to be fairly intuitive from discussions with the RoL-E fleet managers and drivers. Regenerative braking and one-pedal driving are a new learning experience for drivers, but relatively obvious once in the driver is in the seat. Minimal instruction is needed to get a new driver to operate a BEV. One RoL-E fleet exposed drivers early to BEV technology by providing an electric car for short home trial use before getting in the battery electric trucks.

To learn more about electric vehicle safety training, listen to the replay of NACFE's Electric Truck Bootcamp training, Maintenance, Training & Safety.

7 BEV Regional Tractor Performance in Run on Less – Electric

RoL-E was a freight efficiency demonstration that featured a total of 13 electric vehicles. Four of them were regional haul heavy-duty tractors, three were vans and step vans, three were medium-duty box trucks, and three were terminal tractors. All the vehicles in RoL-E were electric.

Four regional haul tractors were followed in the RoL-E program as shown in Figure 85. Their data over the three weeks is available for viewing at the Run on Less – Electric metrics dashboard. [93]

Terminal Tractor Participants

Fleet	Location	Tractor Make & Model	Battery Capacity
Anheuser-Busch	Los Angeles, CA	BYD 8TT	435 kWh
Biagi Bros.	Napa, CA	Peterbilt Model 579 EV	396 kWh
NFI	Chino, CA	Volvo VNR Electric	396 kWh
Penske	Temecula, CA	Freightliner eCascadia	440 kWh

Figure 85. Regional haul tractors that participated in RoL-E

The key to the RoL-E dashboard is shown in Figure 86. For a more detailed description of what was measured, see Section 7.1 below.

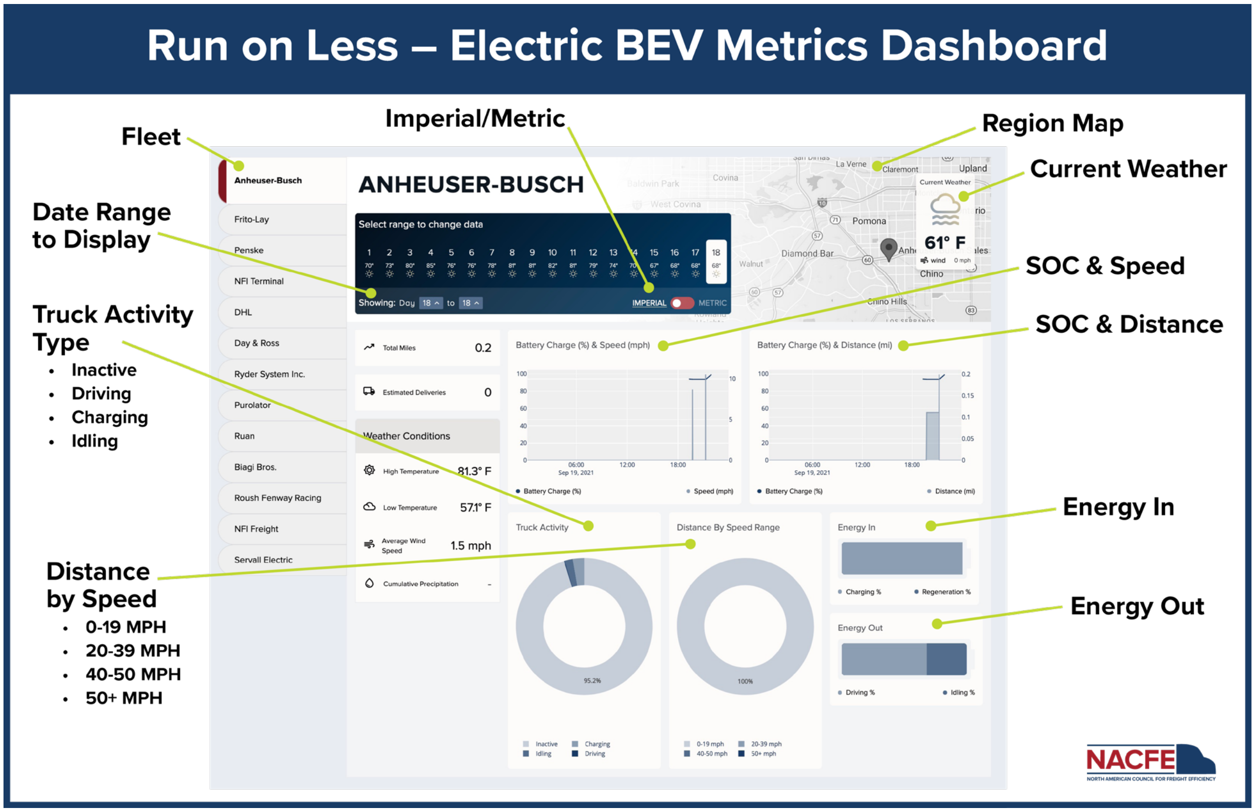


Figure 86. RoL-E BEV metrics dashboard key

Specifications of the four regional haul tractors in RoL-E are shown in Figure 87. [95]

	BYD 8TT	Freightliner eCascadia	Peterbilt 579EV	Volvo VNR
ROL-E Site	Los Angeles, CA	Temecula, CA	Napa, CA	Chino, CA
Fleet	Anheuser-Busch	Penske	Biagi Brothers	NFI
Service Territory	Inland Empire	San Diego	Sonoma, CA	Port of LA/Long Beach
Facility Details	200,000 sq. ft. facility	Not available	350,000 sq. ft. warehouse	8 warehouse complex
Weather – Temp Range	57 – 100 degrees F	59 – 94 degrees F	53 – 96 degrees F	60 – 101 degrees F
Duty Cycle Requirement	Less than 100 miles / day	100 miles / day	120 - 150 miles / day	300 miles / day
Battery Capacity	435 kWh	440 kWh	396 kWh	396 kWh
Battery Range	150 – 200 miles	175 miles	150 miles	175 miles
Battery Chemistry	LFP	LFP	LFP	LFP
Charging Rate	40 kW	150 kW	150 kW	150 kW
Battery Charger	J1772	CCS1	CCS1	CCS1 / CCS2
Total Miles	304	902	253	1533
Estimated Moves	47	78	48	28
% of Speed <40 mph	71.%	27%	92%	44%
% of Speed >50+ mph	15%	58%	0.5%	37%
Charging Opportunity	Overnight	Overnight	Overnight	Overnight
Charger Location(s)	On yard	On yard	On yard	On yard
Charging Port on Tractor	Passenger-side behind cab	Driver-side behind cab	Driver-side rear of tractor	Driver-side below door
Parking to Charge	Nose-in	Nose-in	Nose-in	Nose-in
Days in Operation	11	12	8	12

Figure 87. Specifications of the battery electric regional haul tractors from RoL-E (NACFE)
(A larger version of this chart is available in the Fact Sheet in Appendix A.)

7.1 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 originated from the vehicles themselves through the Geotab integration on all regional haul Class 8 tractors that participated in the Run. A look at what was measured is seen in Figure 88. 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*. [94]

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 88. 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. [96]

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 SOC.

NACFE reported speeds on the RoL-E metrics dashboard. Speeds along with SOC were graphed versus time, and then speed was categorized as percent distance in speed bands.

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 but was not yet in significant use on the regional haul tractors. Drayage operations are working with some port authorities to install charging at both ends of routes, the port, and the inland warehouse, to permit mid-shift charging. This type of arrangement also may work shipping between distribution centers or between factories and distribution centers, where both ends of the route can see sufficient use of chargers to rationalize installations. DCFC charging and MCS charging at public sites is some time in the future once higher volumes of BEVs are operating in a region.

BEVs 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. There are no vehicle-based systems that specifically highlight a delivery instance. NACFE developed an algorithm for regional haul estimating deliveries were when there was a key-off event at least 2 miles (straight line distance) from the home terminal and the truck hadn't had a key-off event in the previous 0.2 miles. The 2-mile range was to permit on-site operations such as loading to occur since some of the facilities have large sites and vehicles travel inside the fence. The 0.2 miles is because occasionally the truck would stop in the parking lot of a delivery site before going to the dock to unload. The 0.2-mile range avoided double counting a delivery at a site. For 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.

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.

7.2 Details on Vehicles and Fleets in RoL-E

Four fleet-OEM pairs in RoL-E operated heavy-duty regional haul tractors: Anheuser-Busch with a BYD 8TT tandem axle Class 8 tractor, Biagi Bros. with a Class 8 Peterbilt 579EV with a Meritor electric drivetrain, NFI with a Volvo VNR electric truck, and Penske with a pre-production Freightliner eCascadia. See Figure 89.

Figure 89. Heavy-duty regional haul tractors from BYD, Peterbilt, Volvo and Freightliner that participated in RoL-E.

7.2.1 Anheuser-Busch and BYD

Anheuser-Busch (AB) operated a BYD 8TT tandem axle Class 8 tractor in Pomona, CA during RoL-E.

Anheuser-Busch is a global beverage producer and distributor. William Avis, regional fleet manager Anheuser-Busch said, “Anheuser-Busch loves innovation. So, this is an exciting adventure. Our goal is to reduce 25% CO_2 by 2025. We started looking at the electric trucks back in 2018. And the trucks that we’re running now we started them back in April of ‘20 and it’s been an awesome adventure.”

The corporation is committed to carbon emissions reduction detailed in its 2025 Sustainability Goals. [51] AB estimates that converting its fleet to zero-emission technology alone will reduce its transportation carbon footprint 18% by 2025. AB is investigating a variety of technologies toward this goal, and announced in 2019 it was purchasing 21 BYD battery electric tractors for use in Southern California. [52]

According to Christopher Cochran, senior director of operations Anheuser-Busch, the Inland Empire — where the BEVs operate — is a 200,000 square foot facility combined in three warehouses. “We distribute Anheuser-Busch products in the Inland Empire area which range from the eastside of Los Angeles all the way to Redlands, California and as far south as Riverside.”

The company operates eight electric trucks every single day in Inland Empire. “We try to keep them closer to the branch just to be more efficient with our routes and we run them as an end-loader truck because it’s the way we can be most efficient with them and carry the most beer,” Kassidy Kiesel, senior delivery manager Anheuser-Busch, told NACFE.

The BEV duty cycle uses end-loader beverage trailers to deliver to chain stores with multiple stops and trips per day. AB has 60 drivers and runs between 48 to 52 routes per day. The company has three different truck types. “We run end loaders, side loaders and draft routes,” Kiesel explained. The end loaders deliver to chain stores, side loaders deliver to liquor stores and markets, and draft routes run to restaurants and bars.” The tractor and trailer are shown in Figure 90.

Figure 90. BYD tractor with end loader trailer at AB

Cochran talked about people's reaction to the truck, "Rene Solis, our driver, says that when people walk up to him outside it's like wow, that's the coolest electric truck I've ever seen." They ask him how it works. Solis, who has been driving for AB for 30 years, commented on the silence of BEVs. "You'll have better understanding around you. You can hear things. I think that for a driver it's a good thing because if you hear something you know something is not right.

"We have stores that have curfews, and you cannot make noise [during certain hours]. This truck is perfect because I can go in the back and I don't bother anybody," Solis said.

Avis believes drivers are not the only people who will love these BEVs. "Mechanics are going to love this stuff because it's easy to work on. What we need is to get energized with the younger generations and the schools. Positive and negative, batteries are simple."

A positive benefit of BEVs is their ability to operate inside of buildings without worry of fumes or need for exhaust systems. AB does some loading inside of warehouses with diesel trucks today as seen in Figure 91.

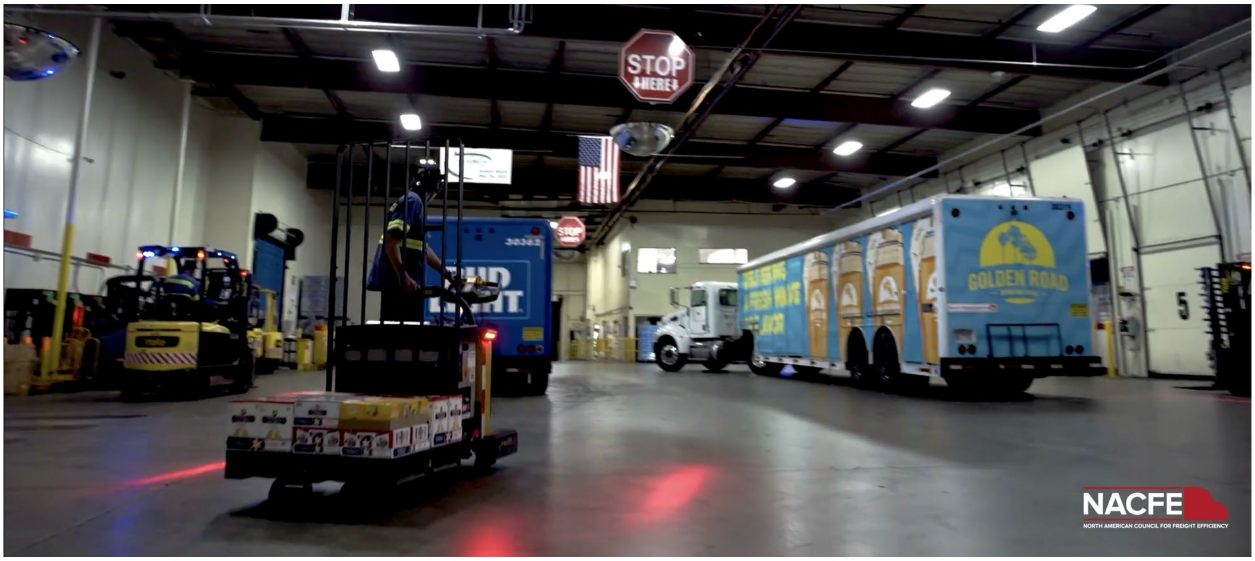


Figure 91. Operations inside of warehouses can be simplified with BEVs

BYD is a leading commercial electric truck manufacturer headquartered in Los Angeles. [53] According to George Miller, formerly senior sales manager BYD North America, BYD has manufactured more than 60,000 electric buses and more than 13,000 electric trucks. “When we build something, it really is commercializable and this truck is our Gen 3 which has all the new automated driver assistance systems to make it safer for drivers. What we have now will be the standard range and then we’ll add an extra 30% on to that for extended range batteries.”

