OHIO

DriveOhio

The Future of Smart Mobility

FREIGHT ELECTRIFICATION

Last-Mile ▪ Medium-Duty ▪ Heavy-Duty

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DriveOhio

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List of Abbreviations

AADT	Annual Average Daily Traffic	L2	Level 2
AC	Alternating Current	MPG	Miles Per Gallon
AEP	American Electric Power	MPO	Metropolitan Planning Organization
AFDC	Alternative Fuels Data Center	MUD	Multi-Unit Dwelling
EV	Battery Electric Vehicle	NOACA	Northern Ohio Area Coordinating Agency
BMV	Bureau of Motor Vehicles	ODAS	Ohio Department of Administrative Services
Btu	British Thermal Unit	ODOT	Ohio Department of Transportation
CCS	Combined Charging System	ODPS	Ohio Department of Public Safety
CHAdeMO	CHArge de MOve	OEC	Ohio's Electric Cooperatives
CMAQ	Congestion Mitigation and Air Quality	OEM	Original Equipment Manufacturer
DC	Direct Current	OTIC	Ohio Turnpike Infrastructure Commission
DCFC	Direct Current Fast Charger	OTR	Over-The-Road (freight)
DGE	Diesel Gallon Equivalent	PHEV	Plug-In Hybrid Electric Vehicle
DP&L	Dayton Power & Light	PUCO	Public Utilities Commission of Ohio
EPA	Environmental Protection Agency	SAE	Society of Automotive Engineers
EV	Electric Vehicle	SR	State Route
EVSE	Electric Vehicle Supply Equipment	TCO	Total Cost of Ownership
FE	First Energy	TIMS	Transportation Information Mapping System
FHWA	Federal Highway Administration	US	United States
GGE	Gasoline Gallon Equivalent	USDOT	United States Department of Transportation
GIS	Geographic Information System	VMT	Vehicle Miles Traveled
H2	Hydrogen	VW	Volkswagen
ICE	Internal Combustion Engine	ZEV	Zero Emission Vehicle

1. Introduction

At 17%, manufacturing makes up the largest sector of Ohio's economy by gross domestic product. Its two largest export commodities are machinery and motor vehicles.[1] Ohio produces the most engines and second-most transmissions in North America – within one day's drive of 72% of the continent's auto assembly plants, and it has a robust end-to-end automotive supply chain.[2]

As the auto industry diversifies into alternative fuels, Ohio is focused on maintaining its position as a manufacturing leader. A review of critical supply chain minerals needed to produce the electric vehicle batteries is underway in Ohio and at the national level.[3]

This report builds on the *Electric Vehicle Charging Study* for passenger vehicle electrification, which the Ohio Department of Transportation (ODOT) published in June 2020, but with a focus on truck freight[4] to summarize the state of the last-mile, medium- and heavy-duty electric vehicle (EV) market, and identifies actions for Ohio stakeholders to help facilitate the transition to an EV future.

The following four categories comprise the discussion of freight EVs:

1. **Terminal and off-road**
2. **Last-mile delivery**
3. **Local freight and drayage**
4. **Regional and long-haul**

The following five categories comprise this report's recommended frameworks for stakeholder support:

1. Federal government
2. State government
3. Regional/local agencies
4. Private shippers, carriers and third-party logistics providers
5. Utility companies

Two-thirds of freight traffic in Ohio moves by truck.[5] Ohio is fourth in Interstate miles, second in intermodal facilities and fifth in warehousing in the United States.[6] Many Ohio fleets currently have electric yard or terminal vehicles and expect to deploy medium- or heavy-duty freight vehicles in the next few years.

Almost all ODOT funding comes from the motor fuel tax, with 25% of this generally coming from the purchase of diesel fuel – primarily used for freight. Traffic volumes in 2020 were down 15.5% compared with 2019, with a peak decrease of 50% in April 2020, resulting in a revenue shortfall.[7] In contrast, truck traffic rebounded by June and exceeded 2019 numbers, as U.S. e-commerce increased 33% with a shift toward direct-to-consumer brands.[8] Most analysts believe the shift to online shopping will continue after the COVID-19 pandemic.[9]

1.1. Possible Futures

There are several possible scenarios when planning for a lower carbon freight future, including:

1. ***Mixed Fuels Bridging Scenario:*** *Through the foreseeable planning horizon, over-the-road freight will remain a mixture of slowly evolving lower to net zero technologies, including EVs, renewable natural gas (RNG), renewable diesel and biodiesel, plug-in hybrids (PHEV), and other efficiency technologies and processes.* Note: This is plausible if federal and state governments are unable to agree on policy directives or market factors shift to favor other decarbonization options.
2. ***EV + FCEV Scenario:*** *By 2035 a significant portion of trucks will transition to EVs for short range operations such as drayage, terminal, last-mile, and regional logistics. Longer haul operations at the regional and interstate level will be more frequently powered by hydrogen fuel cell electric vehicles (FCEV).*
3. ***EV Scenario:*** *Technology advances allow for trucks, including some of the more challenging long-haul vehicles, to convert to EV by 2035. Short range EV operations such as drayage, terminal, last-mile, and regional logistics are likely to make up over a third of the market by 2035 in this scenario.*[10]

This report focuses on the EV scenario, as this is where most of the private investment and public policy focus is currently. Ohio has an opportunity to help lead the shift to this 21st century transportation economy.

1.2. Electric Vehicle Momentum

China has heavily invested in the EV industry with the goal of transitioning to all-electric or hybrid cars by 2035.[11] Europe saw significant policy changes in 2020,[12] which resulted in a +260% year over year growth in electric vehicle purchasing and a market share of 20%, on the passenger vehicles side.[13] In the U.S., General Motors just committed to spending $35 billion on electric and autonomous vehicles through 2025[14] and Ford increased electric vehicle spending to over $30 billion by 2030.[15] Favorable policies, continued advances in powertrain and battery technology, expanding electric vehicle availability, longer driving ranges, faster charge times, lower costs, and superior performance will continue to accelerate market adoption.

These and other dynamics are driving substantial changes in the OTR freight sector, where medium and heavy-duty trucks account for 5% of the road fleet, yet 20% of the greenhouse gas emissions.[16] The speed of this fleet transition will vary by vehicle type.

2. Freight Electrification Projections

The commercial freight consumers have a different set of constraints than passenger vehicle consumers when deciding which type of vehicle to purchase. Performance and range requirements are more critical factors, especially given that the typical semi averages 63,000 miles per year[17] compared with 13,476[18] for a passenger vehicle.

2.1. Truck Volumes

Most freight growth in Ohio is expected to be in trucking. Truck traffic on Interstates and major U.S. and state routes is forecast to increase approximately 34 percent by 2035.[19] Trucked tonnage is projected to be evenly split between Ohio-based and through trips.[20] Nationally, trucks (as opposed to railroads, airplanes, and ships) move 64% of tonnage and 69% of value. Continued growth is expected.[21]

2.2. The Transition to Freight EVs

Based on projections, it is likely that battery electric vehicles (EVs) will supplant internal combustion engine (ICE) vehicles in short-range, regional, and fixed-route applications as EVs will have an increasing advantage in Total Cost of Ownership (TCO). However, even freight use cases with TCO parity today will likely not be fully electrified before 2030 without aggressively addressing barriers on a national scale. Availability of reliable charging infrastructure, for example, is key to the success of EV deployments. Freight operations with daily returns to a home base with charging infrastructure under their control will have the greatest success.

As demand for home delivery rises and electric van production ramps up, Last Mile Delivery vehicles are expected to be the first to electrify, as soon as 2022. Midrange battery electric trucks are expected to find cost parity with diesel powered Medium Duty freight vehicles by 2025. In anticipation of this, manufacturers are racing to provide best of kind technology to scale production (see **Figure 1**).

Class 7 and 8 freight vehicles will likely experience a delayed transition due to high costs for EV chargers and lack of long range vehicle options. With current cost projections, HD EVs aren't expected to capture significant market share before 2025 and are anticipated to achieve near cost parity around 2030.

Table 1: Total Cost of Ownership by Vehicle Type

	Light-Duty	Medium-Duty	Heavy-Duty
Charging Configuration Description			
Charger Type and Usage	• L2 • 1-2 cycles per day	• Average of L2 and DCFC (50-150 kW) • 2-4 cycles per day	• DCFC (350 kW - 1 MW) • 10 cycles per day
Vehicles Supported	Mostly Class 2b delivery vans	All commercial classes	Mostly Class 7-8
Cost per Charger			
Chargers	\$8,645 - \$8,797	\$30,790 - \$91,490	\$154,000 - \$439,460
Make-Ready	\$10,520 - \$12,250	\$13,340 - \$28,490	\$53,320 - \$491,800
Annual O&M	\$3,010 - \$7,400	\$10,760 - \$55,130	\$52,120 - \$169,350

	Light-Duty	Medium-Duty	Heavy-Duty
Total Ownership Cost (per Mile) Vehicle and Chargers			
Electric	$0.67 -$0.82	$0.80 - $1.12	$0.77 - $0.93
Gas/Diesel	$0.62 - $0.68	$0.61 - $0.77	$0.76 - $0.83
Projected EV/ICE Cost Parity	2022	2025	2030

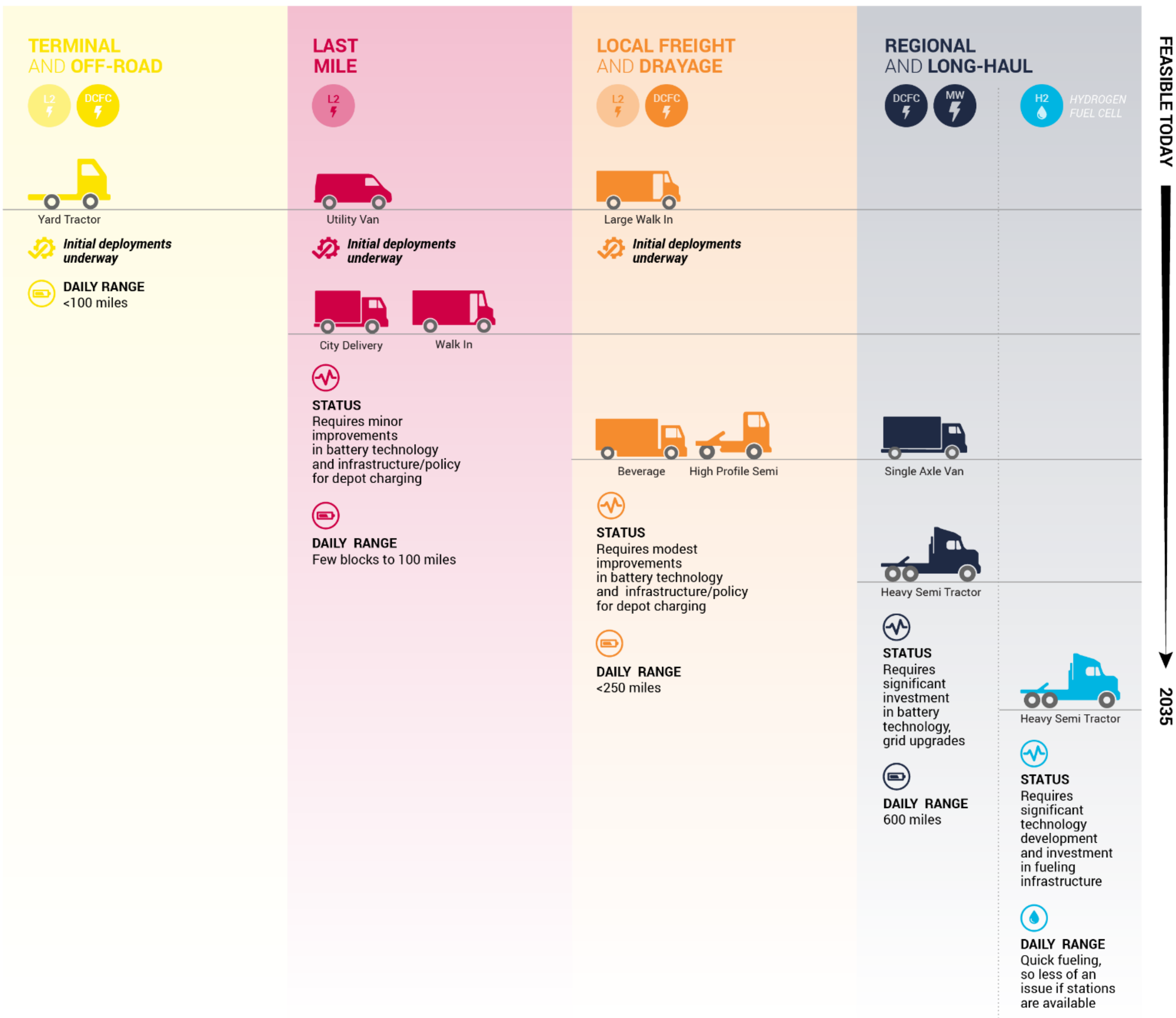


Figure 1: Timeline of Use Cases

2.2.1. Model Availability

As battery and charging technology improves, more use cases will become viable, which will encourage development in adjacent market segments. CALSTART's ZETI tool, used for **Figure 2**, tracks the number of announced truck models in the U.S. and Canada and shows significant growth over the next few years.