The AB RoL-E participant vehicle was a BYD 8TT heavy-duty tractor and AB has been able to use these models without making any compromise when replacing the diesel tractors. Vehicles cover an entire day’s delivery needs with no issues with weight, range or charge times. An overview of the AB BYD BEV is shown in Figure 92. [94]

NACFE’s report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on Anheuser-Busch and BYD. There is also a fleet profile and a video.

Truck

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

Figure 92. Anheuser-Busch and BYD (NACFE)

The Anheuser-Busch BYD tractor's SOC, speed and distance with respect to the 18 days of the Run are graphed in Figure 93. [93] The data shows this truck consistently stayed above 80% SOC while completely performing its required duty cycle. The longest day trip was ~40 miles, with several trips between 10 and 30 miles per day. This data highlights the fact that the fleet has an opportunity to expand the use of this vehicle to longer range duty cycles.

The manufacturer estimates the nominal range of the battery pack to be 150 to 200 miles on a full charge. Another way to view this data is that the fleet has the opportunity to run two days between charges and still have more than 50% battery pack in reserve. Further experimentation might allow for three days between charging sessions. This kind of a schedule could allow for staggering charging among vehicles, so one charger could service three or more tractors.

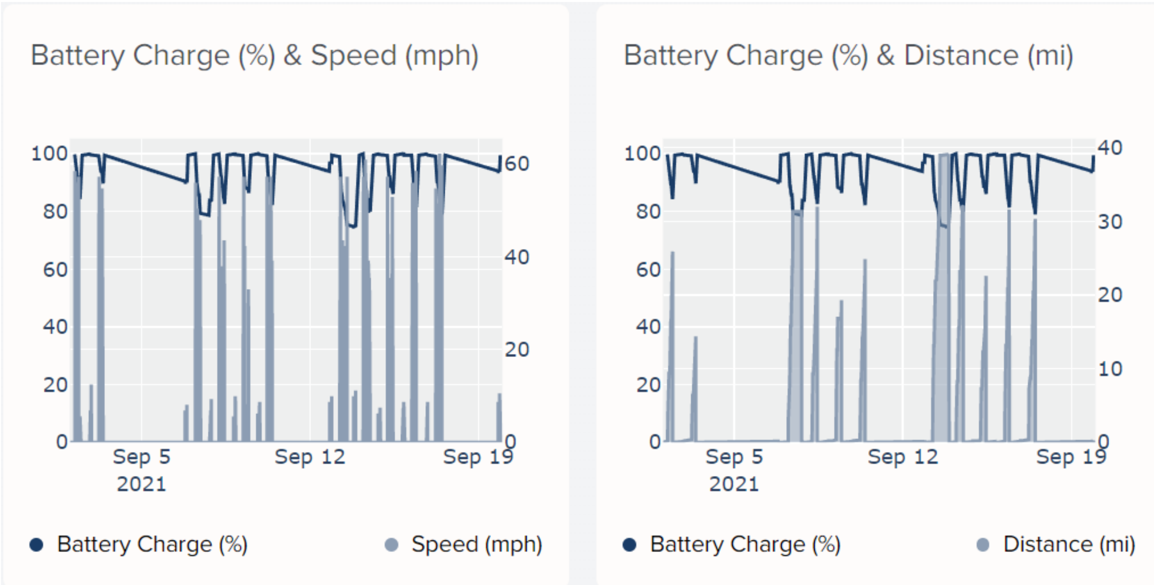


Figure 93. Anheuser-Busch BYD SOC, speed and distance history (NACFE)

The distribution of truck by activity and by speed for the Anheuser-Busch BYD tractor are shown in Figure 94. [93] The graphs show that this truck had a significant amount — 85.5% — inactive dwell time over the 18 days. The span included weekends when the vehicle was not in use, but even looking at operating days 6 thru 9 shows the dwell time was 79.2%. The vehicle was only driving about 7% to 12% each workday, consistent with making multiple deliveries to stores. Speeds were distributed across urban and highway distances, with the majority of distance being in slower urban segments of the duty cycle.

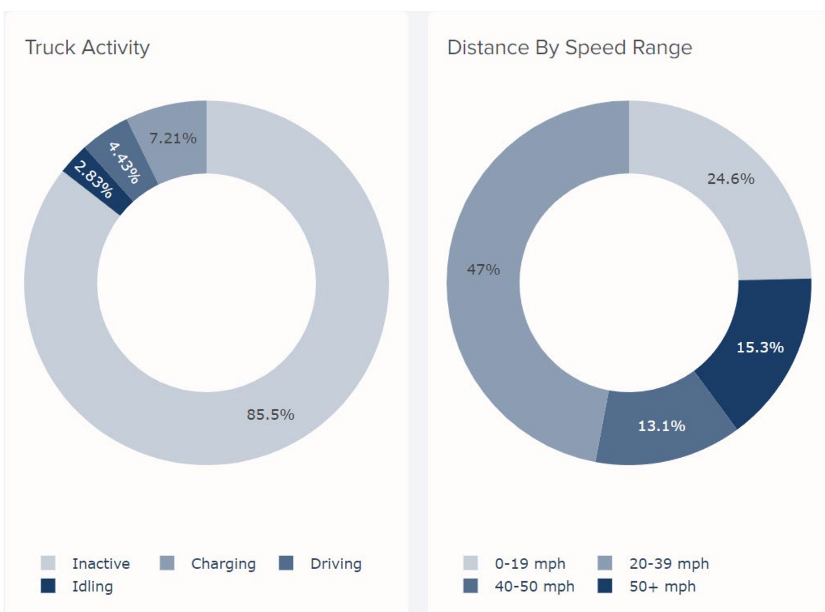


Figure 94. Truck activity and speed distribution over 18 days (NACFE)

The energy-in and energy-out diagramed in Figure 96 illustrates that ~20% to 25% of energy was recovered through regenerative braking, helping extend the range of the battery packs significantly. [93] This behavior highlights that significant urban stop-and-go driving seen in this beverage delivery application provides a great opportunity for energy recovery, so range anxiety should be less of a concern. The Energy-Out graph in Figure 95 shows that the vehicle had very little time in idle, meaning it was parked but still on perhaps running air conditioning for only brief periods.

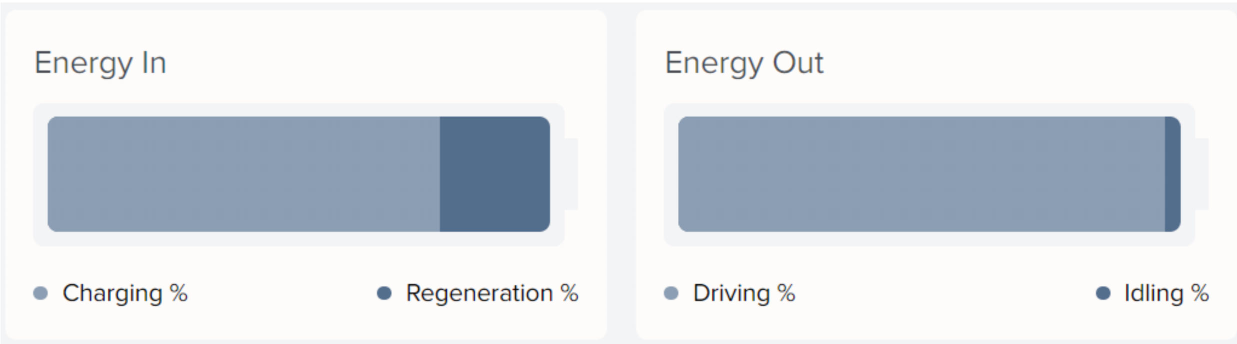


Figure 95. Energy In and Out over workdays 6-9 (NACFE)

Charging for this vehicle appears to be fairly quick looking at a typical two-day cycle shown in Figure 96. [93] In the graphs, charging is the steep upward angled line when no speed or distance is happening. Charging is completed in perhaps 10% of the available dwell time. This means that a lower charging rate setting could be used allowing for lower cost electricity via managed charging.

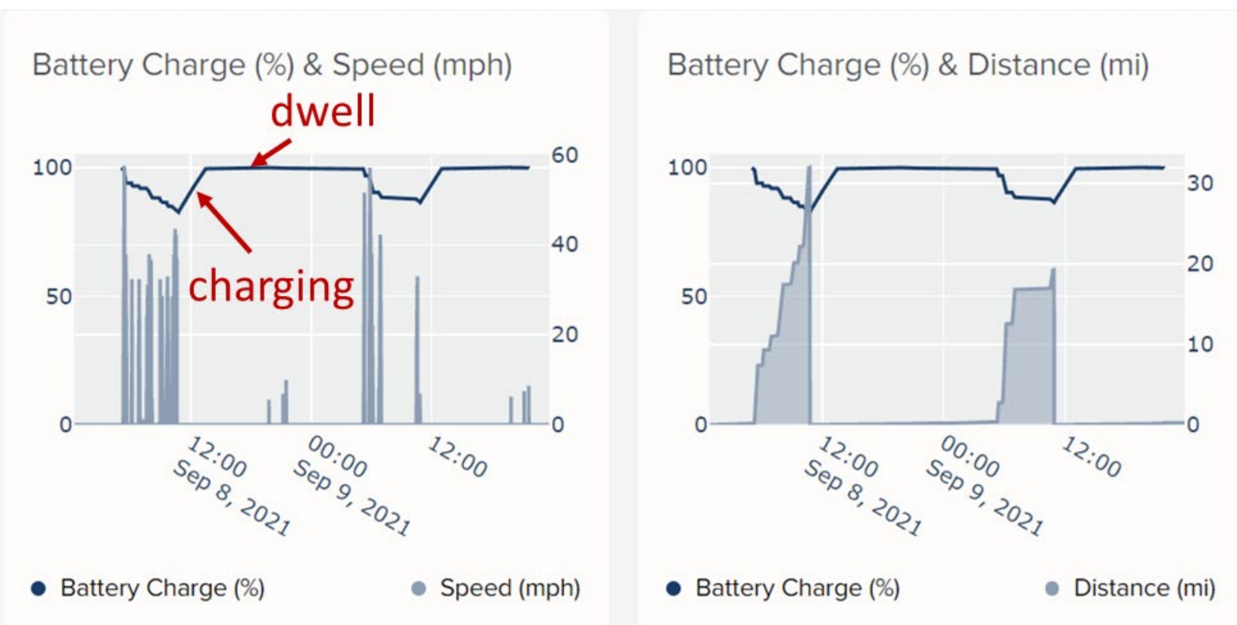


Figure 96. Charging over days 7-8 (NACFE)

The Anheuser-Busch BYD RoL-E data shows it is feasible to operate a BEV in heavy beverage delivery duty cycles. The urban nature of the duty cycle provides excellent opportunity for regenerative braking to recover battery energy. The daily miles are less than 50 miles while the battery pack has the capacity to easily handle three times that distance. This means the truck could be used on longer routes, or be charged only once every three days, allowing multiple trucks to use the same charger each week by staggering charge days. Managed charging could be used to stretch out overnight charging and allow lower cost power charge settings.

7.2.2 Biagi Bros. and Peterbilt/Meritor

Biagi Bros. operated a Class 8 Peterbilt 579EV with a Meritor electric drivetrain hauling wine between Napa, CA and Sonoma, CA in Run on Less – Electric.

Biagi Bros. is a full-service logistics company providing businesses and organizations with 3PL and supply chain solutions. Founded in 1978, the company still operates as a family-owned and operated supply chain management enterprise. It has distribution centers, warehouses and truck terminals strategically located throughout the US with a workforce of 600+ employees. The company owns more than 270 tractors, 750 trailers, operates 3.5 million square-feet of food-grade warehouse space, and has 20 distribution centers. [58] Fred Biagi, co-founder Biagi Bros., said, “We started out with just a couple trucks and then gradually worked our way into the warehouse business.”

The duty cycle for RoL-E was a short 13-mile route between Napa and Sonoma with some rural highway and urban traffic and grade changes. Gregg Stumbaugh, corporate equipment director, Biagi Bros., described the duty cycle as one run. “It goes from our warehouse in Napa to a bottling facility in Sonoma, shuttling from the bottling facility back to our warehouse.”

Frank Falcone, chief engineer Meritor Electric Vehicles, said the truck really lent itself to short haul daily use. It is often used in drayage and delivery applications where the routes are well known and very repeatable. “This is a case where a BEV can offset thousands of dollars a year in fuel cost.” The vehicle is operating on country roads with some stop-and-go at stoplights, but there is a lot of cruise and rolling hills. “Anytime you are going down a hill you get to recapture some of that energy as the motors brake the vehicle as opposed to the mechanical brakes. And then the vehicle can very efficiently climb the hills and ultimately take its cargo to its destination,” he said.

RUN ON LESS ELECTRIC

Lesson Learned

Plan for cold weather, terrain, heavy loads when calculating needed battery sizing.

Stumbaugh said the fleet was concerned about the weight of BEVs. “Our customers expect us to haul a certain amount and we are able to do that with the current truck. Hopefully the new truck with the e-axle will be the next step. The more experience we get, the more buy-in we get with the drivers. Because the drivers are key to being successful.”

Commenting on the BEV, Pat Brandon, driver with Biagi Bros, who has been driving for 35 years – 10 of them for Biagi Bros. – said, “The first time I ever drove this truck I was like you picked me to drive the electric truck? I could not believe the honor it was to be the first one. And it’s amazing because it’s quiet. You can hear the radio. You don’t have to crank it way up. I hear everything in this truck.”

Stumbaugh said Brandon does a great job giving the fleet feedback, whether that is positive or negative. “He’s not shy about talking about the truck when people ask. He’s a good ambassador for that truck.”

Brandon said other drivers have walked over to ask him about the truck. “I say, read it on the hood. It’s all electric.” And it’s not just drivers who react to the truck. Brandon explained the public has positive reactions as well. “We drive through a couple small towns where the streets are narrow. When I drive through with a diesel truck, people look at us, because we’re interrupting them as they’re talking, they’re eating their lunch. I’ve gone through with this the BEV quite a few times and they don’t even know I’m there. I’ve got thumbs up from people that realize it’s an all-electric truck. It’s a great feeling to know you are not polluting and that you are doing something for the future.”

The Biagi Bros. RoL-E participant vehicle was a Peterbilt 579EV Class 8 tractor with a Meritor electric drivetrain operating between Napa and Sonoma transporting wine to temperature-controlled storage facilities. Peterbilt has been deploying pre-production BEVs with fleets to assess their strengths and weaknesses to provide input for production vehicle designs [59]. Meritor is Peterbilt’s and Kenworth’s non-exclusive supplier for electrification as the initial launch partner and primary supplier for the integration of functional battery-electric systems. [60]

Matt Weta, national account manager – EV, Peterbilt Motors Company, said that Peterbilt tries to stay on top of the latest technologies and makes sure they are incorporated into its vehicles. “Almost every single drive that I’ve done with a potential customer, almost immediately someone makes the comment about just how silent and quiet the vehicle is to operate. And usually, the second comment is about the performance. I think there is a day in the future where all our transportation will be done with zero-emission vehicles. This is the first step on the road to that end goal.” Peterbilt’s strategy is to identify those niches where the technology is most ready and the financial benefits for its customers make sense and then work its way up from that point.

Biagi Bros. has been operating a first-generation Peterbilt/Meritor pre-production prototype and received a second-generation production intent vehicle at the start of RoL-E shown in Figure 97.

Figure 97. The series production Peterbilt 379e intended for Biagi (Meritor)

Data reported from RoL-E was for the first-generation pre-production prototype. [61] Falcone explained Peterbilt built a batch of pre-production units for testing, learning and development. The truck that is going to market now is coming in series production using the company's 14Xe ePowertrain. "It truly is a generational leap over what we have had before." The previous generation had an electric motor transmission driveshaft and conventional rear axle. Meritor's innovation is taking that motor and that transmission and building all of that into the axle. This new generation truck is using two of these epowertrains which frees up room between the frame rails. "Now we're able to build a truck that has more energy storage on board and a short wheelbase that is more in line with the typical day cab. This improves maneuverability in tight yards and other places that these types of trucks tend to drive," he said.

For RoL-E, individual round trips of 26 miles even with maximum payload weights were not an issue. However, multiple trips in the same shift had the potential to exceed the battery pack net range requiring a second truck to complete the shift. An overview of the Biagi Brothers Peterbilt/Meritor BEV vehicle is shown in Figure 98. [94] NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on Biagi Bros. and Peterbilt. There is also a fleet profile and a video.

Truck

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

Figure 98. Biagi Bros and Peterbilt/Meritor (NACFE)

The Peterbilt/Meritor Biagi Bros. tractor had initial communications issues with its charger due to a last-minute change of both the truck and charger just as the Run was starting. Corrections were implemented by reverting to an older prototype truck and its prior charging system that had been reviewed by NACFE during an earlier visit to the Biagi Bros. facility. The gap in initial data is seen in Figure 99. [93]

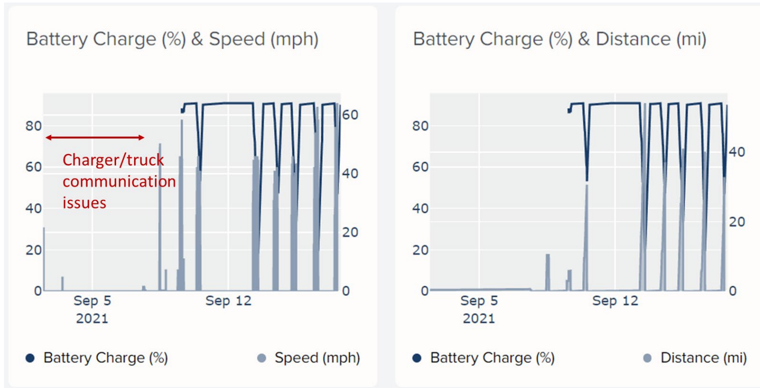


Figure 99. Peterbilt/Meritor Biagi SOC, speed and distance history (NACFE)

Daily use of the tractor is seen as consistent through days 12 to 18, as shown in Figure 100. [93] Similar to the Anheuser-Busch example, charging occurred quickly, and could be done at a somewhat lower power level if managed charging was used over the available dwell time. The vehicle is seen to be continuously moving at highway speeds with very little stoppage time between the start and end of the driving part of the duty cycle. The vehicle consistently saw 40 miles per day, reflecting the predictable nature of this duty cycle.

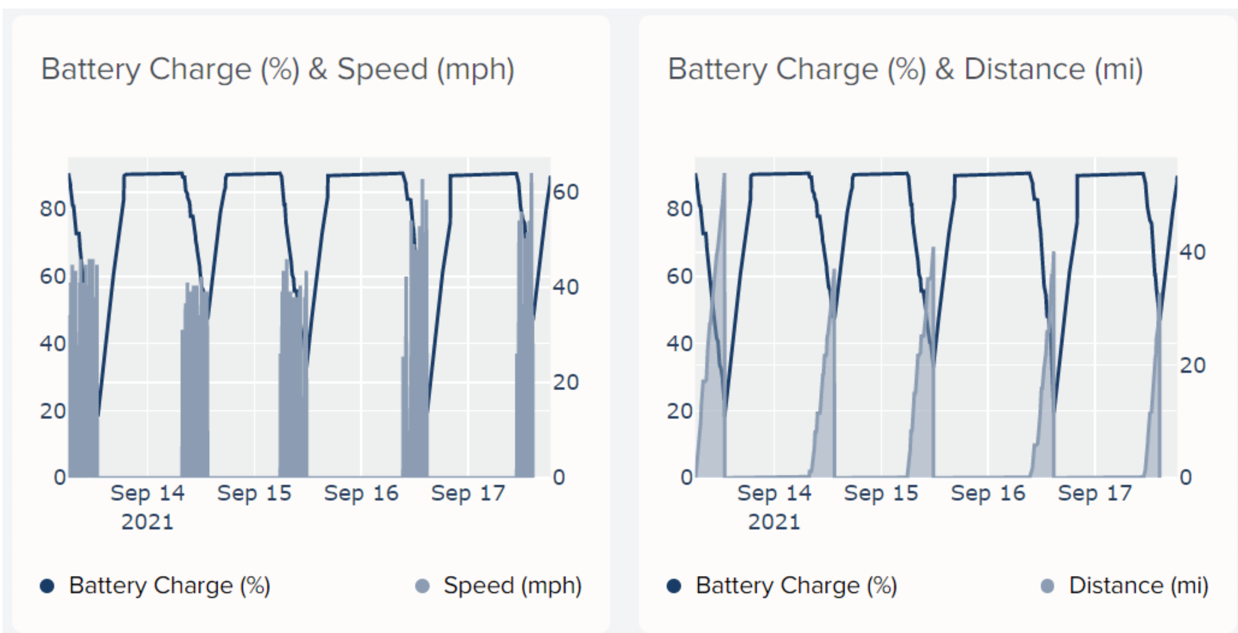


Figure 100. Peterbilt/Meritor Biagi SOC, Speed and Distance history days 12-18 (NACFE)

Truck activity over days 12 to 18 shown in Figure 101 finds the truck hooked to the charger 69% of the time, driving 13%, inactive 11% and idling ~6%. [93]

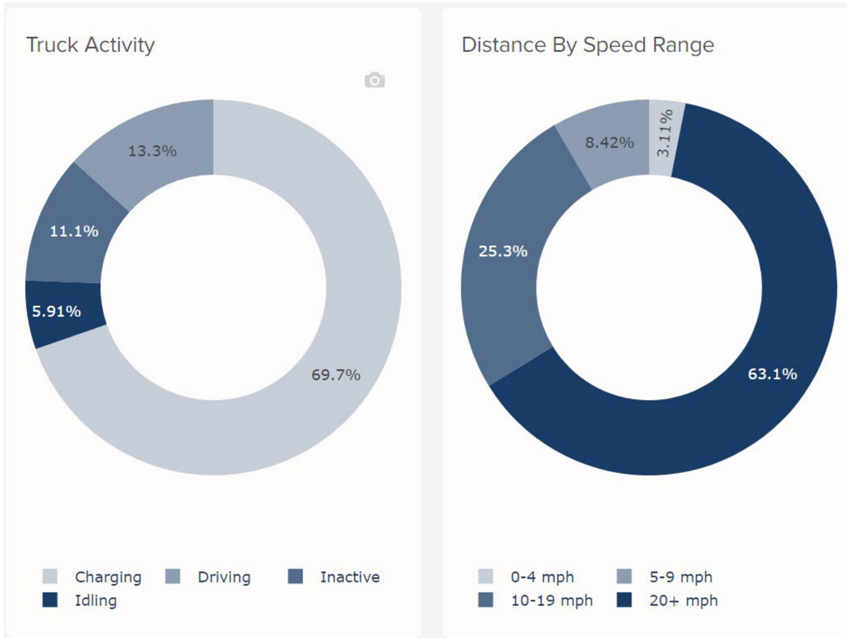


Figure 101. Truck activity and speed distribution over days 12-18 (NACFE)

Regenerative braking energy recovery opportunities on this duty cycle are less, about 6% to 8% as seen in Figure 102. [93] The driver was on a state highway between two warehouse sites, with much less urban driving — only at each end of the route — and whatever traffic congestion is encountered on the highway. The truck was idling a very short period of time, less than 2%.

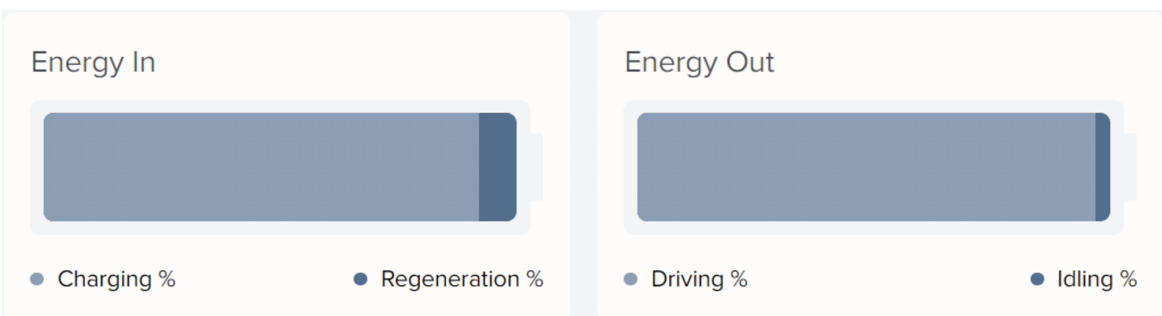


Figure 102. Energy recovery and use days 12-18 (NACFE)

The Peterbilt/Meritor Biagi Bros. tractor was pulling 53’ van trailers full of heavy bottled beverages between Napa and Sonoma sites, a map distance of ~15 miles. Daily mileage for the truck was ~41 miles, indicating one to two round trips per day. The driver completes his shift in a second diesel tractor. The current series production Peterbilt 579EV shown at the March 2022 TMC event in Orlando, FL, is conservatively capable of 150 miles per full charge. This new production vehicle is capable of doing four round trips for the Biagi Napa-Sonoma 15-mile route, sufficient for a day’s shift for the driver.

7.2.3 NFI Freight and Volvo

NFI operated a Volvo VNR electric truck hauling shipping containers and trailers between the Port of Long Beach and California’s Inland Empire.

NFI is a leading supply chain solutions provider operating in excess of 4,500 tractors and more than 12,500 trailers across the US and also has drayage operations at many US ports. NFI is an industry leader in investing in zero-emission alternatives with operations in Southern California in partnership with state and regional agencies and manufacturers. [42]

Bill Bliem, senior vice president, fleet services, NFI Industries, says his company is excited about what's going on with electrification. "We feel so strongly that this is the right thing to do for the environment. We're committed to it. A lot of customers have lofty goals of being zero emission and carbon negative. We need to help them get there and electrifying trucks in our fleet is how we are doing it and it just makes sense with our dedicated operations."

Trips are typically out and back and average length of haul is about 300 miles. "We have the perfect fleet, to pilot [BEVs]," he said. Regarding the maturity of the technology, Bliem said the company is working with OEMs to help them get their trucks to the point where they can scale. "That's where we are at today. We need a little more range, a little less weight and we're good to go."

Bliem has confidence that the technology is viable and said NFI management is confident it can make the technology work in its operations. "We can work out the bugs to get it into those other dedicated operations and move it across the country."

Volvo started electrification in Southern California. According to Keith Brandis, vice president, partnerships and strategic solutions, Volvo Group, in 2018, Volvo won an award with California Air Resources Board through Southcoast Air Quality Management District called the Volvo LIGHTS project — low impact green heavy transport solution. Brett Pope, director electric vehicles, Volvo Trucks North America, said, "This allowed Volvo to accelerate our speed to market. Here in Southern California the VNR electric is one of the first units we have in operation." The truck in the Run was a production unit that is available now and Volvo is testing and validating some of the energy systems storage within NFI's drayage operations. "The truck is very easy to drive, very comfortable and very quiet. We just created a very easy way to transition into a zero-emission product with the electric driveline," Brandis said.

He expects the technology to evolve quickly. "Five years ago, I didn't believe that electric trucks were a possibility much less had a road for success. I've been proven wrong. The technology is transformative." He also believes this technology can reach younger people entering the industry. "When I'm on college campuses trying to recruit young engineers, IT specialists, and business majors, it's fun now to talk about how we're not seen as a typical smokestack manufacturing industry." He brings up what the company and the industry are doing to improve the air quality, to make trucks safer. He talks about the way vehicles are connected and speaking to one another. "It's a great time to be in the transportation business," he tells students.