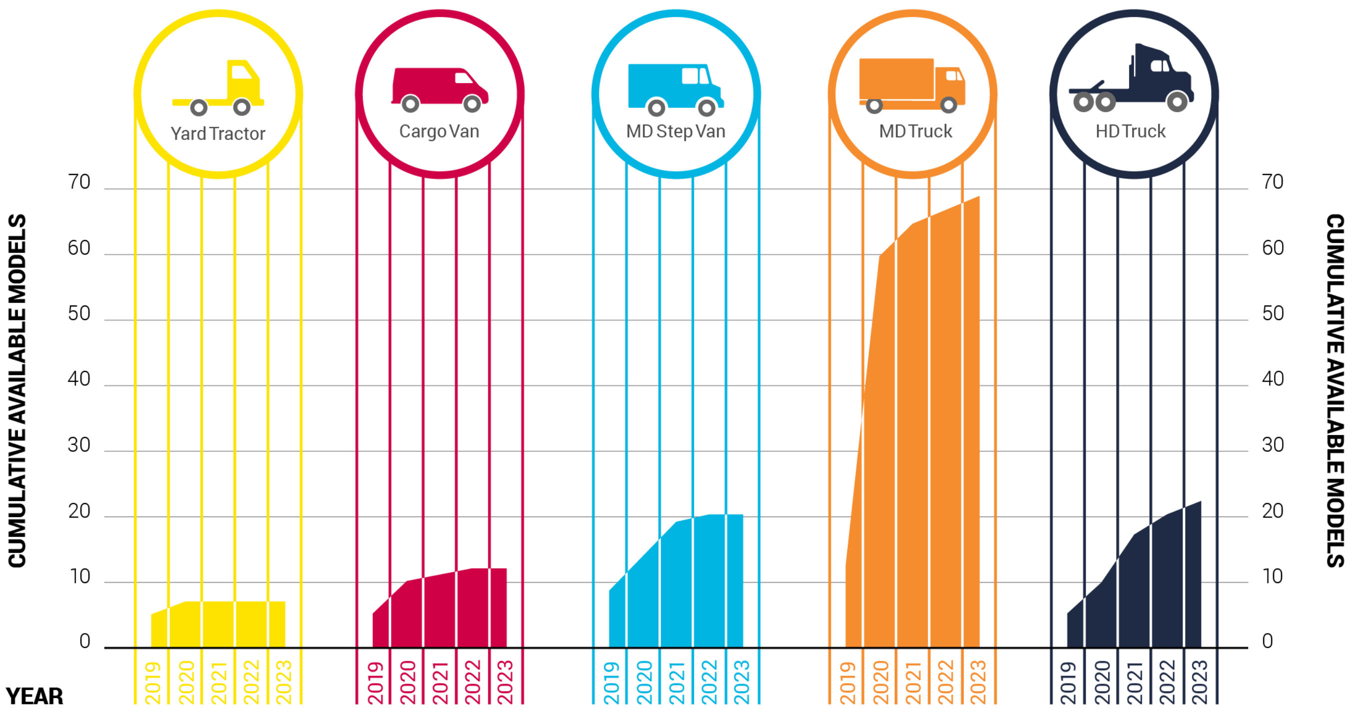


Figure 2: Total Cumulative EV Models by Type and Year[22]

2.2.2. Market Prediction

Table 2 summarizes some recent industry projections indicating that the EV market will double by 2033 as the number of available EVs increases. The industry will also become more distributed.[23]

Table 2: Predictions on Prevalence of EVs

	2025	2030	2045 and beyond
CA Staff Report Bill 2127	-	• 180,000 MD & HD ZEVs • 157,000 DCFCs • 16,000 > 350kW	-
McKinsey Institute	-	• <5% HD vehicles • 15% MD vehicles	-

	2025	2030	2045 and beyond
NACFE Guidance Report on Electric Trucks	• Class 3-6 Tare Weight Parity	• Class 3-6 Max Daily Range Parity • Class 7-8 Tare Weight and Max Daily Range Parity	• Mixed fleets the norm through 2050
SARTA BUILD Market Demand for Fuel Cell Veh.	• 0.05%-0.01%	• 0.01%- 0.25%	• 30%- 35% (2050)

The long-haul freight segment is challenged by the need to supply sufficient power to drive up hills at speed without sacrificing range, general range concerns, and the availability of uniform, reliable sufficiently fast chargers.

2.3. Estimated Taxes

State and federal motor fuel tax make up most of the total annual revenue generated for ODOT. Diesel fuel tax generally accounts for 25% of this, although during the COVID-19 pandemic this has trended a few percentage points higher.

2.3.1. Tax Impacts of Commercial Vehicle Electrification

States will experience tax implications as fleet operators begin replacing ICE vehicles with newer EVs. To estimate tax implications in Ohio, market maturity and model availability was examined for Last Mile Delivery (Class 2 commercial), Medium Duty (Classes 3-6), and Heavy Duty (Classes 7-8) vehicle class categories.

To determine the number of fleet EVs in the future a model was developed that assumes new vehicle market share for EVs will apply to total industry growth rates and current replacement rates over time as conventional freight vehicles retire.

Given current estimates for EV purchase rates and the starting inventory of vehicles for each class, **Table 3** shows estimated numbers and market share for the EVs for each vehicle category by 2035. **Figure 3** shows the resulting growth rates to the 2035 EV counts and the percent change in tax revenue in the commercial vehicle segment, which surpasses 13% in 2035.

Table 3: EV Adoption Projections for 2035

	Last Mile **(Class 2b)**	Medium Duty **(Class 3-6)**	Heavy Duty **(Class 7-8)**
Total EVs	83,575	70,070	9,879
% of Vehicles on-Road	36%	33%	7%

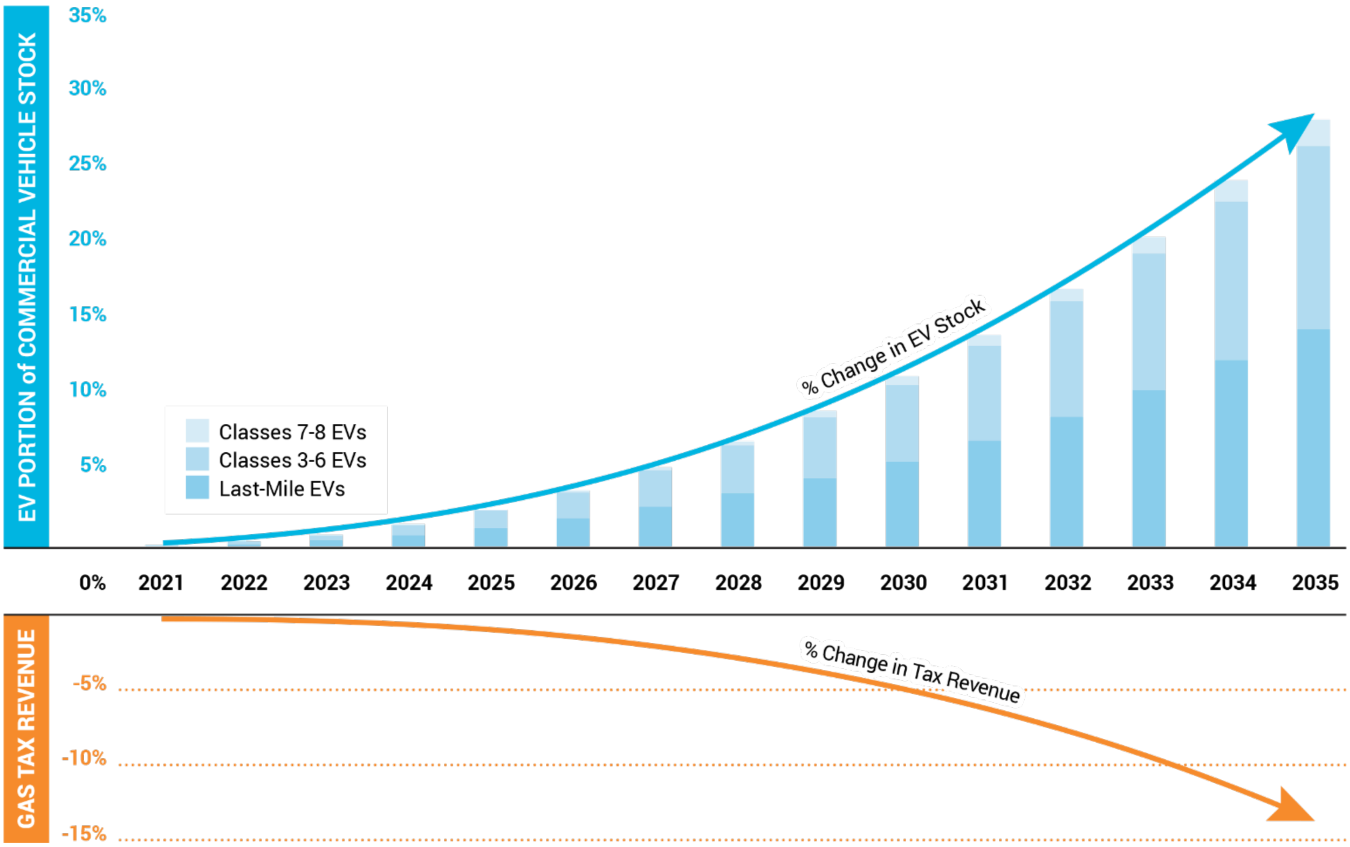


Figure 3: Revenue Loss Related to Electric Fleet Vehicle Stock

2.3.2. Current State of Taxation

Ohio has implemented a fuel tax structure adjusted on a BTU-based rate for alternative fuels including CNG, diesel, and biofuel. Currently, no fuel consumption tax has been developed for electric vehicle charging in Ohio. Ohio has opted for a registration fee of $200 per year for EV vehicles and $100 per year for plug-in hybrids to compensate for revenues lost from vehicle electrification. Based on current fuel taxes and commercial vehicle registration fees, the electrification of Classes 2b-8 vehicles is projected to result in a 13% drop in Ohio's commercial vehicle tax revenue – $103 million per year by 2035. This equates to an average per-vehicle annual tax revenue of $800 for medium-duty vehicles and $5,000 for heavy-duty vehicles.

One option is to apply a fuel consumption tax on electricity. This would present new challenges. Pennsylvania is the first International Fuel Tax Association (IFTA) jurisdiction to implement a motor fuel tax for electricity to power vehicles. The current Pennsylvania tax is set at 1.72 cents per kWh. This rate was determined by normalizing the tax rate for alternative fuels to reflect a taxation based on energy content of gasoline.

Freight electrification comes with several tax concerns that need to be addressed including unfamiliarity of vehicle owners with the new taxes (compliance), the need to determine equitable tax rates and vehicle registration fees, and IFTA ramifications among others. Vehicle electrification also has implications on the federal fuel tax revenues and possibly ODOT revenues from federal taxation that will also need to be addressed.

2.3.3. Revenue Recovery Mechanisms

There are several approaches to addressing the tax implications of fleet and commercial vehicle electrification. **Table 4** outlines the fees that would be needed to offset the state fuel taxes by vehicle class, where appropriate, or by unit of fuel (kWh). Also, listed are brief pros and cons to utilizing each revenue recovery method.

- The motor vehicle registration fee is calculated by vehicle class using average miles traveled, fuel economy and the applicable tax rate.
- The motor fuel tax shows the kWh equivalent of the current Ohio state gasoline tax rate based on the gasoline gallon equivalent (gge) energy.
- The vehicle mile traveled fee would recoup the state tax revenue lost due to electrification based on average miles traveled.