Jeffrey Howard, driver for NFI Industries, has been driving for three and a half years and has a family history with driving including his father and grandfather. "We do two runs to the port usually, every single day if we have time. It's a good truck. It's very strong. It's quiet. It's smooth. It's like you're not hauling anything."

According to Hector Banuelos, fleet operations manager, NFI Industries, the duty cycle consists of about a 240-mile round trip run. "Usually, it's one round trip out of one truck although the driver tries to do two each day. Once the driver comes in, he'll drop off the truck and hook it up to the charger and take the second truck down." The duty cycle for this truck includes some urban street, yard, and interstate driving with round trips on the order of 110 to 120 miles and a localized 6% grade crossing a steep bridge at the ports. Examples of the trailers and container chassis are shown in Figure 103.

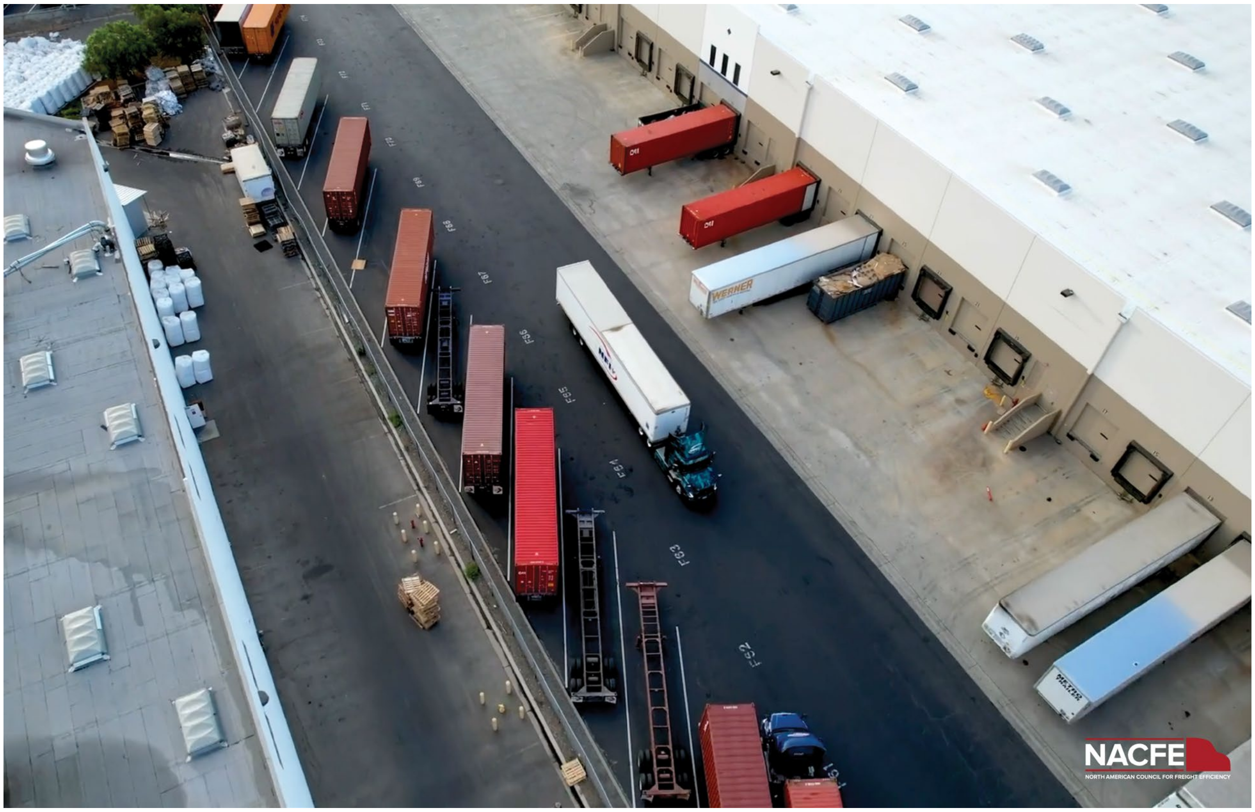


Figure 103. NFI example trailers and containers

Brett Pope, director electric vehicles, Volvo Trucks North America, describes the truck, "The VNR electric has a short bumper to back of cab which allows for tight operation in city environments. "Our energy storage system is lithium-ion battery. The propulsion system for the VNR electric consists of two electric motors with a two-speed transmission. These electric motors provide 340 kW of power, or 455 Hp. The truck has a two-speed and has to pull 82,000 lbs. We have that lower first gear for launch capability — acceleration. Then we shift into second gear, and we have the wide operating band of the electric motor to provide that high efficiency driveline."

RUN ON LESS ELECTRIC

Lesson Learned

BEVs offer significant and steady accelerating when compared to the rocking of diesel AMT powertrains.

Weights for the containers and trailers tend to be in the 35,000 lbs. to 40,000 lbs. range. NFI estimates the maximum gross vehicle weight leaving the ports is 72,000 lbs. and the average is less than that. The payload weight and the single round trip of 110 to 120 miles is not an issue for the electric trucks. However, multiple trips in the same shift are challenging and require a second vehicle. An overview of the NFI Volvo BEV vehicle is shown in Figure 104. [94] NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on NFI Freight and Volvo Trucks. There is also a fleet profile and a video.

Truck

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

Figure 104. NFI Freight and Volvo (NACFE)

The Volvo NFI freight tractor had continuous use during the 18 days of the Run, however there was a long holiday weekend at the start of the Run which can be seen in the graphs in Figure 105. [93] The data shows issues reading the signals from the truck. The first issue manifests itself as going from a low state of charge to fully charged the moment the vehicle started its next workday's trip. This is not accurate. Charging, for example, over the long three-day weekend around September 5 would have been completed fairly quickly, not stretched out to fill the entire time span. While that behavior would normally suggest managed charging, in this case, it is an anomaly. The second issue seen was that miles continuously accumulate over the entire 18 days. This was an error unique to displaying this tractor's data; the other RoL-E truck graphs show miles reset to zero each day. This highlights that unlike diesels, where SAE J1939 data bus is a guide for all OEMs, the new world of BEVs has no similar standard protocols.

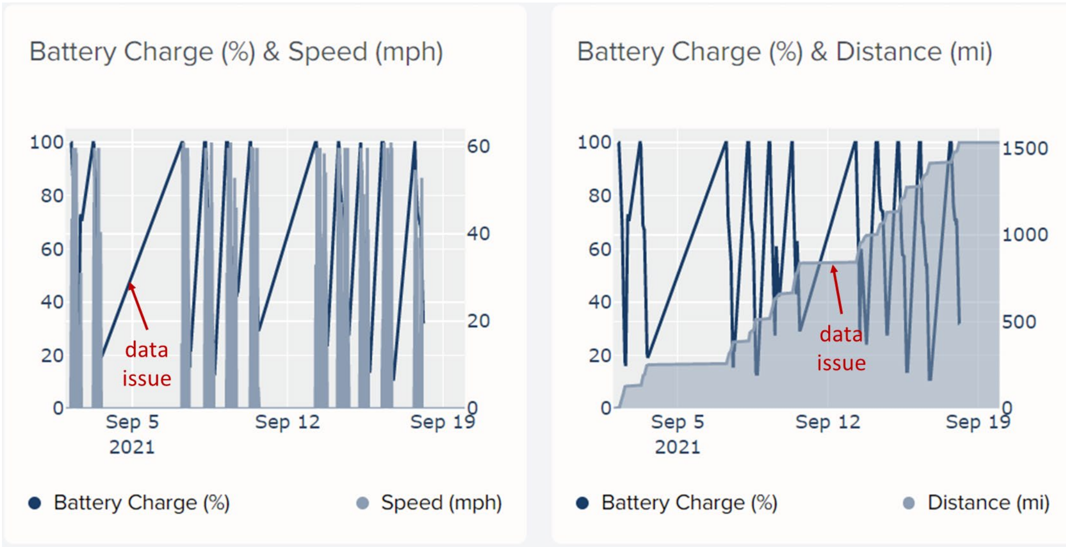


Figure 105. Volvo NFI freight SOC, speed and distance history (NACFE)

Figure 106 shows activity for this Volvo VNR electric truck and shows it never charged, another data issue, so this graph is not helpful. [93] The distance by speed is useful and shows a fairly distributed use of mph over the duty cycle. This duty cycle includes urban, highway and freeway driving.

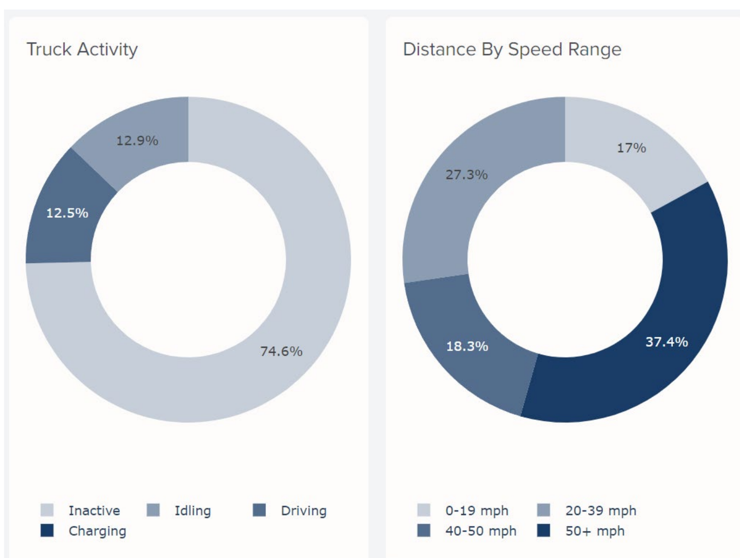


Figure 106. Truck activity and speed distribution over 18 days (NACFE)

The energy recovery through regeneration as shown in Figure 107 may be an accurate assessment but because of the issues with charging data, it also may be incomplete. [93] Certainly, the duty cycle would have significant opportunities for regenerative braking based on the speeds shown in Figure 106. [93]

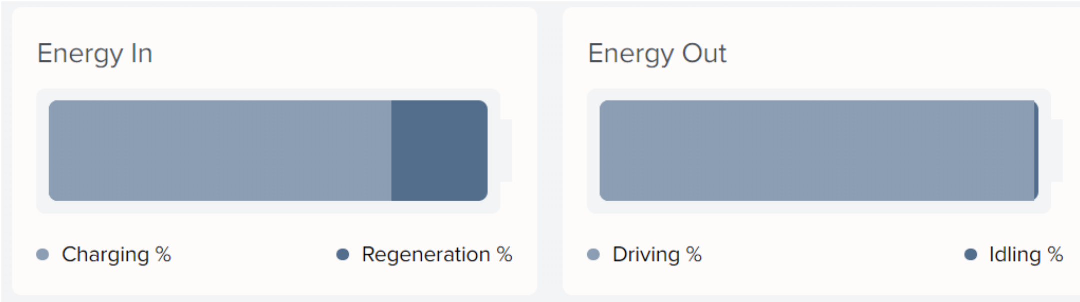


Figure 107. Energy recovery and use (NACFE)

The Volvo NFI tractor has a duty cycle that has it traveling between the Port of Long Beach and the Inland Empire, roughly 110 miles round trip. This tractor has an estimated range of 175 miles. This requires the driver to switch to a second truck while the first one recharges after a trip. This drayage duty cycle is a particularly long one for the Los Angeles region. There are several other drayage routes with shorter distances.

Weight is not an issue as these tractors are hauling oceangoing containers that are 40’ in length, and weigh on average between 36,000 lbs. and 40,000 lbs. Multiple trips per day with longer routes require potentially en route charging at both ends to increase the daily achievable miles. Another approach to adding range is to add more battery packs to the vehicle since there is an opportunity to add tare weight because of additional battery packs without compromising freight. Volvo offers two battery capacities on the series production units, one with a range of 175 miles and the other is 275 miles per details provided by Volvo to the California HVIP site. [49]

7.2.4 Penske and Daimler

In RoL-E, Penske operated a pre-production Freightliner eCascadia between Temecula, CA and San Diego, CA.

Penske Transportation Solutions is the umbrella brand for Penske Truck Leasing, Penske Logistics, Epes Transport Systems, Penske Vehicle Services, and related businesses. Penske Logistics provides supply chain management and logistics services to leading companies around the world. Penske’s focus on sustainability includes participation in the US and Canadian SmartWay programs. It has even used an independent third-party consulting firm to inventory its carbon footprint to target reduction efforts. [55]

Penske has been heavily engaged with Freightliner on testing electric trucks. Paul Rosa, senior vice president, procurement and fleet planning, Penske said, “I have not seen the amount of collaboration between component providers with the respective OEMs any better than it is now. There’s so much to learn and that’s what this project has been about. With any new technology we must have a good understanding of what it can do and what it can’t do. This is just a normal progression of our learning before we go and educate our field operators, our field salespeople, and thus our customers.” He adds that Penske has to feel good about the technology before it’s ready to make it available to its customers.

Jed Proctor, manager, customer consulting, Detroit eConsulting, explained that Freightliner brought Penske into the development process early. “We showed them the innovation fleet and what we were designing for series production and then asked them what their thoughts were. He said that Penske gave Freightliner some really candid, good feedback that the company has since implemented into series production vehicles. "We feel like when we come to market next year with our series production vehicle, it is going to be the easiest to maintain in the market, and most of that we can attribute to feedback from Penske."

RUN ON LESS ELECTRIC

Lesson Learned

Get started, learn by doing. Fleet feedback to OEMs and utilities will help the industry.

Rosa stressed the importance of communication in the successful transition to BEVs. "We have continuous conversations to review what we've learned from the various routes that the vehicle was running." He says the company is looking at how a vehicle is performing in different ambient temperatures, how it is working with different loads, how it is working with routes that have hills and those that have no hills. "We are trying to understand all the different ways the vehicle can be utilized," he explained.