Table 4: Potential Revenue Recovery Methods for Offsetting Lost Gas Tax Revenue

Revenue Recovery Method	Equivalent Fee	Pros	Cons
Motor Vehicle Registration Fee (per vehicle per year)	• Class 2b: $250 • Class 3-6: $800 • Class 7-8: $5,000	• Reliable means of collection	• Not directly related to driver usage • Vehicles traveling from other states will not pay registration fees
Motor Fuel Tax (gasoline gallon equivalent)	• $0.0115 per kWh • Pennsylvania, first IFTA jurisdiction to implement a motor fuel tax on the electricity that powers vehicles, set tax at $0.0172 per kWh	• BTU rate-based method consistent with other alternative fuels	• Requires new method of revenue grade metering for vehicle charging • Requires new IFTA standards for HD vehicles
Vehicle Mile Traveled Fee (per mile)	• Class 2b: $0.022 • Class 3-6: $0.064 • Class 7-8: $0.078	• Accurate tax based on usage	• Requires new methods for measuring VMT

These recovery mechanisms could be used in conjunction with one another to provide a holistic approach to vehicle taxation based on vehicle class, use, and the IFTA implications of their use.

3. Current Freight Conditions

This section defines which freight vehicles are addressed in this study, provides an overview of the current common fueling types and the current state of the market, discusses factors affecting fleets decisions to electrify, and summarizes Ohio's transportation, logistics and utility assets.

3.1. Definitions

3.1.1. Vehicle Types and Use Cases

Freight needs vary depending on what the vehicles are being used for (i.e. use case), as summarized in **Table 5**. Shorter trips are usually correlated with smaller trucks.

Table 5: Trucking Segments and Typical Distances

Type of Trucking	Driver Experience	Daily Range Required
Terminal/Off-Road Vehicles: Terminal tractors, also called yard spotters or yard tractors, are used primarily in off-road, low-speed (under 25 mph) operations. They rarely, if ever, leave home base. These tractors are used to move cargo containers around a terminal, port, warehouse to facilitate transfer of cargo as it enters and exits. Diesel units are long-lived and often heavy polluters due to their age. They also sit and idle most of the time.	• Long distance trucking following a drayage shipment • Each mode of transport has its own carrier and contract	<100 miles
Last Mile: Deliveries, usually beyond a mile, but within an urban region or close by. These vehicles may be small, sometimes even light-duty, but typically Class 2 to 7 vans and trucks. Routes can vary, but include fixed, back-and-forth between a terminal or warehouse and another single location. More typically, these routes include multiple stops as a vehicle makes deliveries to several locations. Increasingly, as online, on-demand retail grows, more vehicles within this subsector deliver directly to people's homes. Drive cycles are low to moderate speed, with frequent stops and starts. Vehicles may return to base once or a few times per day. Some operate nearly constantly over a single shift or two shifts within 24 hours.	• Last leg of any delivery process • No set route (i.e. DHL, UPS, Amazon, FedEx, JB Hunt)	Few blocks to 100 miles
Local Freight: Goods movement between two fixed points, each workday, and sometimes multiple shifts per day. It encompasses a broad range of vehicles, generally Classes 6 to 8. These vehicles serve a variety of transportation needs, including manufacturing supply chain logistics, finished products and package transportation. Travel distances range from just a few miles to a maximum of 400 to 500 miles.	• Same route(s) every day • Driver returns to home base every night	10-500 miles

Drayage: On-road, heavy duty trucks that transport containers and bulk to and from the ports and intermodal railyards as well as to many other locations.	• Short distance trucking as part of a long-distance shipment • Run in the same metro area or close region • 1 driver shift	<250 miles [24]
Regional/Multi State: Class 8 vehicles. Regional trips are above 500 miles but within 1,000 miles of home base operations.	• Regular set of routes • Driver away for multiple days	250-400 miles
Long-Haul: Routes are typically above 1,000 miles up to intercontinental. Long-haul routes may be fixed or variable, depending on needs of shipping clients and drivers' situation.	• Different route every time • Utilize driver switching. • Home every 2-3 weeks.	~600 miles

For purposes of freight electrification, these six general use cases will be discussed in four categories as shown in **Figure 1.** The Federal Highway Administration (FHWA) uses eight categories to classify vehicles based on their Gross Vehicle Weight Rating (GVWR). Medium-duty (MD) typically refers to Classes 3-6, and heavy-duty (HD) refers to Classes 7-8.[25]

For purposes of this study, Class 2 is also included in the discussion and recommendations sections, as many last-mile deliveries are being completed using step vans. **Figure 5** illustrates the vehicles that most often fit into these categories (i.e. last mile, local freight) listed within the specified class. There can be exceptions, depending on vehicle availability, but for simplicity the chart is meant to cover most trips, but not every trip. The intersection of weight class and use case affects the rate at which electrification can happen, as more battery power is needed to move heavier vehicles.

3.1.2. Truckload Typologies

The weight and volume of the truck load is a factor in the complexity of the shipment. The three most common types of truckload are:

- **Partial Truckload** – blends the benefits of the TL, FTL and LTL options – the speed and minimal transfers of TL with the lower cost of LTL. It is primarily for medium sized loads and typically involves booking by volume. The cost is lower than TL because the shipper shares the trailer volume with other shippers and does not pay for empty space.
- **Less than Truckload (LTL)** – smaller volumes of freight that do not require the entire volume of the trailer. LTL is the most common type of freight shipping. This method is used when shippers need reduced costs, freight tracking, specialized delivery, and increased freight security. Most LTL shipments are packaged onto pallets and sometimes un-packed and re-packed at distribution centers often three or more times over the course of a shipment.[26] LTL is typically the least expensive way to ship.
- **Truckload (TL) or Full Truckload (FTL)** – shipments occupy half or more of the capacity of a trailer (typically a 48- to 53-foot trailer and sometimes a shorter box truck). Truckloads are picked up at the origin and delivered directly to the destination. This method is used when shippers need faster shipping times, less chance of damage due to transfers because shipments travel by means of one truck only, or where the full trailer is a value proposition compared to other options. Truckload is typically the most expensive option.

Figure 4[27] below shows the inside of a PITT OHIO warehouse in Parma, Ohio, where packages are sorted and processed. This facility conducts both Less than TL and FTL operations. The electric forklifts used to sort these loads can be seen in the bottom left. Cargo is loaded from incoming trucks, sorted and processed in this facility and then loaded onto outgoing trucks for delivery to customers. Highly reliable equipment and trucks are necessary to keep goods moving on schedule.

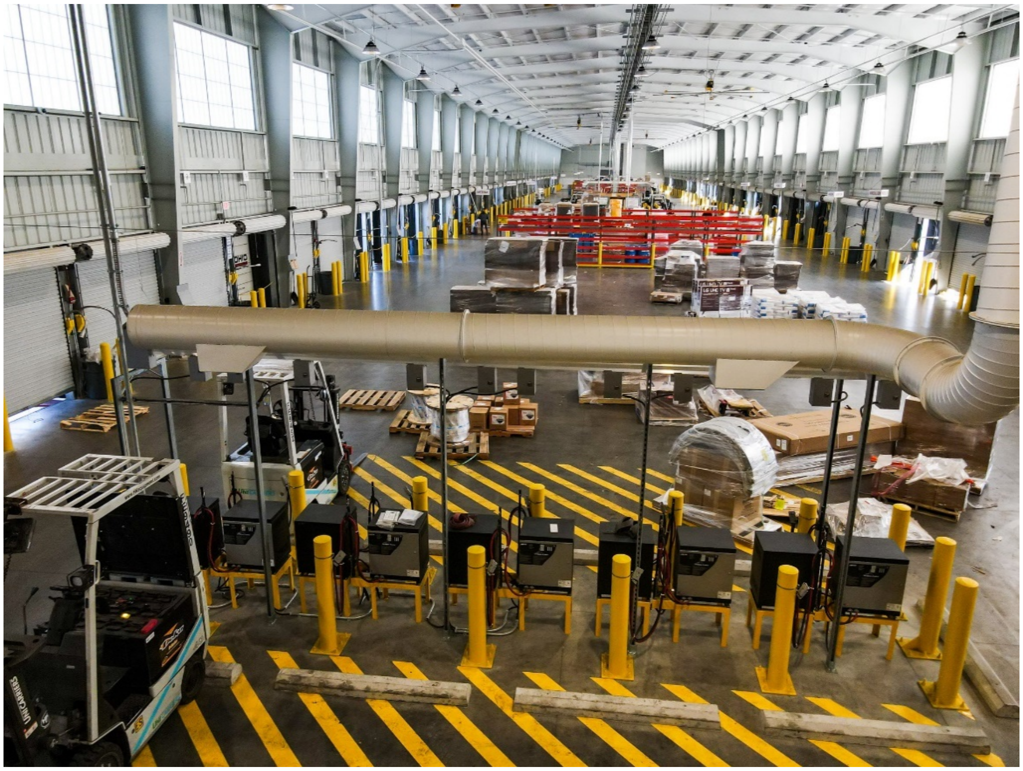


Figure 4: Warehouse Operations in Ohio

While electric trucks are being loaded and unloaded there is an opportunity to refuel them. Loading times and the availability of fast charging need to be analyzed to determine which Battery Electric Vehicle (EV) truck routes can currently match diesel vehicles in travel and refueling time. This is critical as shipping is time sensitive, where more time means higher cost. LTL shipping is well-suited to EVs because the travel distances are typically shorter and EVs with a 300-500-mile range can likely make the full journey without stopping to charge.

TL and partial truckload shipping are more challenging because trucks typically drive longer distances with limited stops and would likely require mid-journey charging. Future vehicles with ranges of 1,000 miles and a network of reliable and dependable fast chargers will need to be commonly available for TL and partial truckload to fully convert to electrification.

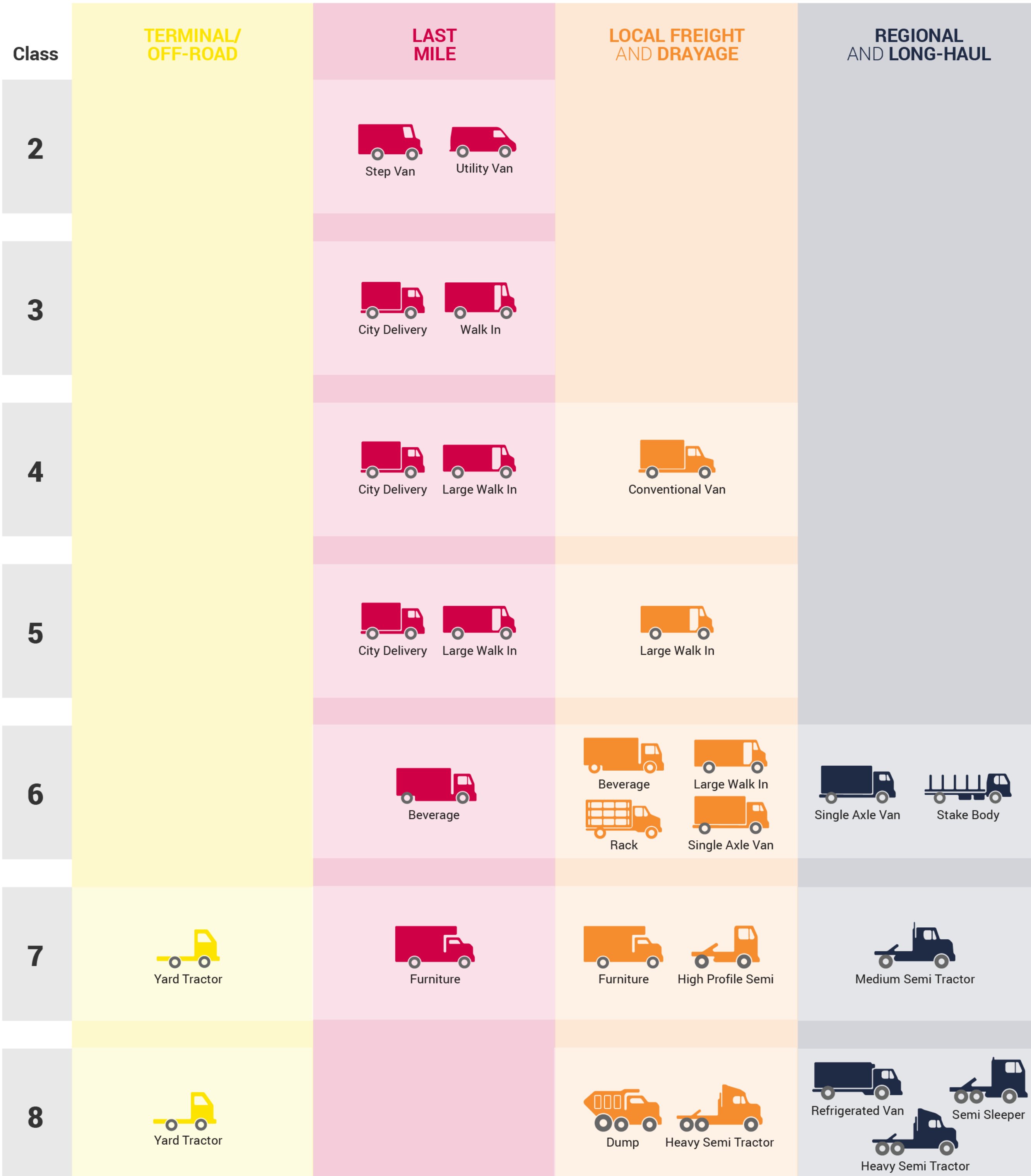


Figure 5: Vehicles Included in this Study

3.2. Fuels

This section reviews key characteristics of fuels in use today. **Table 6** compares various fuel types by specific energy, tailpipe emission, relative cost, and the number of fueling stations in Ohio and across the U.S. Energy density is the measurement of the amount of energy stored in a given unit of mass. The higher the specific energy of the fuel, the more energy that can be stored in a unit of mass.

The overall environmental benefits of EV technology depend on the energy mix used to generate the power that charges the vehicles. EVs emit less than a third of carbon emissions as those from petroleum powered vehicles.[28] EVs also emit no tailpipe emissions. So even in the case of EVs charged from carbon-intensive electricity generation, the associated pollution is more concentrated and thus easier to mitigate, as emissions from a handful of power plants are more easily addressed than hundreds of thousands of vehicles.

Table 6: Fuel Type Comparison

Fuel	Specific Energy[29 30 31]	Tailpipe CO_2 Emissions	Relative Cost[32 33 34]	Ohio Fueling Stations[35 36]	U.S. Fueling Stations[37]
Diesel	42-46 MJ/kg	22.40 lb/gal	$2.40/gal	2,680	63,250 (estimated)
Biodiesel (B20)	39-41 MJ/kg	20.83 lb/gal	$2.29/gal	3 public, 7 private	299 public, 361 private
Renewable Diesel	~44 MJ/kg	21.50 lb/gal	$3.73/gal	0	<10
CNG	42-55 MJ/kg	0.12 lb/cf	$2.18/gge	39 public, 15 private	865 public, 680 private
LNG	54-56 MJ/kg	9.83 lb/gal	$2.72/dge	1 public, 2 private	55 public, 46 private
LPG/ Propane	46-51 MJ/kg	12.52 lb/gal	$2.73/gal*	66 public, 9 private	2,707 public, 277 private
Hydrogen	120-142 MJ/kg	0	$13.70/gge	0 public, 2 private	48 public, 18 private

MJ: megajoules per kilogram, gge: gasoline gallon equivalent, dge: diesel gallon equivalent

** Propane prices reflect the weighted average of "primary" and "secondary" stations. Primary stations have dedicated vehicle services and tend to be less expensive. Secondary stations are priced for the tanks and bottles market and tend to be more expensive.*

3.2.1. Today's Dominant Fuel: Petroleum Diesel

Petroleum diesel has grown with the trucking industry for over 100 years and is today's dominant freight fuel. It won out over other forms of petroleum because it provided the torque necessary to move heavily loaded trucks. The global petroleum industry provides it through an extensive national network of fueling stations.

Fuel economy for newer diesel trucks is generally in the range of 6-7 MPG. Eco-conscious drivers in ideal conditions can reach as high as 12.5 MPG.[38] And while gas mileage has improved, primarily as a result of the 2011 U.S. EPA and NHTSA *Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*, diesel engines are approaching their theoretical efficiency limit.[39, 40] Recently, the addition of trailer skirts and reduced rolling resistance tires have increased truck fuel efficiency while necessary pollution controlling equipment has decreased it.

Petroleum diesel generates about 22 pounds of CO_2 for every gallon burned (for gasoline it is 20 pounds).[41] For this reason, many governments around the world have taken steps to reduce dependence on petroleum diesel and gasoline – leading manufacturers and end users to explore alternatives.

3.2.2. Today's Alternative Fuels

The following alternative fuels allow vehicle owners to reduce their carbon footprint at a relatively low cost. These fuels do not eliminate emissions but generate fewer than petroleum diesel. They include:

- **Biodiesel** is a fuel derived from vegetable oils and/or animal fats generated as waste products at restaurants. Although burning it releases less carbon dioxide,[42] it is more expensive and much less commonly available than standard diesel. Biodiesel meets ASTM D6751 and is approved for blending with petroleum diesel. It is readily available in Ohio and is priced comparably to petroleum diesel.
- **Renewable diesel** is derived from biomass and is sold primarily in California to leverage Low Carbon Fuel Standard incentives as part of that state's climate change combatting measures. It has the benefit of being compatible with existing diesel engines and fueling infrastructure and meets the ASTM D975 specification for petroleum sales in the U.S. It has significant CO2 reduction benefits, compared to diesel, when considering well-to-wheel lifecycle emissions from the production of the fuel. While produced at five plants nationally, it is not currently available in Ohio.[43]
- **Compressed Natural Gas (CNG)** store fuel in tanks where it remains in a gaseous state. CNG is used in more than 175,000 vehicles in the United States. It's used for many buses and some trucks. It's lighter than air, so during a spill it disperses quickly.[44] The CO_2 emissions reductions of CNG compared to diesel can be 20-30% when well-to-wheels lifecycle emissions are considered.
- **Liquified Natural Gas (LNG)** is more expensive but has a greater energy density than CNG and is better suited for Class 7 and Class 8 vehicles.[45] The emissions savings from LNG are similar to CNG.

  CNG and LNG work similarly to petroleum diesel in terms of operation and fueling but require specific fueling stations and purpose-built engines designed to accommodate the fuel. Their distribution networks have grown across the U.S., including in Ohio.
- **Liquified Petroleum Gas (LPG)** or "propane" contains about 27% less energy than gasoline but has a higher octane rating that can result in improved performance and better fuel economy. It is stored in tanks under pressure as a liquid and vaporizes into a gas for the combustion cycle. Propane is produced as a by-product of natural gas processing and crude oil refining.
- **Hybrid** drivetrains are starting to become available in Class 8 tractors and can provide temporary zero-emissions operations in environmentally sensitive areas without sacrificing range or power.

3.2.3. State-of-the-Art Alternative Fuels

- **Fuel Cell Electric Vehicles (FCEVs)** depend on hydrogen for fuel and are zero-emission, as they only emit water from their tailpipes. For even lower carbon intensity, renewable hydrogen, made from methane from dairy cows, can be used. Their fueling process is similar to diesel, but infrastructure is very limited and, like electricity, is not necessarily produced from a carbon-free source. Beyond the pathway to zero emission vehicles, the interest in hydrogen as a transportation fuel stems from its promise for domestic production, high energy density, extended vehicle range potential, fast filling times, and FCEVs' high efficiency when compared with internal combustion engines.[46] For these reasons, FCEVs are seen as future options for freight vehicles that need to haul weight at longer range. Broadening electrification to include Hydrogen can reduce dependence on a single supply chain for materials and energy distribution,[47] but before hydrogen is viable for the trucking industry, critical factors such as hydrogen generation at scale, a robust distribution network, and vehicle cost parity must be in place. Although Scania, the first major heavy-duty vehicle manufacturer to have FCEV trucks in operation, recently announced they are stopping their FCEV program to focus on full electric powertrains,[48] there are many large OEMs, including Hyundai,[49] Volvo,[50] Daimler,[51] Toyota,[52] and GM[53] with active fuel cell development programs. Additionally, The North American Council for Freight Efficiency (NACFE) released a December 2020 Guidance Report titled "Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors,"[54] which suggests fleets should consider hydrogen fuel cell trucks if:

- Zero-emissions at the tailpipe is important
- Tractor tare weight is critical to maximizing payload
- Long distance routes over 500 miles are common
- Winter conditions are significant to operations
- Green or blue hydrogen is readily available
- Regions have incentivized hydrogen use
- Operate in less mountainous regions

- **Battery Electric Vehicles** (EVs or EVs) use a battery pack to store electrical energy to power a motor. The batteries are charged primarily via an external power source but can also restore some energy to the batteries using regenerative braking while the vehicle is in motion slowing down. The vehicles do not emit any exhaust and have only a fraction of the moving parts compared to an internal combustion engine vehicle.

3.3. Freight Operations

Several factors influence if, how and when electric vehicles are integrated into fleets, including: tare (unloaded vehicle) weight, the truckload typology, hours of service, the ownership model and incentives.

3.3.1. Current Status of Freight Electrification

Passenger vehicle registrations are tracked at the federal level and are a good measure of electric vehicle adoption. This information is not currently tracked at the federal level for electric trucks as they are not yet a significant part of the market. However, there are many levers in play that are accelerating the market. In June 2020, California enacted the Advanced Clean Truck Rule,[55] which over 12 years from 2024 through 2035, increases the percentage of zero-emission trucks that manufacturers must sell in the state. As of July 2020, fourteen states (including Ohio's neighbor, Pennsylvania) plus Washington, D.C., have signed an MOU to join California to ban the sale of diesel trucks by 2050. This pledge includes an intermediate target requiring 30% ZEV sales for the MD and HD segments by 2030.[56]

In today's MD-HD and light-duty sector of the market, three applications are most common:

- MD work trucks, and step/cargo vans,
- HD vehicles which include transit buses, yard tractors, cement trucks, and refuse trucks,
- HD vehicles with well-defined and limited operating characteristics.

As indicated in Table 7, about 40% of MD and HD alternative fuel vehicle models are available in electric today and they are forecasted to surpass the CNG, LPG, and propane models that currently lead the alternative fuel options. The shaded rows are the focus of this study.

Table 7: Summary of Available Medium and Heavy-Duty Alternative Fuel Vehicles[57]

Vehicle Type	Electric[58]	Hydrogen Fuel Cell	CNG, LNG, & Propane	Hybrids	Total
Passenger Van/Shuttle Bus	15	2	18	2	**37**
Pickup	0	0	2	3	**5**
Refuse	3	0	12	0	**15**
School Bus	14	0	8	0	**22**
Step Van	10	1	0	0	**11**
Street Sweeper	2	0	14	2	**18**
Tractor	2	1	9	0	**12**
Tractor - Vocational/Cab Chassis	3	0	0	0	**3**
Transit Bus	36	4	18	15	**73**
Van	3	0	4	2	**9**
Vocational/Cab Chassis	11	0	26	6	**43**
Grand Total	**99**	**8**	**111**	**30**	**248**
Percent by Fuel Type	**40%**	**3%**	**45%**	**12%**	**100%**

The chassis for these larger vehicles are typically modular, so OEMs or third parties are able to retrofit or modify an existing frame to accommodate an all-electric powertrain. Additionally, these types of HD vehicles travel relatively short, constricted distances and are stored centrally, conditions well-suited to today's battery technology. These vehicles also stop frequently providing opportunities for batteries to be recharged through regenerative braking, which converts braking energy typically dissipated as heat into energy to charge a battery. As the EV industry matures, range and charging speeds are increasing, enabling vehicle types with less EV conducive operating requirements to become viable candidates for electrification.

Many MD and light duty (LD) vehicle types including cargo vans, work trucks, and step vans currently on the market are based on the Ford E-450 platform. While the E-450 is not currently manufactured as an electric vehicle, Ford certifies companies such as Lightning and ROUSH, under their qualified vehicle manufacturer (eQVM) program to modify the vehicles for EV operation, installing proprietary batteries, powertrain, and charging equipment. Through this program, Ford honors the OEM warranty on the frame and chassis and the vehicles can be serviced at any Ford dealership while the eQVM provides an equivalent warranty on the battery and electric powertrain. How major OEMs like Ford are handling the future of transportation is ever changing and with Ford entering the MD EV market with the 2021 Transit[59], the future of how these programs will be launched is uncertain. Only time will tell if they continue to use the eQVM program or build the vehicles from the ground up off their own assembly lines.