Alex Voets, eMobility product and sales strategy manager, Freightliner Trucks, also believes collaboration is the name of the game when it comes to electrification. "It's really nice that with Run on Less we are able to tell the story to a broader audience about what it takes [to be successful with BEVs]. It's not only the vehicle. It's the infrastructure. It's the utility companies. It's ensuring that you have somebody to talk to when something goes wrong. And it's also the incentive applications to fund these vehicles." DTNA has been actively deploying pre-production Class 8 BEVs and is actively consulting with fleets to understand how the vehicles are used and where improvements are needed. [56]

The utilities are a key part of the BEV effort with Penske and Freightliner. Simon Horton, senior project manager, transportation electrification, Southern California Edison, said, "In order to become familiar with the trucking industry, we've done a lot of outreach to fleets that operate in our areas." The utility developed a transportation electrification advisory group that works with fleet customers that are making the transition to electrification. "With that group we are able to engage with the fleets and understand their needs and understand how that translates to the service connection they need from Edison so we can support their transformation."

Donald Disesa, a driver for Penske with 10 years' experience, said he felt honored to drive the electric truck. "I was one of the first guys to drive it on my team. The truck is so quiet. Everything is smooth. It gives you time to focus on what's going on around you. With the diesel trucks, there's rattling, there's driver fatigue. As soon as I got into the electric truck, I realized this is the way of the future. This is really the way it's going to go." Rosa confirmed that drivers love the BEVs, and he believes that is very important. "You get drivers in a vehicle that they love driving every day and there's nothing but positives that can come out of that."

Disesa's day starts at 4 pm when he begins delivering to eight to 15 different customers. At the end of the day, the truck ends up at a charging port, where he says it is easy to charge. "I pull in, plug it in, see a green light and I'm good to go."

Lesson Learned

It is quick and easy to charge — park in the designated spot, plug in, confirm charging and go home.

The Freightliner eCascadia operates in the Los Angeles region between Temecula and San Diego on Interstate 15, approximately 60 miles each direction. The duty cycle involves urban and on-highway miles pulling refrigerated trailers as shown in Figure 108.

Figure 108. Refrigerated trailer

Individual round trips with opportunity charging have no issues, however, multiple trips in a day may exceed the capacity of the batteries. An overview of the Penske DTNA BEV is shown in Figure 109. [94] NACFE's report *Electric Trucks Have Arrived: Documenting A Real-World Electric Truck Demonstration* contains more detailed information on Penske and Freightliner. There also is a fleet profile and a video.

Truck

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

Figure 109. Penske and Daimler (NACFE)

The Freightliner Penske tractor traveled a total of 903 miles during the 18 days of the Run. The unit consistently ran 100-mile days, but there was a three-day long dwell time in days 6 to 8, seen in Figure 110. [93] The long dwell times were not due to charging needs — charging occurred fairly quickly. This duty cycle was somewhat less predictable. Compounding that, an attempt was made to see how far the vehicle could go on one charge over several days of use, essentially taking the SOC to its lowest achievable value. In the test the battery achieved 218 miles of range.

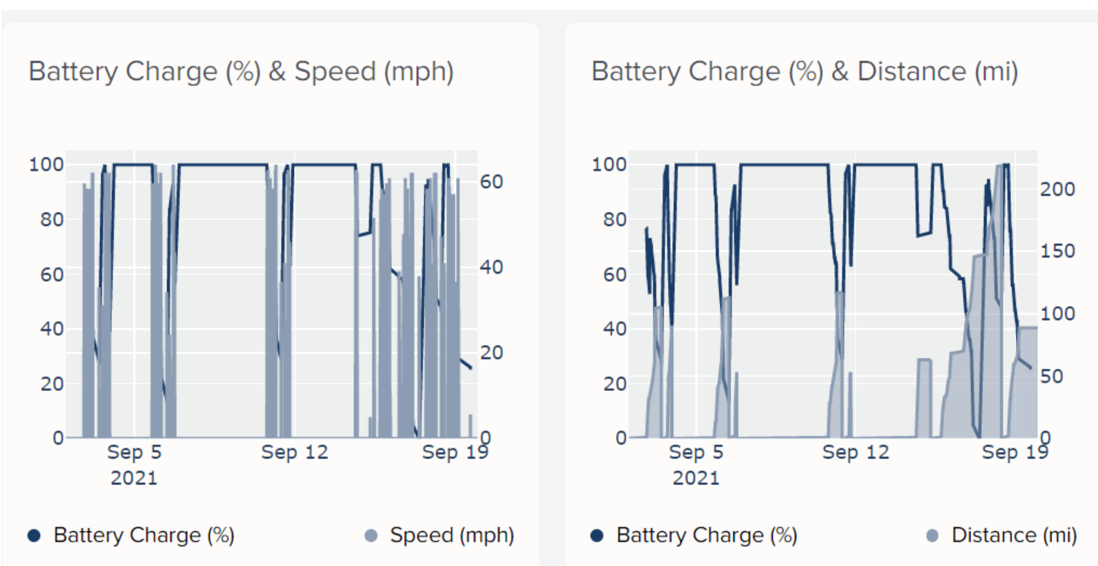


Figure 110. Daimler Penske SOC, speed and distance history (NACFE)

The activity for this truck shown in Figure 111 has it inactive 81.8% of the time, charging only 6.8% of time, and driving 6.6% of the time. [93] Distance by speed shows the majority, 58.5%, of miles were at highway speeds. This freeway driving in this region can see high traffic congestion. This might explain the high and low speed segments with stop-and-go driving on the freeway.

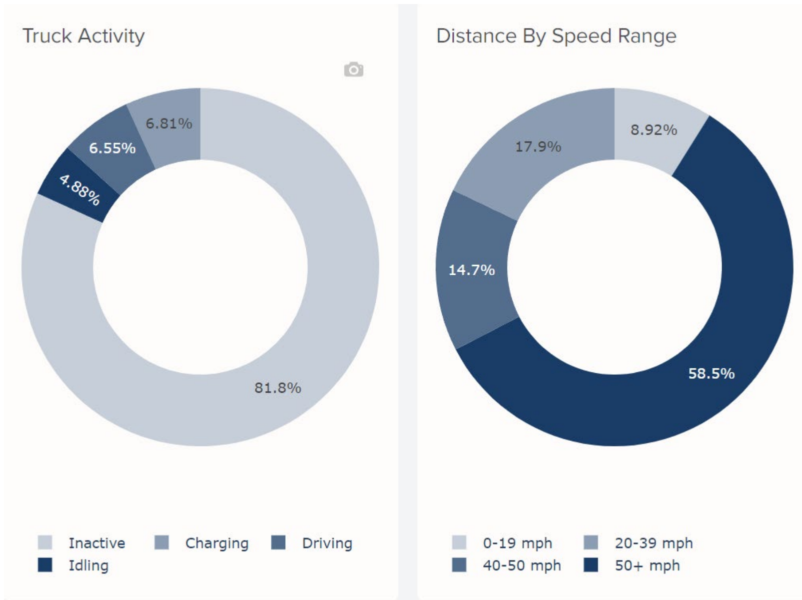


Figure 111. Truck activity and speed distribution over 18 days (NACFE)

The regenerative energy recovery for this duty cycle is shown in Figure 112. [93] Surprisingly, given that a majority of miles were at highway speeds, there is a significant amount — ~20% — of energy recovery from braking. The highway traffic congestion may explain the high regenerative braking combined with the high amount of speeds over 50 mph. The vehicle also had very little idle time.

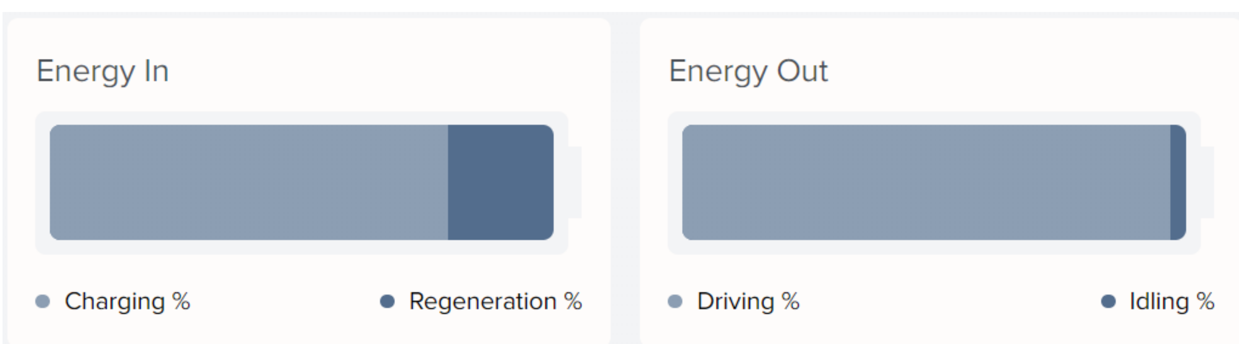


Figure 112. Energy recovery and use (NACFE)

The Freightliner Penske tractor has a duty cycle that has it traveling on freeways and some urban travel. Traffic congestion on freeways may explain both significant high speeds combined with significant regenerative braking. Hills also may be relevant. The vehicle is capable of 200 miles with some margin of safety provided by the energy recovery from regenerative braking. The series production Freightliner eCascadia in 2022 has a useable battery capacity of 475 kWh and a gross battery capacity of 535 kWh, advertising a 250-mile range. [49]

8 MARKET SEGMENT PERFORMANCE OF BEV REGIONAL HAUL TRACTORS FROM RUN ON LESS – ELECTRIC

There are several duty cycles for Class 8 tractors, like regional haul, drayage, beverage delivery, city diminishing load, milk runs and dedicated fast turns including long distances, with each one presenting its own unique challenges. Currently, there are an estimated 937,563 regional haul Class 8 tractors in the US and Canada. This estimate does not include vocational trucks, off-highway tractors, or long-haul tractors.

One of these vehicles, a BYD 8TT used by Anheuser-Bush to make beverage deliveries around Pomona, CA, completed the Run and its assigned job in an equivalent manner to its diesel counterpart. In fact, all eight of these electric trucks at this location do. The other three tractors – Penske using the Freightliner eCascadia to haul freight from Temecula, CA to San Diego, CA; Biagi Bros using the Peterbilt 579EV to run shuttle loads between Napa, CA and Sonoma, CA; and NFI using the Volvo VNR on routes between Chino, CA and the Port of Long Beach – all performed as expected but as of 2021 did not have the range to complete the full day's work of their diesel incumbents.

Collectively, the duty cycles and use cases for the Run on Less – Electric heavy-duty tractors are highly representative of return-to-base, single-shift operations within this market segment. Furthermore, the duty cycle of the beverage segment, represented by the BYD 8TT at Anheuser-Busch, is optimal for electric trucks, with the HDEVs capable of doing the same amount of work as their diesel counterparts.

The challenge with regional haul tractors is the opportunity for dynamic (unpredictable) routing, longer routes, more wait time, and drivers not returning to base each day. As this segment transitions into the long-haul end of the regional spectrum, these opportunities are amplified and make electrification dependent, at minimum, on regional charging infrastructure.

As Run on Less – Electric concluded in September 2021, NACFE predicted that 70% of this market segment was electrifiable. Given the more detailed analysis, interviews with industry experts and further research, we now consider this market segment to be 50% electrifiable with lower average daily miles which results in the avoidance of nearly 29.4 million metric tonnes of CO_2e (e equals carbon dioxide equivalent) annually as shown in Figure 113. [94] NACFE estimates the entire CO_2e to be eliminated by this segment at an average of 250 miles per day to be 97.8 million metric tonnes.

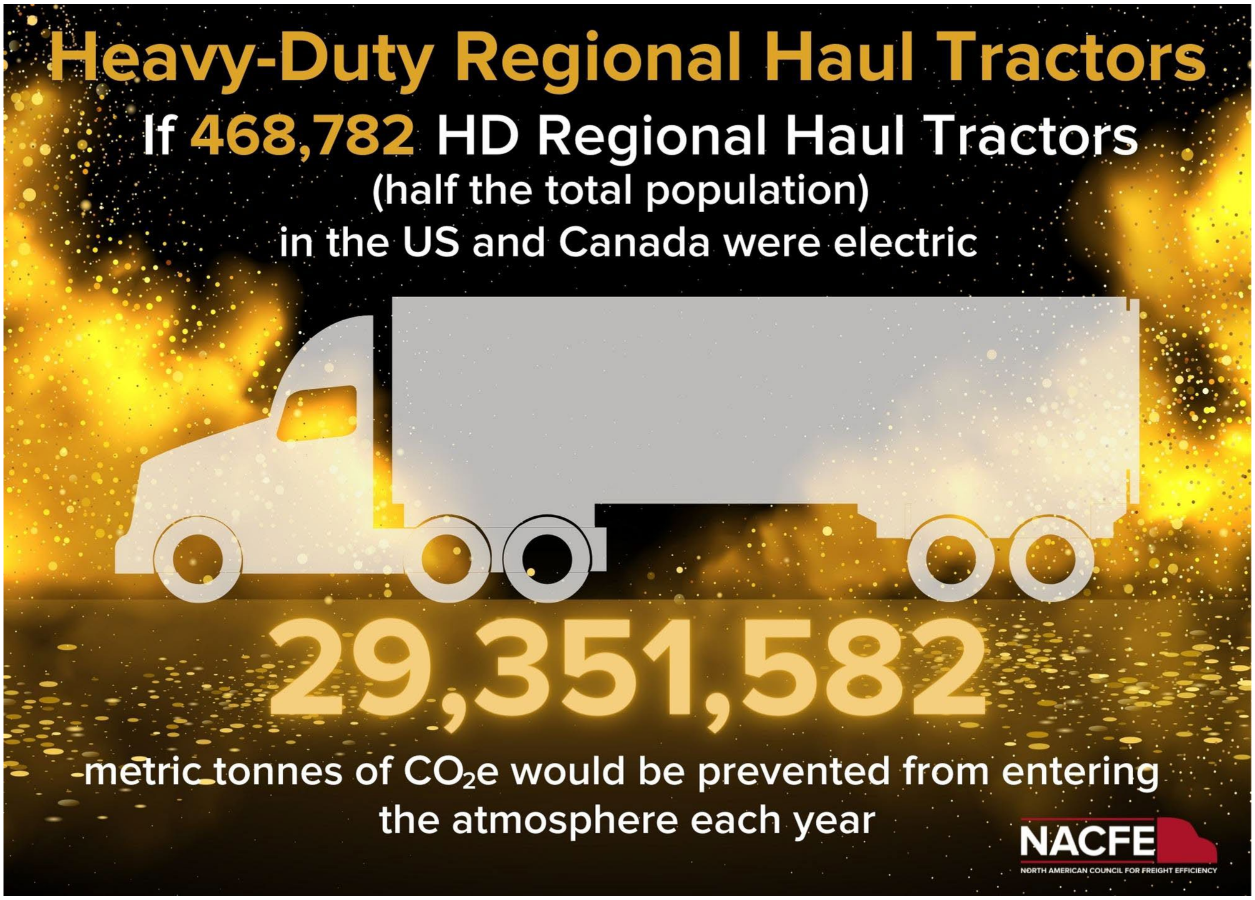


Figure 113. Carbon avoided if all US and Canadian heavy-duty regional haul tractors were battery electric

RUN ON LESS ELECTRIC

Lesson Learned

Expect new OEMs and faster delivery of next generation products over the next several years.