3.3.2. Hours of Service[60]

Truck drivers involved in Interstate commerce must follow federally mandated hours of service rules. Per current regulations, a driver can drive a truck for 11 hours within a 14-hour on-duty window, after which the driver must be off duty for 10 hours. Within the 11-hour window, drivers can drive for up to 8 hours, but then must take a 30-minute break where they can continue to work (to refuel the truck, for example) but cannot be driving. In addition, drivers cannot be on duty more than 60 hours in 7 days or 70 hours in 8 days. Slightly different rules apply in adverse conditions and to accommodate dual drivers in sleeper berths. These federally mandated restrictions were initiated to ensure safety on America's roadways and are strictly enforced by law enforcement. Penalties include shutting the truck down for periods of time until the driver complies and/or fines ranging from $1,000 to $17,000 per event.[61] The Hours of Service definitions are available in **Appendix D**.

The Hours of Service regulations, limiting the number of hours truck drivers can drive between breaks and the length of those breaks limit the range trucks can travel between stops – works to the advantage of electric vehicles. It reduces the range required since vehicles are able to refuel during breaks. See **Appendix E** for battery state of charge estimates based on average vehicle speeds and hours of service requirements.

3.3.3. Ownership and Service Models

Ownership models for freight vehicles vary by industry position – larger nationwide shipping companies with hundreds of vehicles operate differently from smaller regional companies. Of note, 90% of registered trucking companies operate six or fewer vehicles, according to the American Trucking Associations.[62] Regardless of the size of the operator or ownership model, the initial purchase price will remain a barrier to fleets until it can come in line with ICE trucks, estimated by NACFE to be around 2030-2035.[63]

With all trucking, dependable service is crucial – as downtime can severely impact business profitability. As EVs are a new technology, service centers along key freight corridors will need to be updated to meet the unique requirements of EVs including powertrains and regenerative braking.

Table 8: Typical Electrification Ownership and Service Models

Fleet	Ownership	Service
Large: 1,000 trucks or more	Centrally managed, where a large operating company purchases multiple vehicles for use until the warranty expires. These vehicles are then sold on the secondary market where they have an additional life with higher operating costs, at which point those still operable are sold, often to smaller fleets and/or developing countries. Larger fleets have greater revenues from which to work from to meet regulatory measurers or to meet their own sustainability plans. Larger fleets benefit from incentives and opportunities to offset the cost of electrification. Since many larger fleets operate regionally or nationally, they can place EVs where incentives are available.	If larger fleets have vehicles domiciled at regional hubs in large enough quantities, then larger fleets service and maintain their own vehicles. This allows them to control all aspects of preventative maintenance, parts inventory, and vehicle uptime. In scenarios where fleets have more decentralized hubs with smaller numbers of units at each location, third party maintenance providers may be contracted to provide vehicle servicing, such as Penske or Ryder. In even more select cases, a larger fleet may have a combination of both. Control of vehicle servicing and maintenance of vehicles means larger fleets have the ability to control when and how they deploy advanced vehicle technologies, as those servicing variables are controlled internally.

Fleet	Ownership	Service
Medium: 100-999 trucks	Similar to large fleets in that they are held until off warranty, used on the secondary market, and then sold if still operational, to smaller fleets or independent operators. Medium sized fleets will need to rely on incentives to offset the cost of electrification until cost parity with today's ICE vehicles is met. Since many medium fleets operate in smaller geographic regions, they are more constrained than larger fleets by the incentives available in their region.	Similar to larger fleets, as long as medium sized fleets have vehicles domiciled at regional hubs in large enough quantities, then medium fleets will service and maintain their own vehicles. This provides ability to control all aspects of preventative maintenance, parts inventory, and vehicle uptime. In scenarios where fleets have more decentralized hubs with smaller numbers of units at each location, third party maintenance providers may be contracted to provide vehicle servicing. Control of vehicle servicing and maintenance of vehicles means medium fleets have the ability to control when and how they deploy advanced vehicle technologies, as those servicing variables are controlled internally.
Independent: Fewer than 100 vehicles and typically not more than 3	An independent fleet, also known as owner operators, have truck drivers that are not classified as employees of the truck company they drive for. Owner operators set their own schedules, choose what type of work they want to do and choose their own equipment. The cost of operation greatly affects independent fleets or owner operators' ability to electrify their fleet as 75% of an owner operator's expense's goes directly to their equipment for an ICE. To go electric will require strong incentives and funding to offset the costs.	Smaller fleets lack the economies of scale to control vehicle servicing and contract with third party maintenance providers, such as Penske or Ryder if they have more vehicles or even simply use a local dealership for service if they have smaller quantities of vehicles. Lack of control of vehicle servicing and maintenance of vehicles means smaller fleets need the buy-in, cooperation, and training of service providers before they can deploy advanced vehicle technologies.

3.3.4. Fuel Pricing: Diesel versus Electric

The main metric for comparing operations costs between diesel and electric trucks is the fuel cost.

- **Diesel Pricing:** Beyond the straight fuel price, existing industry norms can play a role. As diesel prices fluctuate, carriers are somewhat insulated from the fluctuations by fuel surcharges which they pass on to customers. While each carrier has a different method to calculate their surcharge, they try to establish a stable shipping cost, which is independent from the more variable cost of diesel.

  When purchasing fuel, fleets have several options, they can pay retail prices at the pump, negotiate a specific rate at a particular chain or with a card provider, or have fuel delivered to on-site tanks. With the latter two options, fleets negotiate a bulk fuel purchase, paying less than retail price and typically receive a volume discount. Regardless, fuel costs are almost always passed directly to the customer, so they become more about providing a competitive service than outright cost savings.

- **Geographic Variation in Electricity Rates:** Electricity rates for electric trucks are the equivalent of the price of fuel for a diesel and can also vary widely across the country with New England and California paying higher rates and the mountain west and southern plains paying the lowest rates. For freight applications, the commercial rate is assumed. As of December 2020, Ohio ranked 16th nationally for average commercial electricity rates with $0.0914 per kWh, and is slightly behind Pennsylvania ($0.0836/kWh) but ahead of Indiana ($0.1111/kWh), Michigan ($0.1219), and Kentucky ($0.10/kWh).[64]

o **Time-of-Use Charges:** In addition to variability over geography, the price of electricity may increase during times of greater demand. Utilities often refer to these as “peak” or “critical peak” rates. These charges have daily and seasonal variation, following system load, which reaches a maximum in Ohio in the coldest months and in the evening as people return home from work. Peak charges vary by state, season and utility with some utilities charging much higher rates than others. Peak charges affect pricing across much of the U.S. and are increasing at approximately 8% per year, incentivizing consumers to charge off-peak and making determining a flat rate of cost per mile challenging.[65] Several utilities in Ohio offer or are in the process of implementing time-varying-rate programs that offer lower rates during periods of low demand and higher rates during periods of high demand. However, they require smart meters to administer effectively and are not available widely in the state.

o **Demand Charges:** Many utilities charge commercial customers based on the highest amount of power they draw in an interval, typically 15 minutes. They reflect the cost of providing high-power infrastructure to a site and attempt to “flatten” the load so that a site does not have large, idle capacity. These are referred to as “Demand Charges.” Some utilities have constant demand charges, while others increase the amount depending on the difference between peak and average demand, or set tiered rates scaled to the peak demand seen on a site. These charges are important for fleet owners to understand, as they can result in high electric bills even if all vehicles are charged overnight. For example, the electric bill for a truck depot that charges 30, Class 8 trucks overnight in Cleveland for a month would be about $82,000, with demand charges making up about 45% of the bill. The same depot charging the same trucks in 45-minute windows at a peak power of 3MW would cost about $113,000, with demand charges making up about 60% of the bill. For more details and more cities in Ohio, see **Appendix C**.

3.4. Infrastructure

Ohio has one of largest transportation and logistics networks in the U.S., is home to significant warehouse capacity, and has extensive utility infrastructure.

3.4.1. Transportation Infrastructure

The Ohio Department of Transportation is responsible for 1,652 miles of Interstate, along with 3,911 miles of U.S. routes and over 14,000 miles of state routes.[66] Together, they carry most of the freight moving around and through Ohio. Ohio is also second in the nation in the number of intermodal terminals[67] – mapped in **Figure 7.**

Ohio is a crossroads, with access to international water ports on Lake Erie. In fact, 34% of truck traffic in Ohio is pass-through, neither originating nor terminating in the state. This number increases to 69% on the Ohio Turnpike.[68] In 2021, the American Transportation Research Institute identified the junction of I-71 and I-75, on the Cincinnati side of the Brent Spence Bridge, as the #2 truck bottleneck in the nation.[69]

Table 9: Travel Activity by Vehicle Type (2019 Data)[70]

	Rural			Urban		
Vehicle Type	**Interstate**	**Other Arterial**	**Other Rural**	**Interstate**	**Other Arterial**	**Other Urban**
Motorcycles	0.44%	0.55%	0.80%	0.32%	0.43%	0.68%
Passenger Cars	58.74%	66.60%	68.47%	72.48%	76.06%	75.59%
Light Trucks	14.29%	18.50%	22.90%	12.98%	16.30%	18.00%
Buses	0.23%	0.55%	0.43%	0.12%	0.33%	0.43%
Single Unit Trucks	4.00%	3.60%	3.60%	3.60%	3.00%	3.20%

	Rural			Urban		
Vehicle Type	**Interstate**	**Other Arterial**	**Other Rural**	**Interstate**	**Other Arterial**	**Other Urban**
Combination Trucks	22.30%	10.20%	3.80%	10.50%	3.88%	2.10%

Figure 6 shows registrations for Class 2-8 trucks by county as of April 2021. The size of the circle represents the number of registrations by county. The highest concentrations are around Cleveland, Cincinnati, and Columbus.