While specifications are incomplete on production vehicles, NACFE found information from various sources which we used to make estimates for current production level BEV Class 7 and 8 tractors. See Figure 114. Fleets should contact their OEMs and dealers for specific details.

Factor	Freightliner	Kenworth	Volvo	Peterbilt	BYD	Lion	Nikola
Model	eCascadia	T680e	VNR Electric	579EV	8TT	Lion 8	Tre
Max Battery	550 kWh	396 kWh	6 bats -565 kWh	396 kWh	435 kWh	Up to 653 kWh	753 kWh
Useable Battery	475 kWh	-	6 bats - 475 kWh		409 kWh		
*Range Full Charge	250 miles	150 miles	4 bats - 175mi 6 bats- 275 miles	150 miles	125 mi	Multiple ranges based on bats - max 260 mi	up to 350 mi
*Range 80% Charge	200 miles	-	225 miles				
Charging Speed Capable	240 kW	120 kW	250 kW	at least 120 kW	at least 240 kW		up to 240 kW
Charge Time 80%	90 min	-	4 bats - 60 min 6 bats - 90 min at 250 kW			Minimum 3 hours at Level III	120 min 10-80% at 240 kW
Charge Time 100%	-	3.3 hours at 120kW DC Fast Charger	-	3 hours at 120kW DC Fast Charger	2 hrs 240 kW DC		
Weight	21,986 lb	~22k lbs	~24k lbs	22,500 lbs	26,235 lb		~29,000 lb
Front Axle	12.5k	13.2 k		13.2 k			
Wheelbase	190"	190"		190"	166.3"	200"	
BBC	116"	~117"		117"		79"	
Horsepower	525 hp	536 hp continuous 670 hp peak	455 hp	536 hp continuous 670 hp peak	483 hp max	536/670 hp	645 hp continuous
Torque					1,770 lb-ft	840/1,622 ft-lb	
Regenerative Braking built into estimates			5-15%				

*Range assumes 65,000 lb total weight with load

Figure 114. Estimated specifications for current production units

9 TCO and ROI Discussion

Several of the OEMs that manufacture battery electric tractors have a TCO calculator that they use to help evaluate whether the purchase of a battery electric regional haul Class 8 tractors makes financial sense.

Lesson Learned

Know your baseline metrics to compare against what the BEV delivers to calculate TCO.

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.* [52]
- Factoring in maintenance cost of diesel regional haul Class 8 tractors.
- Understanding available incentives to lower the purchase price of a battery electric regional haul Class 8 tractors. 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 regional haul Class 8 tractors will be operating. Incentives for adding charging systems also may be available.
- Include "difficult to monetize" benefits of EVs such as driver attraction and retention.

RUN ON LESS ELECTRIC

Lesson Learned

Achieving TCO goals will be about managing your specific operation's details.

If only considering list purchase price, the fuel savings and maintenance cost savings for a typical battery electric regional haul tractor application, the payback can be eight years or more. In reality though, factoring in credits, incentives, grants and the many other benefits of electric versus diesel offer other real cost benefits, the payback can be under five years. The diesel vs. electric comparison is shown in Figure 115.

Diesel vs. Electric Comparison

Diesel	Factor	Electric
80,000	GVWR	82,000
152"-256"	Wheelbase	166"-200"
400-565	Horsepower	360-536
up to 2050	Torque (lbs-ft)	up to 4050
~50,000	Max Payload (lb)	~47,000 lb
$123,000	List Price	$250,000+
0	Incentives etc	$100,000+

Figure 115. Comparison of diesel and electric regional tractors

NREL published the results of a study showing that "by 2030, nearly half of medium- and heavy-duty trucks will be cheaper to buy, operate, and maintain as zero-emissions vehicles than traditional diesel-powered combustion engine vehicles." [103][104] NREL also concluded that "Battery electric trucks are expected to become cost-competitive for smaller trucks before 2030 while heavy trucks with less than 500-miles of range are projected to be cost-competitive by 2035" without incentives. [103][104] Long haul greater than 500 miles is forecasted to be cost competitive for hydrogen fuel cell powered by green hydrogen by 2035. The researchers graphed cost parity without incentives of ZEVs versus diesels based on shipment ranges in Figure 116. [104]

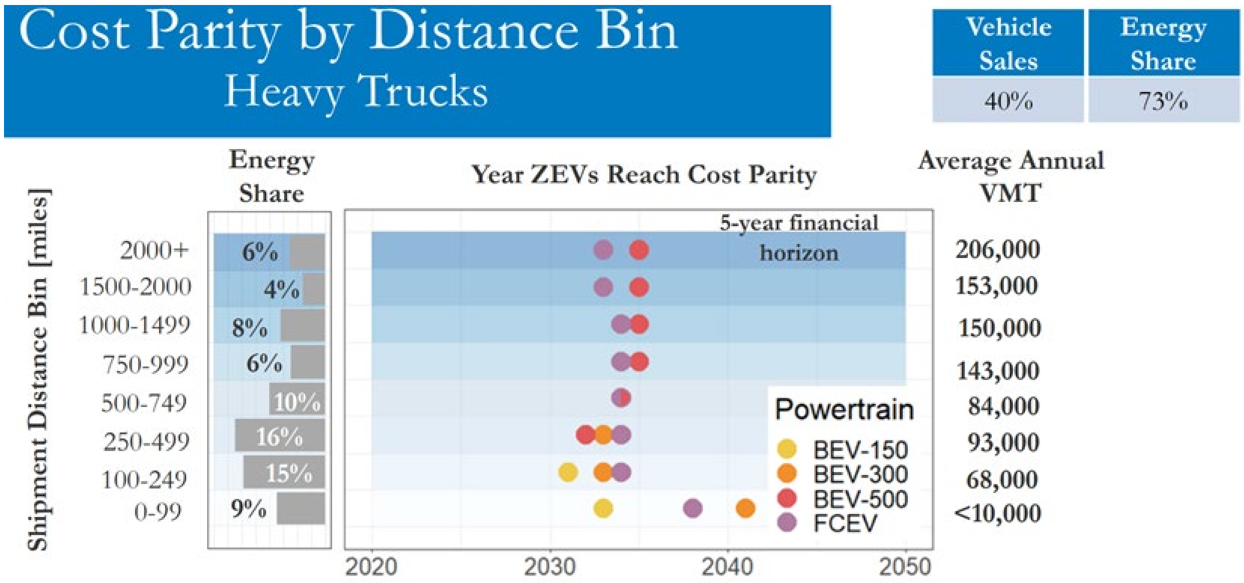


Figure 116. Cost parity BEV/ZEV vs diesel

RUN ON LESS ELECTRIC

Lesson Learned

Include all difficult-to-monetize BEV benefits in your TCO calculations.

10 BEV Regional Haul Report Findings

The study team has five key findings based on the four battery electric regional Class 8 tractors that participated in RoL-E and based on available research.

1. NACFE considers short and medium regional heavy-duty tractors electrifiable today with their range of 200 miles, about 3,000 to 4,000 lbs. of freight capacity penalty compared to diesels and improving total cost of ownership when monetizing all benefits. Regional haul tractors perform in various duty cycles including out-and-back, hub-and-spoke and diminishing return. Tractors currently available are meeting the needs of about 50% of this market segment.
2. Regional haul tractors return to base daily giving fleets confidence about making investments in charging infrastructure. These trucks often have 10+ hours of overnight dwell time for charging. Many people mistakenly assume Class 8 heavy-duty tractors are used in mostly long-haul disparate routes. In fact, only 40% are used in long-haul and 30% are vocational trucks and regional haul tractors respectively. These regional haul tractors are good candidates for electrification due to their shorter daily distances and return to base operation.

3. Operational changes such as the choices of the truck for each daily route, en route opportunity charging, driver incentives and managed charging are all examples of actions to improve the TCO of heavy-duty regional haul BEVs. Many actions are emerging to improve the TCO of operating electric vehicles in this market segment with many having to do with increasing range. Batteries are expensive and heavy so fleets can reduce the up-front cost by taking actions to extend the range. Others include lowering other costs such as charging during off peak hours.
4. The drivability (particularly in getting up to speed), quietness and other aspects make these trucks ones that drivers prefer over diesels, improving driver attraction and retention for fleets. Drivers of all sizes of electric vehicles share how much they like the driving experience over internal combustion engines. For regional haul driving much time is spent accelerating to highway speeds and this specific aspect of day cab electric tractors definitely will help attract and retain drivers in this segment.
5. Some medium and longer regional haul duty cycles pose more demanding requirements for current BEVs, but the next generations of products are bringing larger battery packs, better performing systems and lighter solutions to improve the TCO. Incentives are key to help the financials for these applications. NACFE defines medium and longer regional haul as vehicles that return to base frequently and travel in a radius of 100 to 200 miles or 200 to 300 miles respectively. Improvements are needed to make these vehicles – with their more than 150 and up to 600 miles of range – acceptable for total cost of ownership operations.

11 REFERENCES

All Website links were last accessed in February, March and April of 2022.

1. Mihelic, Rick. Mike Roeth. 2019. *More Regional Haul: An Opportunity for Trucking?* North American Council for Freight Efficiency (NACFE). https://nacfe.org/regional-haul/.
2. Mihelic, Rick. Mike Roeth. 2018. *Electric Trucks: Where They Make Sense.* North American Council for Freight Efficiency (NACFE). https://nacfe.org/emerging-technology/electric-trucks/.
3. Mihelic, Rick. Kevin Otto, Jessie Lund, Mike Roeth. 2019. *Guidance Report: Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors*. North American Council for Freight Efficiency (NACFE). https://nacfe.org/emerging-technology/electric-trucks-2/viable-class-7-8/.
4. Transportation Research Board and National Research Council. 2010. *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12845.
5. Hernandez, Sarah. 2017. *Estimation of Average Payloads from Weigh-in-Motion Data*. Transportation Research Record: Journal of the Transportation Research Board. Issue Number: 2644. Publisher: Transportation Research Board. ISSN: 0361-1981. https://doi.org/10.3141/2644-05.
6. Regehr, Jonathan. Kristopher Maranchuk, Jared Vanderwees; and Sarah Hernandez. 2020. *Gaussian Mixture Model to Characterize Payload Distributions for Predominant Truck Configurations and Body Types*. Journal of Transportation Engineering, Part B: Pavements. Volume 146 Issue 2 - June 2020. https://ascelibrary.org/doi/abs/10.1061/JPEODX.0000174.
7. Tok, Andre, Kyung (Kate) Hyun, Sarah Hernandez, Kyungsoo Jeong, Yue (Ethan) Sun, Craig Rindt, Stephen G Ritchie. 2017. *Truck Activity Monitoring System for Freight Transportation Analysis*. Transportation Research Record: Journal of the Transportation Research Board. Issue Number: 2610. Transportation Research Board. ISSN: 0361-1981. https://doi.org/10.3141/2610-11.
8. Mihelic, Rick. 2021. *A trend toward purpose-built vehicles*. Commercial Carrier Journal (CCJ). Jul 19, 2020. https://www.ccjdigital.com/trucks/article/15066562/trucking-industrys-trend-toward-purposebuilt-vehicles.
9. J. B. Hunt Transport. 2015. *660 Minutes: How Improving Driver Efficiency Increases Capacity*. J. B. Hunt Transport Inc. https://www.jbhunt.com/content/dam/jbhunt/jbh/white-papers/white-paper-pdf-docs/660%20Minutes_How%20Improving%20Driver%20Efficiency%20Increases%20Capacity.pdf
10. National Private Truck Council (NPTC). *Benchmarking Survey Report 2021*. National Private Truck Council (NPTC). https://www.nptc.org/benchmarking/benchmarking-report/.
11. Mihelic, Rick. Mike Roeth, Dave Schaller. 2019. *The Feasibility of Intentional Pairing Heavy-Duty Tractors and Trailers*. North American Council for Freight Efficiency (NACFE). https://nacfe.org/report-library/intentional-pairing/.
12. Quimby, Tom. 2020. *NFI plugging in plenty of trucks*. Commercial Carrier Journal (CCJ). Nov. 3, 2020. https://www.ccjdigital.com/business/article/14940086/nfi-plugging-in-plenty-of-trucks.

13. Schneider. 2021. *Schneider to become one of the largest battery-electric truck fleets in North America*. Schneider. Press Release Aug 31, 2021. https://schneider.com/company/news/one-of-largest-battery-electric-fleets.