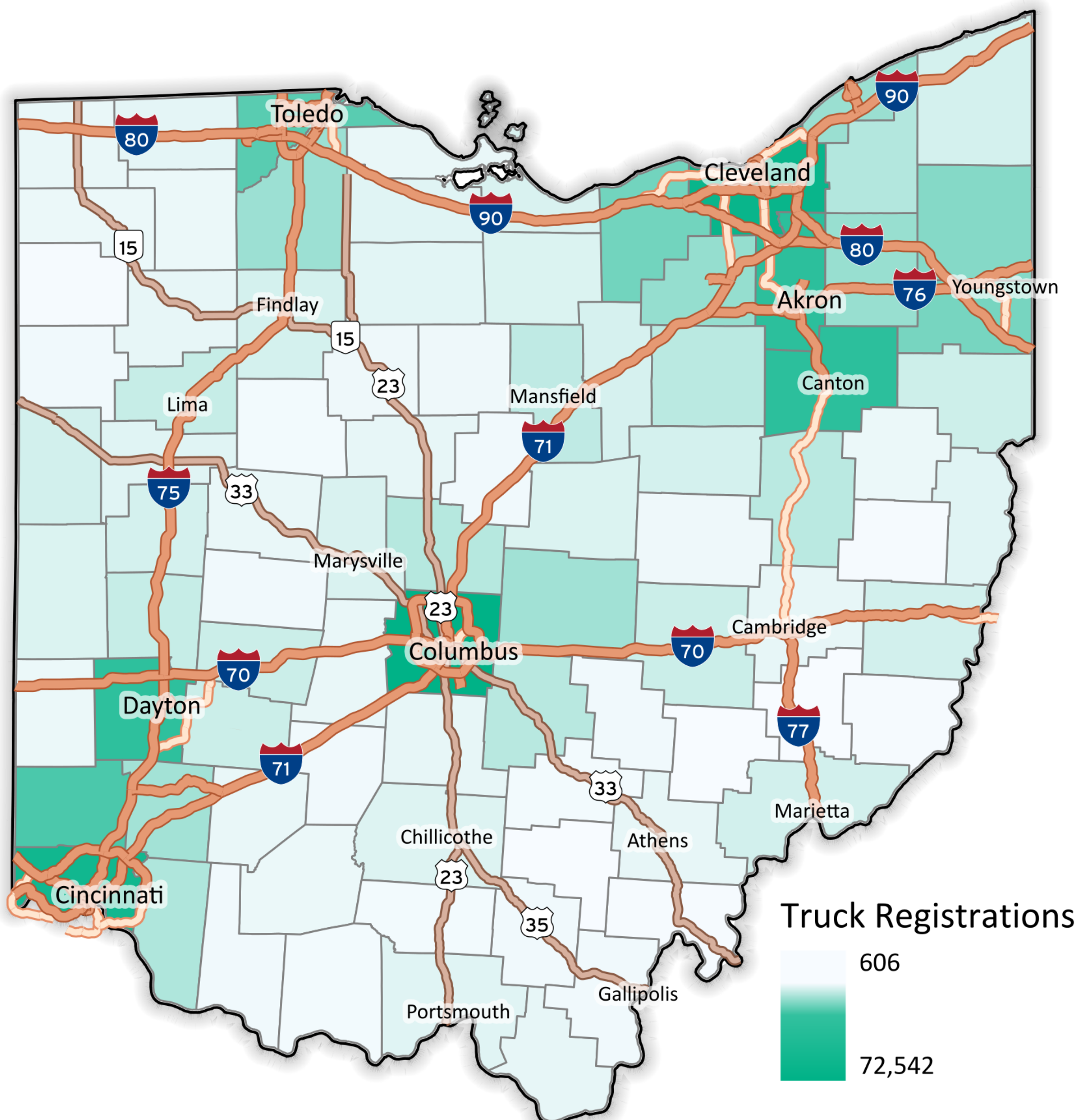


Figure 6: Class 2-8 Truck Registrations by County

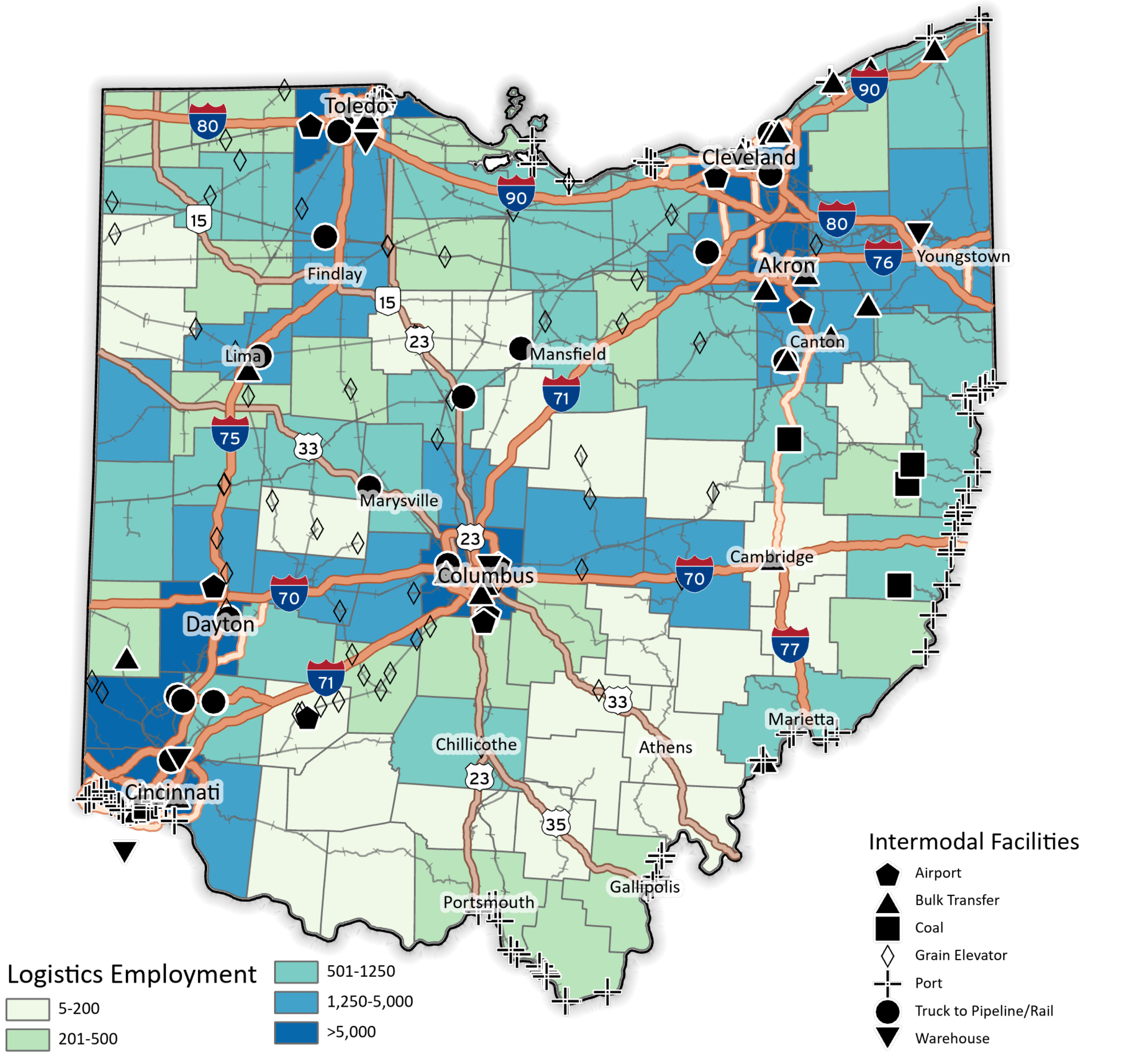


Figure 7: Transportation Infrastructure

3.4.2. Logistics Facilities

As mentioned earlier, Ohio is ranked fifth in the U.S. in warehousing, storage services, freight, and 100,000 people are employed in logistics jobs in Ohio. Data on warehouse locations for major shippers, including Amazon, FedEx, UPS, and others were gathered to understand Ohio's freight capabilities and needs.

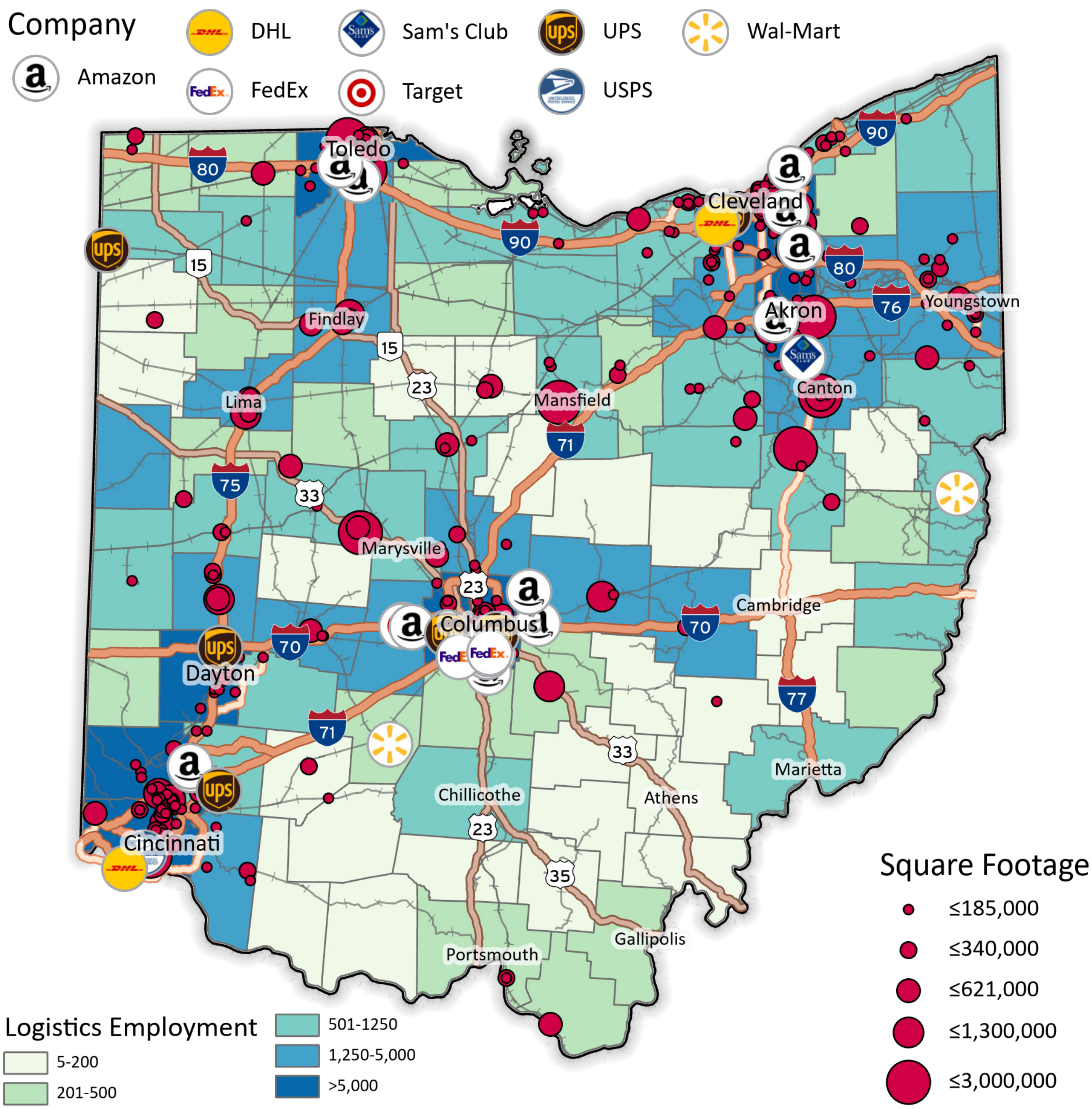


Figure 8: Logistics Employment and Warehouses in Ohio

Truck Stops, shown in **Figure 9** were mapped and, in conjunction with power availability, used to identify potential charging locations. See **Figure 16** in **Section 6.4** for the results of this analysis**.**

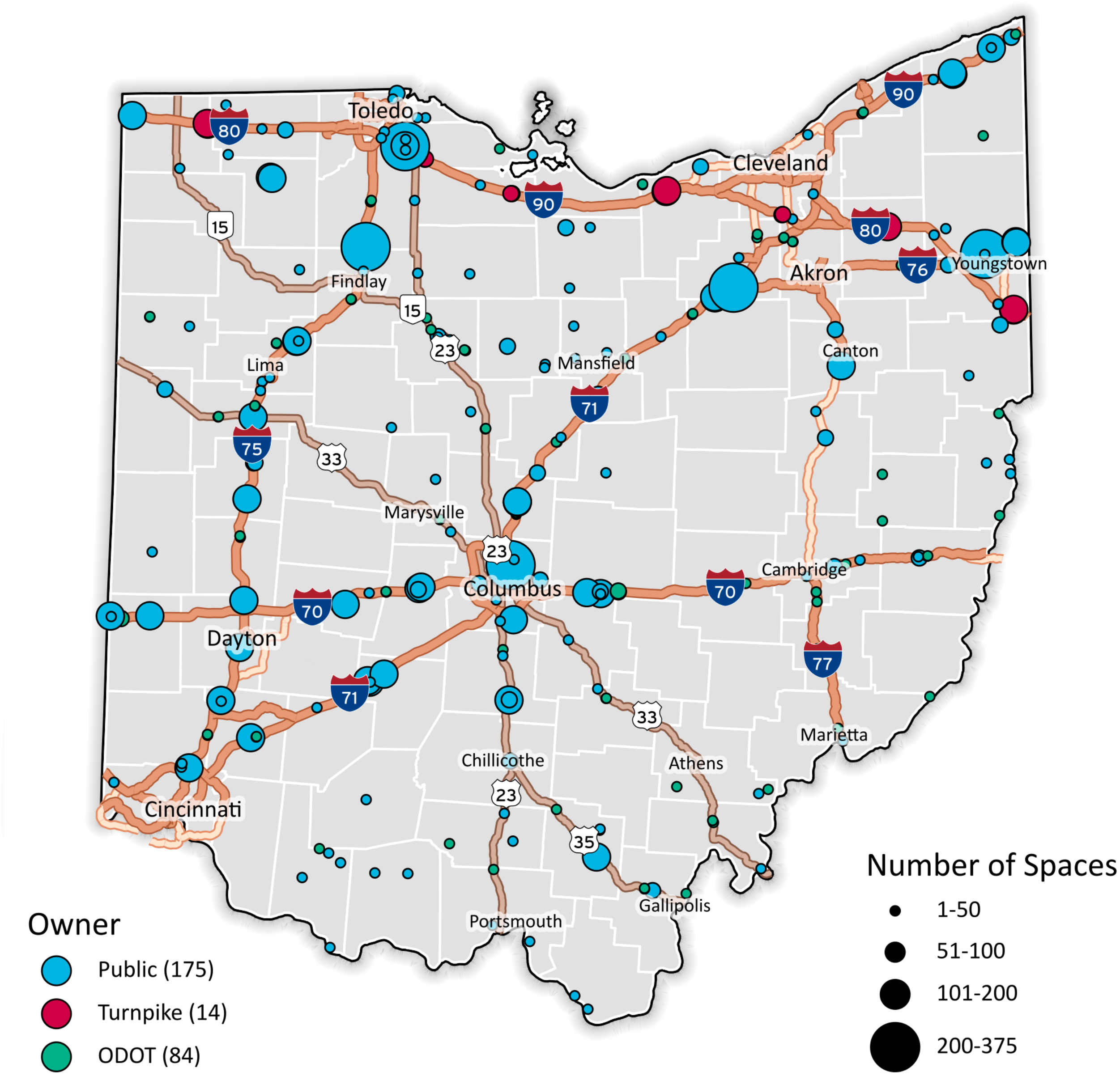
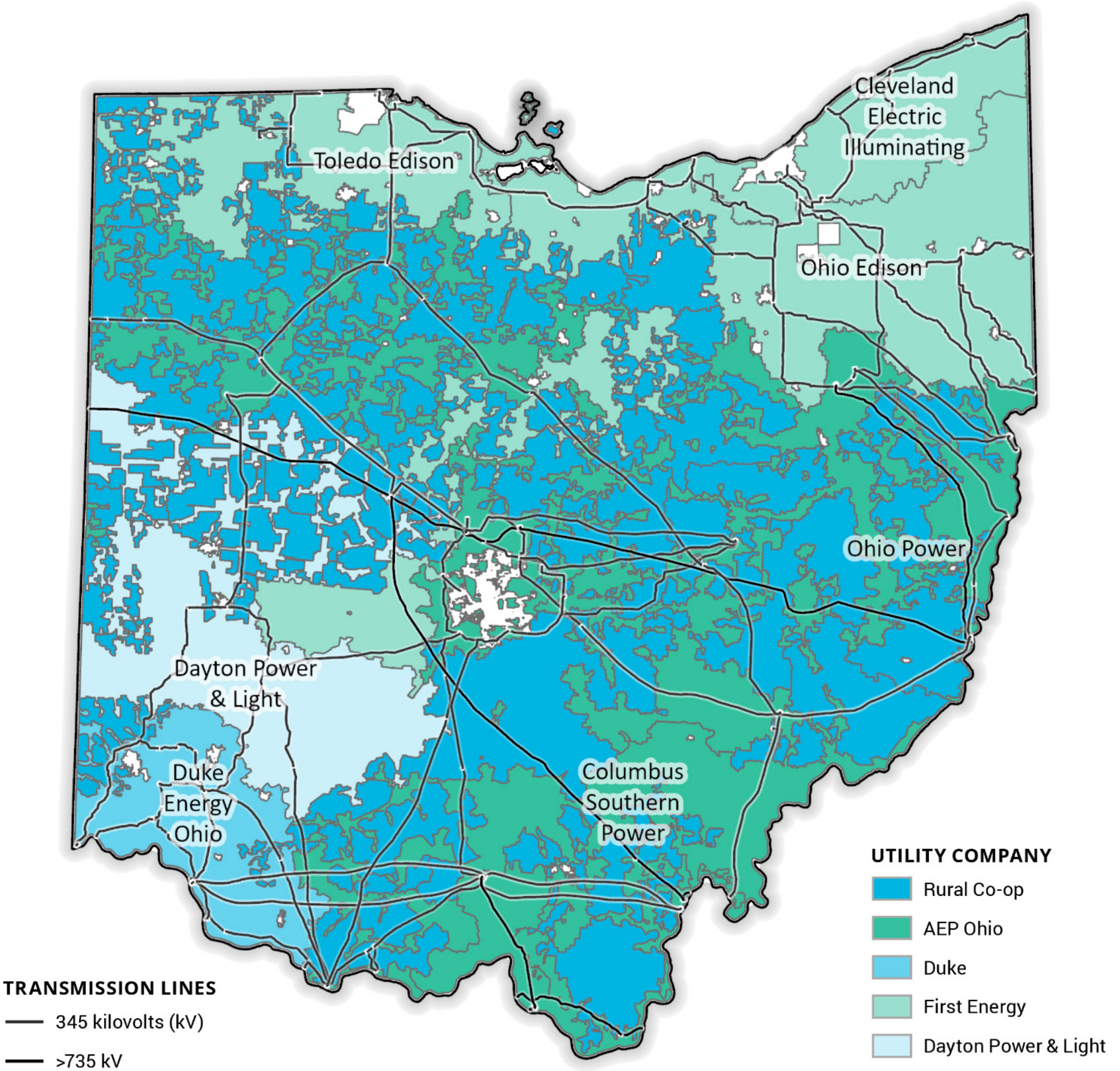


Figure 9: Truck Parking Sites in Ohio [71]

3.4.3. Utility Coverage

Coverage areas for Ohio's investor-owned utilities, which include American Electric Power Ohio, Dayton Power and Light, Duke Energy Ohio, and the First Energy distribution companies (Ohio Edison, Cleveland Electric Illuminating Company, and Toledo Edison) are mapped in **Figure 10: Utility Service Territories in Ohio** along with the municipal power companies, and the electric cooperatives (co-ops) around the state. Ohio has 85 municipal power companies and 25 co-ops. High-power transmission lines are also shown to illustrate where the most significant power infrastructure exists.



Note: Satellite imagery provides transmission line data; voltage levels are approximate.

Figure 10: Utility Service Territories in Ohio

4. Industry Input

The team met with shipping and logistics companies, vehicle and Electric Vehicle Supply Equipment (EVSE) manufacturers, Ohio stakeholders, and other thought leaders across the United States to determine fleet needs and get an accurate picture of current technological development. Discussion focused on local needs, barriers, and motivations for electrifying fleets. The list of industry leaders consulted is located in **Appendix F**. Takeaways from the industry outreach calls are summarized below.

4.1. Reasons for Electrifying

Fleets were each asked why they were electrifying or considering electrifying. Initially, almost all said it was due to their company's sustainability focus. Some felt it gave them a competitive edge because it was saving them money or simply allowed them to be in early on a big market shift and to be able to message this to their customers. Several noted a reason for continuing to electrify was that their operators prefer driving electric vehicles once they use them and that other operators then expressed a strong interest as well. Below are their most commonly cited reasons.

4.1.1. Competitive Edge

Regulations and OEM commitments indicate EVs are where the commercial vehicle market is moving. Fleets want to lead, not be left behind. Once installation hurdles are overcome (see below at **Section 4.2.5**), there are many potential benefits. Balancing higher upfront costs, EVs are cheaper to operate, even if use taxes or electricity rates rise above existing levels. Fleets able to successfully transition earlier are likely to gain the most benefit.

4.1.2. Safety

Battery Electric Vehicles offer a competitive edge in safety features compared to conventional vehicles. Most EVs include state of the art safety features such as lane departure warnings, driver assist features, and automation features up to Level 3 automation. In addition, while lithium-ion batteries are flammable, the battery technologies are far less flammable than liquid fuels, and therefore offer less fire and explosive risk in crashes or from fire hazards from pooling liquid fuels post accidents. With continuing improvements in design of batteries and automation features, battery electric vehicles will continue to be leaders in vehicle safety.

4.1.3. Drivers Prefer EVs

Fleets, whose revenue has been limited by driver shortages, will find that offering EVs may help with talent recruitment and retention. In addition to the novelty factor, electric trucks are substantially quieter and do not vibrate meaning driving them does not leave drivers' ears ringing at the end of the day. They also emit no diesel fumes, which reduces associated health risks. Firefly Transportation Services (acquired by Lazer Spot Inc.) provides 100% electric trucks for yard management operations to create a safer and healthier work environment.[72]

From a performance perspective, EVs have more torque at lower levels and are three to five times quicker off the line than diesels meaning driving them in congested traffic and up hills will be easier. Fleets noted that drivers appreciated the clean technology and learning the new skills required to maximize EV efficiency.

4.1.4. Carbon Emissions Reduction Goals

Environmental benefits of electrification are significant, and the most common reason fleets offered for electrifying. DHL has a goal of using clean transportation for 70% of their first and last mile services by 2025.[73] Bimbo Bakeries had a global goal of 10% optimization in the use of energy and fuel by 2020. From 2018 to 2019 they reduced their fuel usage by 9%, their natural gas use by 9% and their diesel use by 18%.[74]

4.2. Fleet Feedback

Through conversations about what it takes to electrify operations with several local, national, and international fleets with facilities in Ohio many themes emerged. They are summarized below.

4.2.1. Market Maturation

OEMs, including the leading producers of trucks in North America, are moving quickly towards delivering EVs to market. This technology revolution is attracting new companies to the EV truck market such as Tesla, Nikola, Lion, and others that are rethinking existing delivery and service models.

Table 10: Market Maturation

Fleet Perspective	Mitigation/Alternative
There aren't enough EVS available in the market. We need more vehicle options.	For a list of projected release dates for different truck types, see **Figure 2** in **Section 2.2.1**.
The EV market is in its infancy. It's hard to trust range and total cost of ownership (TCO) estimates from manufacturers.	While it is wise to take announcements from OEMs cautiously, there is an increasing body of real-world evidence to support realistic data for TCO estimates. OEMs are also sensitive to customer reviews, especially when the truck market has relatively few and typically more sophisticated buyers compared to the masses buying passenger vehicles.
Market is moving quickly, and companies don't want to invest in EVs and EVSE for fear their investments will soon be outdated. For example, what if the next generation of EVs jumps from 120 to 300 miles?	Technological advances cause redundancy, even with ICE. EVs should be purchased with TCO (including grants) in mind. Whether EVs jump from 120 to 300 miles of range does not matter much if the daily route need is only 100 miles. Furthermore, given the flexibility of existing chassis designs, a future upgrade to a more efficient battery would likely be possible. And as the market matures over the coming years, the risk of redundancy will decline.

4.2.2. Up-Front Costs

Up-front costs are consistently identified by fleet operators as a barrier to entry. The North American Council on Freight Efficiency (NACFE) estimates that most Class 3-6 EV trucks have Total Cost of Ownership (TCO) parity with diesels today and that Class 7-8 trucks will achieve it by 2025. Initial purchase price will not achieve parity, however, until 2030 or even later for HD trucks.[75] An additional up-front burden, especially for smaller fleet operators, is the 12% federal excise tax on truck purchases. While this is a flat rate across all Class 8 trucks, until battery trucks reach initial purchase price parity, it creates a disincentive for purchasing vehicles.

The bigger up-front cost barrier is the potentially substantial cost of installing charging infrastructure.

Table 11: Up-Front Costs

Fleet Perspective	Mitigation/Alternative
Smaller operations cannot afford to buy electric.	Smaller fleets should focus on gradual transitions to EV and be aware of grant opportunities to replace aging diesels with new EV technology. Smaller fleets also have lower power and charging needs and thus may actually have an advantage over larger fleets which will potentially have a much larger relative capital outlay.

Fleet Perspective	Mitigation/Alternative
Yard spotting trucks have 4x the maintenance costs of traditional diesel.	The TCO for EVS in drayage is already better than for diesels in part because of the maintenance costs. Diesels do better when up to speed. EVs do best in stop and go.
The initial cash outlay is challenging for both EVs and EVSEs. **EVs** • Power, range, and price must improve for ~80,000lbs LTL routes (added battery weight sacrifices available freight load) • EV sticker prices can be 40-100% more expensive than diesel and rely on subsidies to get the initial capital cost down. **EVSE** • Variability of installation (site and utility) costs can make return on investment (ROI)/TCO unworkable • Leased property may not be worth the infrastructure investment.	In the absence of governmental mandates such as those required by Europe, China, California, and states following California's lead, the TCO calculations will help fleet managers determine when to make the shift to EV. Last mile and local deliveries currently have the best TCO for EVs but as technology advances rapidly (and battery weights come down) in coming years, other use cases will see TCO benefits as well. In the case of leased property, governments coordinating with utilities should identify sites where fleet EVSE could be installed economically and encourage landowners to share EVSE investment costs with lessees.

4.2.3. Total Cost of Ownership

Cost-competitiveness between EV and ICE can be measured in several ways, these include TCO, relative cost of fuels, regulations (including tax rates and emissions targets), and performance feasibility. Each of these factors will affect overall adoption rates, both on a state and national level. Given the volume of truck traffic passing through Ohio, the policies and incentives in other states will also affect the rate of freight electrification in Ohio.

TCO calculations depend on reliable information about battery life, residual value of EV trucks and batteries, and long-term industry-specific electric rates. Peterbilt has a TCO calculator for comparing their electric and diesel offerings. It uses a simple $/kWh rate for electricity costs which doesn't fully capture the complexities of fleet charging.[76] As the EV industry is relatively new, this information is scant or may not yet exist, requiring a risk tolerance many are not yet comfortable with. Government agencies can help by clarifying the permitting process and incentive application processes. OEMs can help by standardizing and fully testing EVSE and utilities can help by clarifying the costs and timeline of electrical infrastructure improvements.