14. ACT Expo. 2021. *Electrify America, NFI to Deploy Ultra-Fast DC Chargers for JETSI Project*. ACT Expo 2021 Event News. Aug 31, 2021. https://www.actexpo.com/press-release/act-expo-2021-electrify-america-nfi-to-deploy-ultra-fast-dc-chargers-for-jetsi-project.

15. Zehnder, Katie. Scott Lowry, Robert Evans, Sam Spofforth, Andrew Conley, Maureen Marshall, Niraj Shetty. 2021. *Freight Electrification*. Drive Ohio. https://drive.ohio.gov/about-driveohio/news-and-events/freight-electrification-study.

16. Mihelic, Rick. David Schaller, Yunsu Park, Kevin Otto, Mike Roeth, Denise Rondini. 2020. Run on Less Regional Report. North American Council for Freight Efficiency (NACFE). https://nacfe.org/downloads/run-on-less-regional-report/.

17. NTB Trucking website https://www.ntbtrk.com/careers/why-drive-for-ntb

18. Schneider website https://schneiderjobs.com/truck-driving-jobs/driving-opportunities/regional

19. Werner website http://www.werner.com/content/drivers/driver_opportunities/

20. “Glossary of Trucking Terms,” American Trucking Associations website, https://www.trucking.org/sites/default/files/2019-12/Trucking%20Glossary.pdf

21. J. B. Hunt website https://drivers.jbhunt.com/regional-truck-driving-jobs

22. Smart Trucking website https://www.smart-trucking.com/short-haul-trucking.html/

23. Bliem, Bill. March 2022. Presentation on NFI BEVs at American Truck Association (ATA) Technology & Maintenance Council (TMC) Spring 2022 event. Orlando, FL.

24. Sondhi, Keshav. Sep 2021. Presentation on US Food electrification at SAE COMVEC 2021. Chicago, IL.

25. Sondhi, Keshav. Aug 2020. Presentation on Pepsi Fleet Sustainability at the North American Battery Show. Virtual event.

26. “Total Freight Moved by Distance,” U.S. Department of Transportation (DOT) Bureau of Transportation Statistics (BTS) BTS, table, https://www.bts.gov/browse-statistical-products-and-data/freight-facts-and-figures/total-freight-moved-distance

27. EPA, “Regulatory Impact Analysis, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2,” EPA-420-R-16-900, U.S. Environmental Protection Agency, Aug. 2016, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P7NS.PDF?Dockey=P100P7NS.PDF

28. Communication between Mike Roeth and Steve Tam of ACT Research, Jan 14, 2021.

29. “Fuel Prices.” U.S. Department of Energy Alternative Fuels Data Center (AFDC), Mar 18, 2022

download, https://afdc.energy.gov/fuels/prices.html

30. “Petroleum and Diesel Fuel Update.” U.S. Department of Energy Alternative Fuels Data Center (AFDC), Mar 22, 2022. https://www.eia.gov/petroleum/gasdiesel/

31. Park, Yunsu. Mike Roeth. Feb. 2018. “Run on Less.” https://nacfe.org/run-on-less-reports/

32. Rule 2305. Warehouse Indirect Source rule – Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program. May 2021. South Coast Air Quality Management District (SCAQMD). http://www.aqmd.gov/docs/default-source/rule-book/reg-xxiii/r2305.pdf

33. Sobhani, Casey. George Gigounas, Pual Hemmersbaugh, Andrew Brady, Paul Wierenga, Caroline Lee, Isabella Neal. June 30, 2021. *Understanding California's South Coast AQMD Warehouse Indirect Source Rule – key points for warehouse owners, operators and tenants*. DLA Piper. https://www.dlapiper.com/en/us/insights/publications/2021/06/understanding-californias-south-coast-aqmd-warehouse-indirect-source-rule/

34. "Six States Adopt Clean Truck Rule." Jan. 6, 2022. Transport Topics. https://www.ttnews.com/articles/six-states-adopt-clean-truck-rule

35.Buysse, Claire. Ben Sharpe. Jul 20, 2020. California's Advanced Clean Trucks Regulation: Sales Requirements for Zero-Emission Heavy-Duty Trucks. International Council on Clean Transportation (ICCT). https://theicct.org/publication/californias-advanced-clean-trucks-regulation-sales-requirements-for-zero-emission-heavy-duty-trucks/

36. Advanced Clean Fleets. California Air Resources Board (CARB). https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

37. Daimler Regulatory Update. Mar 16, 2021. Daimler Trucks North America presentation to the National Automobile Dealers Association (NADA) ATD Virtual Roundtable. Provided to Mike Roeth by David J. Bell, Director Legislative Affairs National Automobile Dealers Association.

38. Clean Trucks Rule 2021. Jun 24, 2021. Oregon Department of Environmental Quality (DEQ) Public Stakeholder Meeting. https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ctr2021m1pres.pdf

39. *Proposed Rule and Related Materials for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards*. March 2022. U.S. Environmental Protection Agency (EPA). https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-and-related-materials-control-air-1

40. Heavy-Duty 2027 and Beyond: Clean Trucks Proposed Rulemaking. Mar 2022. U.S. Environmental Protection Agency (EPA). https://www.epa.gov/system/files/documents/2022-03/420f22007.pdf

41. *Enhancement and Standardization of Climate-Related Disclosures*. Mar 2022. Securities and Exchange Commission (SEC). https://www.sec.gov/files/33-11042-fact-sheet.pdf

42. Electric Power Monthly. March 22, 2022. U.S. Department of Energy (DOE) Energy Information Administration (EIA). https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_5_03

43. *An Analysis of the Operational Costs of Trucking: 2021 Update*. November 2021. American Transportation Research Institute (ATRI). https://truckingresearch.org/wp-content/uploads/2021/11/ATRI-Operational-Cost-of-Trucking-2021-FINAL.pdf

44. *2022 Amendments to the Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate*. March 17, 2022. California Air Resources Board (CARB). https://ww2.arb.ca.gov/sites/default/files/2022-03/TRU%20ATCM%202022%20Amendments%20Fact%20Sheet_0.pdf

45. *Trailer Energy Harvesting: Regenerative Braking Systems for Trailer Applications*. January 2022. American Trucking Association (ATA) Technology and Maintenance Council (TMC). Future Truck Position Paper 2022-2. https://tmc.trucking.org/.

46. *Zero-Emission Regulations*. January 2022. Southern California Edison. https://image.email.sce.com/lib/fe9612727166057577/m/5/de84b6cb-8e7b-476f-8a6d-e442fed29720.pdf?et_cid=ISR+Email_01_2022+-+Level+1&et_rid=584259084

47. Yakub, Mehanaz. November 9, 2021. Canada signs global agreement targeting 100 per cent zero-emission truck and bus sales by 2040. Electric Autonomy. https://electricautonomy.ca/2021/11/09/cop26-zero-emission-truck-bus-canada/

48. Electric Vehicles. Peterbilt. https://www.peterbilt.com/electric-vehicles

49. California HVIP. California. https://californiahvip.org/vehicle-category/heavy-duty/

50. Tesla Semi. https://Tesla.com/semi

51. KenworthT680E. Kenworth. https://kenworth.com/trucks/t680e/

52. Lund, Jessie. Rick Mihelic, Mike Roeth. March 2019. *Amping Up: Charging Infrastructure for Electric Trucks*. North American Council for Freight Efficiency (NACFE). https://nacfe.org/emerging-technology/electric-trucks-2/amping-up-charging-infrastructure-for-electric-trucks/

53. Gaton, Bryce. October 10, 2018. Why is Tesla Charging different? The Driven. https://thedriven.io/2018/10/10/tesla/

54. NREL-Hosted Event Supports Industry Development of Megawatt Charging System Connectors. U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL). https://www.nrel.gov/news/program/2020/nrel-hosted-event-supports-industry-development-megawatt-charging-system-connectors.html

55. CharIN website https://www.charin.global/

56. Medium- and Heavy-Duty Electric Vehicle Charging. U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL). https://www.nrel.gov/transportation/medium-heavy-duty-vehicle-charging.html

57. Nelder, Chris. Emily Rogers. 2019 Reducing EV Charging Infrastructure Costs. RMI. https://rmi.org/insight/reducing-ev-charging-infrastructure-costs

58. Nicholas, Michael. 2019. Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas. International Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf

59. Lindgren, Brian. Long-Range Battery Electric Vehicle with Megawatt Wireless Charging. U.S. Department of Energy (DOE). Project elt262. https://www.energy.gov/sites/default/files/2021-07/elt262_lindgren_2021_o_5-14_835pm_KF_ML.pdf

60. Impulitti, Joe, Michael Lehmann, South Coast Air Quality Management District. 2019. Electric Truck Pantograph Retrofit Project. California Energy Commission. Publication Number: CEC-600-2019-059. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-600-2019-059.pdf#:~:text=This%20project%20involved%20the%20retrofit%20of%20pantographs%20to,exiting%20to%20the%20various%20warehouse%20and%20railyard%20areas.

61. Halvorson, Bengt. April 22, 2021. Electric Island: First US charging station for electric semis is ready for megawatt fast-charging. Green Car Reports. https://www.greencarreports.com/news/1132019_first-charging-station-electric-semis-megawatt-fast-charging

62. Heavy-duty Demonstration and Pilot Projects. Aug 2021. LCTI: Joint Electric Truck Scaling Initiative (JETSI). https://ww2.arb.ca.gov/lcti-joint-electric-truck-scaling-initiative-jetsi

63. WattEV website https://www.wattev.com/

64. Hirsch, Jerry. September 1, 2021. WattEV, NFI Fleet and Charging Deals Bolster Electric Trucking. Trucks.com. https://www.trucks.com/2021/09/01/wattev-nfi-electric-trucks/

65. Meritor 14Xe Brochure. https://www.meritor.com/en/products/ePowertrains/14Xe

66. Hall, Vicki. February 15, 2022. Meeting the Divergent Battery Demands of your Medium-Duty Fleet. WorkTruck webinar. https://www.worktruckonline.com/webinars/meeting-the-divergent-battery-demands-of-your-medium-duty-fleet

67. Kelly, John. 2021. EV and Hybrid Training Shop Tour. Weber State. https://weber.edu/evtraining and https://www.youtube.com/watch?v=vHMuwzBM-4A

68. Wiha website https://www.wihatools.com/

69. EL-50332. GM Special Service Tools. https://gmtoolsandequipment.com/en-US/Pages/ItemDetail.aspx?SKU=EL-50332

70. Truckload, LTL, and Tank Verticals - Q2 2021. *TMC/FleetNet Vertical Benchmarking Executive Summary*. https://benchmarkit.fleetnetamerica.com/

71. Freight Analysis Framework (FAF). U.S. Department of Transportation (DOT) Bureau of Transportation Statistics (BTS). https://www.bts.gov/faf

72. Freight Analysis Framework (FAF) application. https://faf.ornl.gov/faf5/dtt_total.aspx

73.SCTG Commodity Codes. 2017 Commodity Flow Survey Standard Classifications of Transported Goods (SCTG). U.S. Department of Commerce, U.S. Census Bureau.

74. U.S. No 2 Diesel Ultra Low Sulfur Less Than 15ppm All Sales/Deliveries by Prime Supplier. U.S. Department of Energy (DOE) Energy Information Administration (EIA). https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=C720000001&f=M

75. Today in Energy. U.S. Department of Energy (DOE) Energy Information Administration (EIA). www.eia.gov/todayinenergy/detail.php?id=7170

76. Lockie, Alex. March 3, 2022. The ‘Amazon effect’ take two: Is long haul trucking fading away? Overdrive Magazine. https://www.overdriveonline.com/business/article/15288584/is-longhaul-fading-away-the-amazon-effect-on-trucking

77. Dills, Tom. January 2, 2019.Freight’s drift toward greater regionalization: Average length of haul on the spot market. Overdrive Magazine. https://www.overdriveonline.com/electronic-logging-devices/article/14895604/freights-drift-toward-greater-regionalization-average-length-of-haul-on-the-spot-market

78. Mihelic, Rick. January 2022. NACFE Run on Less Electric Presentation to 21st Century Truck Program. North American Council for Freight Efficiency.

79. Roeth, Mike. March 8, 2022. Technology & Maintenance Council (TMC) S.11 Battery Electric Vehicle Spec'ing presentation. North American Council for Freight Efficiency (NACFE).

80. Saxton, Mike. December 16, 2020. Get Paid vis California LCFS with No Out-of-Pocket Cost. CALSTART Presentation. SREC Trade.

81. LCFS Basics. California Air Resources Board (CARB). https://ww2.arb.ca.gov/resources/documents/lcfs-basics

82. Clean Transportation Program. California Energy Commission. https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-funding-areas-0

83. Federal Funding Program. U.S. Department of Transportation. https://www.transportation.gov/rural/ev/toolkit/ev-infrastructure-funding-and-financing/federal-funding-programs

84. Buysee, Claire. March 14, 2022. *How much does an electric semi-trailer really cost?* ICCT. *https://theicct.org/cost-electric-semi-feb22/*. And republished in EV News. https://thedriven-io.cdn.ampproject.org/c/s/thedriven.io/2022/03/14/how-much-does-an-electric-semi-trailer-really-cost/amp/

85. Mao, Shiyue. Hussein Basma, Pierre-Louis Ragon, Yuanrong Zhou, Felipe Rodriguez. November 2021. *Total Cost of Ownership for Heavy Trucks in China: Battery Electric, Fuel Cell Electric, and Diesel Trucks*. International Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/ze-hdvs-china-tco-EN-nov21.pdf

86. Randall, Tom. John Lippert. November 27, 2017. Bloomberg News. Tesla's Newest Promises Break the Laws of Batteries. https://www.bloomberg.com/news/articles/2017-11-24/tesla-s-newest-promises-break-the-laws-of-batteries

87. 2022 Tesla Model S AWD Features and Specs. Car and Driver. https://www.caranddriver.com/tesla/model-s/specs

88. Terreri, Mike. March 2022. *Yes, EVs (and Chargers) Need Maintenance, Too*. Presentation at NTEA Work Truck Week 2022.

89. Avista Corp. October 2019. Electric Vehicle Supply Equipment Pilot Final Report. https://smartenergycc.org/wp-content/uploads/2019/10/Avista-EVSE-Pilot-Project-Review.pdf

90. Mihelic, Rick. Mike Roeth, Brian Ballschmidt, Jessie Lund. October 2018. Medium-Duty Electric Trucks Cost of Ownership. North American Council for Freight Efficiency (NACFE). https://nacfe.org/emerging-technology/medium-duty-electric-trucks-cost-of-ownership/

91. Motley Fool. March 2022. Daimler Truck CEO Warns of EV's High Cost of Production. https://www.msn.com/en-us/money/companies/daimler-truck-ceo-warns-of-ev-s-high-cost-of-production/ar-AAVyrf9?ocid=mmx&PC=EMMX01

92. Wolfgang Bernhart. Dennis Gaullus. February 3, 2022. The Lithium-Ion (EV) battery market and supply chain. Part 1: Market drivers and emerging supply chain risks. Roland Berger. https://www.automotive-disruption-radar.com/the-lithium-ion-ev-battery-market-and-supply-chain/

93. Run on Less – Electric dashboard. https://results.runonless.com/

94. Mihelic, Rick. Dave Schaller, Jessie Lund, Yunsu Park, Jennifer Wheeler, Kevin Otto, James Brown, Mike Roeth. January 2021. Electric Trucks Have Arrived: Documenting A Real-World Trucking Demonstration. Run on Less Electric Report. North American Council for Freight Efficiency (NACFE). https://runonless.com/run-on-less-electric-report/

95. Wheeler, Jennifer. December 15, 2021. HD Regional Haul Tractors: Market Segment & Fleet Profile Fact Sheet. North American Council for Freight Efficiency (NACFE). https://nacfe.org/wp-content/uploads/2022/01/HD-Regional-Haul-RoL-E-Fact-Sheet.pdf

96. OpenWeatherMap website. https://openweathermap.org/

97. Clean Cities Coalition. U.S. Department of Energy (DOE). https://cleancities.energy.gov/

98. Mihelic, Rick. Mike Rowand, Robert Erspamer. March 2022. EV101 – The Basics, Getting Started with Electric Trucks. American Trucking Association (ATA) Technology and Maintenance Council (TMC) presentation. 2022 Spring Meeting. Orlando, Florida.

99. Smith, John. March 30, 2022. Canada commits to zero-emission truck sales targets and incentives. TruckNews. https://www.trucknews.com/equipment/canada-commits-to-zero-emission-truck-sales-targets-and-incentives/1003158200/

100. “2030 Emissions Reduction Plan.” Environment and Climate Change Canada. ISBN: 978-0-660-42686-0. https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

101. Coker, Ashley. March 29, 2022. “Zero-emission vehicle regulations on the rise, strong partnerships help fleets get ahead.” FreightWaves. https://www.freightwaves.com/news/zero-emission-vehicle-regulations-on-the-rise-strong-partnerships-help-fleets-get-ahead

102. “EPA Proposes Stronger Standards for Heavy-Duty Vehicles to Promote Clean Air, Protect Communities, and Support Transition to Zero-Emissions Future.” March 7, 2022. US Environmental Protection Agency (EPA). https://www.epa.gov/newsreleases/epa-proposes-stronger-standards-heavy-duty-vehicles-promote-clean-air-protect

103. “DOE Projects Zero Emissions Medium- and Heavy-Duty Electric Trucks Will Be Cheaper than Diesel-Powered Trucks by 2035.” March 7, 2022. US Department of Energy (DOE). https://www.energy.gov/articles/doe-projects-zero-emissions-medium-and-heavy-duty-electric-trucks-will-be-cheaper-diesel

104. Ledna, Catherine. Matteo Muratori, Arthur Yip, Paige Jadun, and Chris Hoehne. March 2022. “Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis.” US Department of Energy (DOE) National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy22osti/82081.pdf

105. Borlaug, B., Muratori, M., Gilleran, M. et al. Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems. Nat Energy 6, 673–682 (2021). https://doi.org/10.1038/s41560-021-00855-0.

106. Davis, Stacy. Robert Boundy. 2021. Transportation Energy Data Book. US Department of Energy (DOE) Oakridge National Laboratory (ORNL). https://tedb.ornl.gov/.

12 APPENDIX A – HD REGIONAL HAUL TRACTOR FACT SHEET

HD REGIONAL HAUL TRACTORS

Jennifer Wheeler, Senior Program Manager, NACFE

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Market Segment & Fleet Profile Fact Sheet

Operational Characteristics

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

Definition

Heavy-duty tractors have a gross vehicle weight rating (GVWR) of 80,000 lbs. and are able to pull a wide range of trailer types and sizes. The most common cab type in North America is the conventional, where the engine is in front of the steering wheel giving the truck a "nose." The cabover (cab over engine) design can still be found in older model tractors, although it is starting to make a comeback in some of the new heavy-duty electric vehicle (HDEV) prototypes. These tractors also come in day cabs or with sleeper cabs depending on the duty cycle requirement. Class 8 tractors can pull a wide variety of trailers, the most recognized being dry vans, refrigerated, and flatbed trailers and depending on the size of the fuel tanks, can drive up to 1,200 miles before refueling. While Class 8 heavy-duty trucks can haul up to 50,000 lbs., trailers also can cube-out (constrained by size) before they weigh-out (constrained by weight) e.g., hauling bulky items like TVs, patio furniture, kayaks, etc.

Diesel vs. Electric Comparison

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

Market Summary

There are several duty cycles for Class 8 tractors, like regional haul, drayage, beverage delivery, and long haul, with each one presenting its own unique challenges. Currently, there are an estimated 656,294 regional haul Class 8 tractors in the US and Canada. This estimate does not include vocational trucks, off-highway tractors, or long-haul tractors.

Run on Less – Electric highlighted four Class 8 tractors: the BYD 8TT operated by Anheuser-Busch to make beverage deliveries around Modesto, CA; the Freightliner eCascadia Penske is using to haul freight from Temecula, CA to San Diego, CA; the Peterbilt 579EV Biagi Brothers is running to shuttle loads between Napa, CA and Sonoma, CA; and the Volvo VNR NFI uses on routes between Chino, CA to the Port of Long Beach.

Collectively, the duty cycles and use cases for the Run on Less – Electric heavy-duty tractors are highly representative of return-to-base, single- shift operations within this market segment. Furthermore, the duty cycle of the beverage segment, represented by the BYD 8TT at Anheuser- Busch, is optimal for electric trucks, with the HDEVs capable of doing the same amount of work as their diesel counterparts.

The challenge with regional haul tractors is the opportunity for dynamic (unpredictable) routing, longer routes, more wait time, and drivers not returning to base each day. As this segment transitions into the long-haul end of the spectrum, these opportunities are amplified and make electrification dependent, at minimum, on regional charging infrastructure.

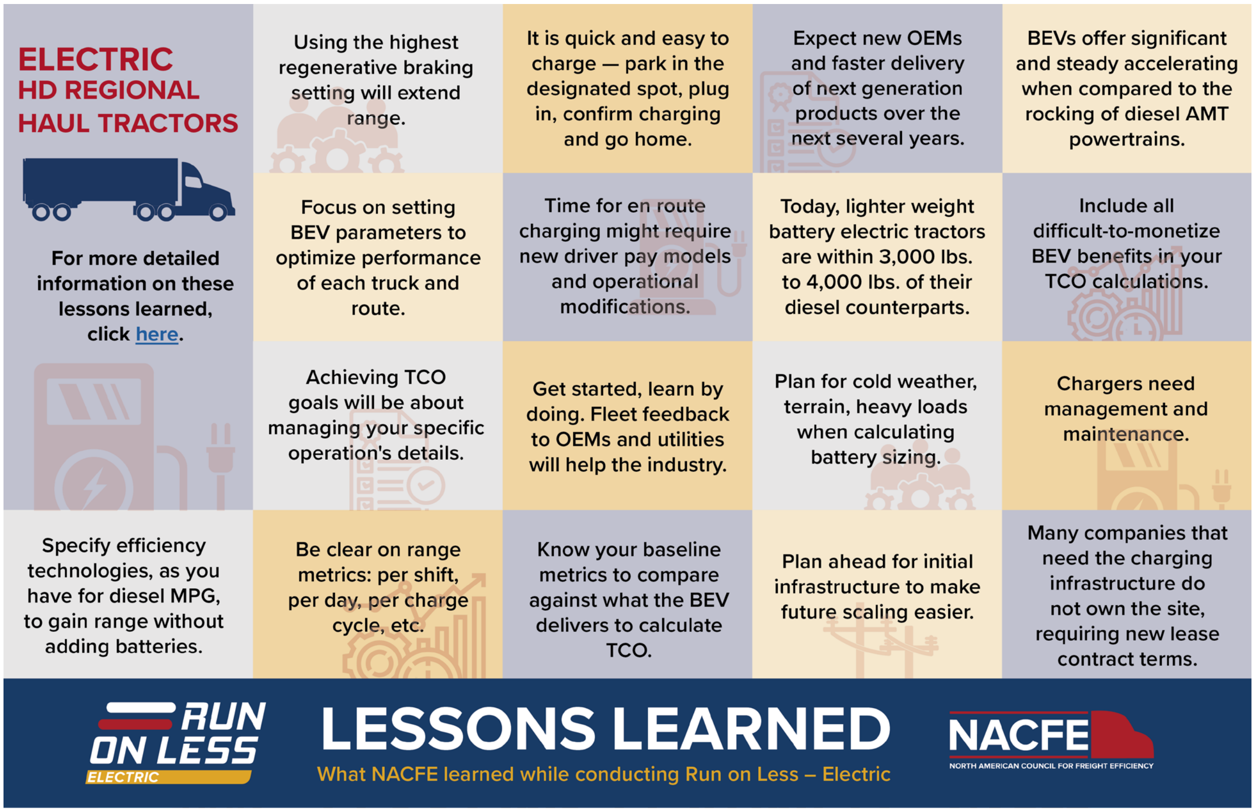
As a result, NACFE considers this segment to be 70% electrifiable.

12/15/21 HD Regional Haul Tractors: Market Segment & Fleet Profile Fact Sheet 1

Download the entire Fact Sheet below:

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

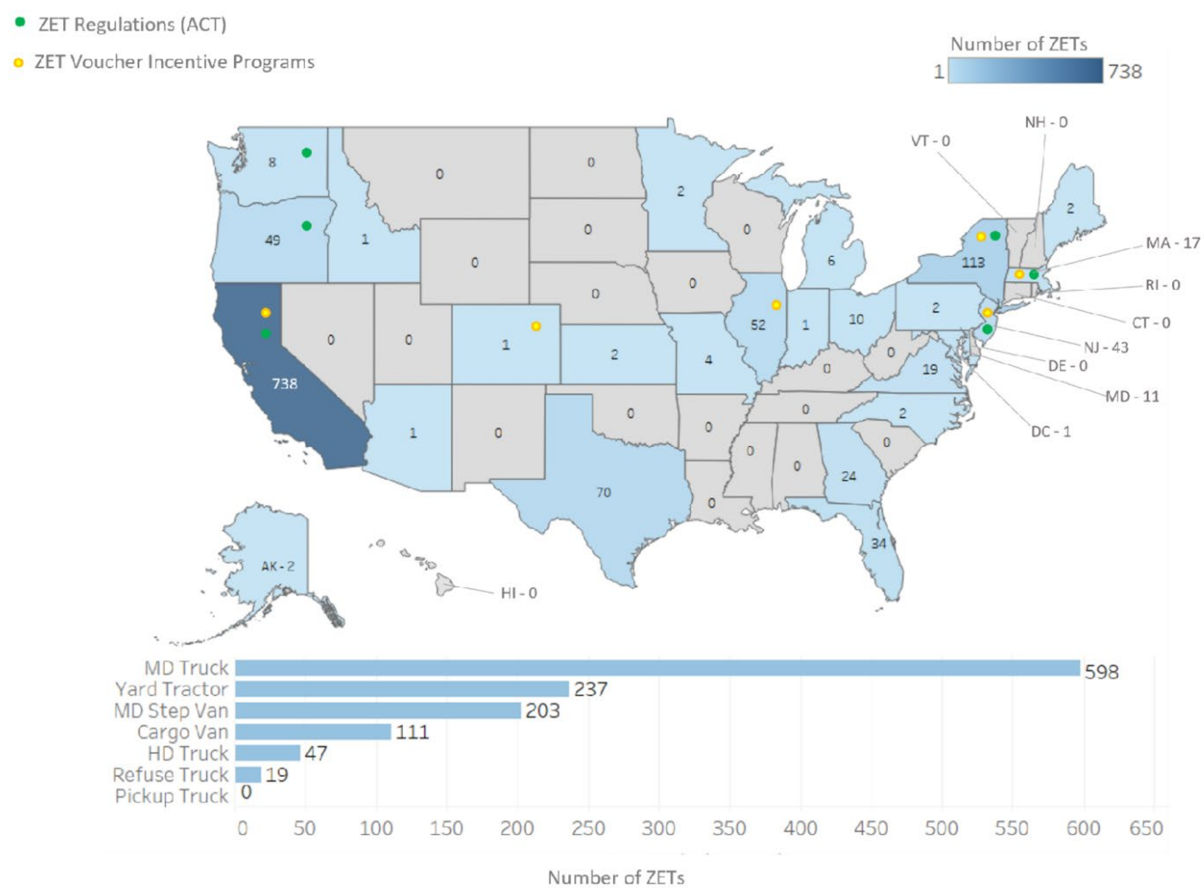
13 Appendix B – Lessons Learned



Download the Heavy-Duty Regional Haul 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-Emissio n 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.