Table 12: Total Cost of Ownership

Fleet Perspective	Mitigation/Alternative
As EV market is still in its infancy, there may be unknown or hidden costs. TCO includes EV, EVSE installation, maintenance, driver and technician training, electricity costs, warehouses costs, and battery recycling.	Especially in locations where regulations strongly favor EVs, some fleets are building models which capture all costs. As this experience accumulates, governments, utilities, and integrators will be better able to support fleet operators on TCO.
As the fuel tax becomes less effective at funding infrastructure, there is an unknown about future taxation impacts on TCO. Will states tax electricity, VMT, or some other mechanism?	States, supported by the federal government, will need to establish road taxes that are fair, easy to adopt and understand, and are similarly equivalent/equitable as existing motor fuel taxes.

4.2.4. On-Route EVSE Availability

The existing lack of electric vehicle supply equipment (EVSE) suitable for trucks is a significant barrier to EV adoption, especially for regional and long-haul trucking. This is a chicken-and-egg problem – low demand for truck chargers has many aspects, the most significant mid to long term issue is the availability of 480V 3-phase power necessary for the high-powered direct current fast chargers (DCFC). While this power type is generally available at larger commercial or industrial sites, it is not typically available along rural highway rest stops. Even in urban areas with higher capacity distribution networks, the installation of large numbers of DCFCs will need to be carefully coordinated across a range of stakeholders, including utilities, trucking companies, truck stop operators, ports, intermodal depots, etc.

On-route charging must also contend with variable electricity rates including potentially significantly higher rates for peak periods. This challenge may be mitigated using load management software and on-site storage batteries, the latter potentially having the ability to boost the power output and/or to charge two vehicles simultaneously with minimal infrastructure upgrades.[77]

Table 13: On-Route EVSE Availability

Fleet Perspective	Mitigation/Alternative
Lack of charging infrastructure severely limits where EVs can go, especially in comparison with diesel which is ubiquitous. ("Range Anxiety") Not enough infrastructure built out for customers if they don't have yard-based charging. The trucking industry is low margin and efficiency is critical. When on the road they cannot have tractors sitting and waiting to charge.	Depending on the use case, fleet operators may need to identify a combination of truck yard and on-route charging. Truck stop operators will likely provide the majority of long-haul on-route charging. If incentives and/or regulations are introduced that make it profitable for truck stop operators to install EVSE, then we can expect a greater supply of on-route charging. OEMs will need to address the challenge of time requirements for on-route charging, which could pivot off hours of service requirements along key routes.

4.2.5. EVSE Installation

Fleets are finding the installation of infrastructure to be more complex than anticipated.

Table 14: EVSE Installation

Fleet Perspective	Mitigation/Alternative
Utility coordination can be time consuming and, most critically, timelines are not predictable.	The state can work with the major utilities to streamline processes and identify points of contact who can help fleets cost out and schedule any necessary electrical infrastructure upgrades.
Retrofitting older buildings is challenging and/or expensive.	Once fleets define their EVSE and electricity needs, they will need to evaluate whether retrofitting their existing space is more cost effective than finding a new location better suited to fleet charging. A commercial vehicle report from Chicago highlights that retrofits could be as much as 4 times as expensive as building new.[78]

4.2.6. Parking, Stopping and Deliveries

Ideally, on-route charging happens at locations where truck drivers are accustomed to making deliveries, stopping to rest, or stopping to refuel. These sites are already designed with freight needs in mind.

Table 15: Parking, Stopping and Deliveries

Fleet Perspective	Mitigation/Alternative
EV charging could take up valuable space at truck stops which is needed for other uses including regular parking.	Truck stop retrofit planning will be a key early step in the EV transition and needs to carefully consider safety, convenience, space implications, and real estate costs in addition to EVSE installation steps.
Cities are looking to re-imagine curb space to support changes in delivery operations, but each city is different.	There is an opportunity for fleets to help design how urban curbs (loading zones) of the future function including how they are priced and if and how charging is made available.

4.2.7. Streamlining EVSE Standards and Permitting Processes

Standardization of EVSE, whether from the vehicle OEM, the publicly available on-route EVSE supplier, or the depot EVSE supplier, will help make TCO calculations, utility planning, the user experience and permitting, easier. Governments and utilities can also significantly streamline their processes to reduce implementation time.

Table 16: Streamlining EVSE Standards and Permitting Processes

Fleet Perspective	Mitigation/Alternative
Publicly available charging networks are not yet standardized or mature. They often require users to go through multiple steps for payment depending on who operates the charger.	For the near term, fleet operators should expect to map out their on-route charging needs in advance so that issues such as membership and payment processes are considered and eliminated as risks. This challenge should recede as charging systems mature.
Consistency with where to locate the charging port so it is accessible within charging locations.	From a fleet perspective, charging equipment should be located so as to be accessible for the EVs purchased. From a publicly available charging provider perspective, charging points on overhead gantries offer the most flexibility in terms of port locations for different vehicles.
Simplicity, consistency, predictability, and expediency are currently not present in permitting processes, which also vary substantially by jurisdiction. Often multiple departments must approve: building department, engineering, code enforcement, etc. The process may take up to two years.	Permitting is critical for EV transitioning companies as they coordinate vehicle delivery and EVSE installation. Counties or MPOs should provide processes to standardize EV installation permits including identifying a lead department and streamlining the approval process. State agencies could promote standardization statewide, and federal agencies could do the same nationally. Lessons learned from other jurisdictions could ease this necessary reform. EVSE manufacturers, integrators, and installers could also develop sample standard drawings and specifications that cities and companies could use to simplify the process and reduce variations across permitting locations.

4.2.8. Charging Time

Charging times for larger batteries required for long-haul trucking are prohibitive with existing battery technology and do not mesh well with the duty cycles of these trucks. Some yard tractors are in use most hours of the day and cannot charge continuously for the 8 hours required by existing charging configurations. However, as charging and battery technologies advance, charging times will come down and may better fit with the duty cycle of the vehicles. Hydrogen fuel cells recharge faster and may meet the needs of these vehicles better. Hot-swappable batteries, that can replace a depleted cell with a charged one in a few minutes, may also be viable for these scenarios.

Table 17: Charging Time

Fleet Perspective	Mitigation/Alternative
Length of charge time may require that fleets purchase more electric vehicles than they would need if running on other fuels. Recharging time may be too long for just-in-time deliveries which negatively impacts profitability. Fleets cannot afford to have vehicles idling for excessive periods of time.	EV transition in fleets need not be all at once. Fleets may want to start small on shorter routes, for example, and learn from experience and then grow in batches as confidence in the technology, vehicle range, and experience of drivers grow. The TCO for EVs will be superior in some use cases, even if on-route charging is needed. The best operational designs for many use cases will limit (or eliminate) the need for on-route charging and possibly only require a shorter “top off”. For other use cases, on-route charging should be coordinated with delivery stops so it can occur at the same time as the truck is loaded/unloaded. For Interstate trucking, charging should be coordinated with required rest breaks. Site owners and utilities coordinated by state, regional, or local governments can install equipment strategically so that a maximum of use cases are served.

4.2.9. Vehicle Sales and Service

As trusted partners, OEMs and their dealer network are being looked to for advice and support when it comes to purchasing and operating an electric vehicle – from the initial fact finding through vehicle maintenance and second life plans.

EV structure and technology are quite different than ICE vehicles, so training mechanics and service technicians on EVs so fleet operators and independent owners can reliably have their vehicles serviced will be important. Personal protection equipment (PPE) is required for anyone working on or around an EV to ensure that they are safely grounded and protected from the current flowing through the high voltage powertrains. Fleets will need quick and reliable access to spare parts and service components that will be new to the entire service supply chain.

Table 18: Vehicle Sales and Service

OEM Perspective	Mitigation/Alternative
When EVs achieve price parity and production scales similar to conventional vehicles, it is expected that OEM sales and service will be streamlined and efficient. Today, with limited production, longer delivery lead times, higher costs for vehicles, and needs for EVSE selection and installation, the EV sales process is longer and more complex. OEMs find they must have staff that understand grants and rebates and must focus on selling vehicles where they can cover part of the cost to make the up-front purchase feasible. This is complicated when grant funds have narrow applicability (e.g., require that they be used to replace trucks that are from 2009 or earlier, only be used for certain truck types like refuse, bucket, or tree trimming, etc.)	The EV transition is complicated but with perseverance and support from key partners in government, industry, and at the utility, it can happen. Fleets need more guidance and better information on total cost of ownership. Analysis and planning is key to success. OEMs, vendors, and electrification stakeholders such as utilities, can help fleets by 1. Making sure EVs are appropriate for the use case 2. Analyzing true TCO 3. Evaluating all financing options 4. Evaluating all infrastructure needs 5. Providing crew training materials The eventual result will be fleet replacements benefitting OEMs and an improved TCO profile and improved driver retention benefitting fleets. When creating grant or rebate programs, governments and/or utilities should look for ways to create flexibility and reduce the effort required, so recipients feel the effort is worth the investment.
The support ecosystem for EVs is not yet well established. Fleets are looking to the major OEMs, as partners they trust, to provide parts, service, and support. Fleets are wary of new EV OEMs (i.e., new manufacturers who have electric vehicles but not a demonstrated business longevity). Fleets are looking to the trusted OEMs (Volvo, Freightliner, etc.) to enter the EV market to ensure long-term availability of parts, service, and support.	Lion Electric, Volvo and others are building out support organizations to address grant opportunities, power planning, mechanic training and fleet support, roadside assistance, and telematics software. OEMs can assist by considering service needs in their designs and by making replacement parts and repair information readily available. Governments can help by promoting EV repair at technical schools and linking graduates to jobs servicing EV trucks.

4.2.10. Gross Vehicle Weight and Cargo Weight

States have the authority to regulate the gross vehicle weight of trucks for safety reasons and to minimize the impact on publicly financed roads. Most states, including Ohio, limit gross vehicle weight without a special permit to 80,000 pounds. (The Ohio Turnpike is an exception, and allows up to 90,000 lbs. without a permit.) Gross vehicle weight is comprised of the weight of an empty vehicle (tare weight, or unburdened weight) of the truck – typically about 35,000 lbs. for a contemporary diesel Class 8 truck – plus the weight of the cargo.[79, 80] Allowable cargo weight in the typical case would then be approximately 45,000 lbs.

Table 19: Gross Vehicle Weight and Cargo Weight

Fleet Perspective	Mitigation/Alternative
Batteries required for long-haul operations weigh more than equivalent diesel systems, will impact tare weight, and will reduce the maximum amount of cargo they can transport.	NACFE addresses this, indicating that tare weights are less of an issue for many duty cycles.[81] While batteries required for long-haul operations currently weigh more, technological advances in battery density and chassis design will reduce this imbalance. Furthermore, for many duty cycles, typical payloads are often well below the gross vehicle weight requirements.

4.2.11. Operations and Maintenance

Although diesel vehicles have more moving parts and are shown to require more maintenance than EV trucks, the support system for them is dependable and widely available. The EV truck market is in its infancy and maintenance supply chains will take time to develop. Some manufacturers address this by bolting electrical components onto existing chassis, which leverages existing supply chains for most other components.

Table 20: Operations and Maintenance

Fleet Perspective	Mitigation/Alternative
Fleet operators want to gain personal experience. They do not trust white papers and are reluctant to take another fleet's advice.	Government agencies and NGOs can make key introductions and support relationship development – focusing on non-competitor fleets to increase peer to peer sharing. Support for demonstration programs that span a quarter or longer followed by tours and Q&A sessions may provide the most benefit.
Due to the variety of equipment on units (i.e. lift gates, cabin climate control, refrigeration) anticipating total power draw for a vehicle (and by extension a fleet) is challenging.	Calculating the total power need of a delivery truck is a key input to identifying the appropriate vehicle and accompanying EVSE. Power draw information is available for each piece of equipment (including an allowance for drivers' personal equipment), plus experience from other users can help identify needs with the greatest impact (such as refrigeration). Also, if deliveries are made at locations with electrical capacity, trucks can charge while delivery equipment is being used.

Fleet Perspective	Mitigation/Alternative
Due to range limitations, EVs may need to be "route specific" and cannot be swapped out to other routes limiting depot flexibility.	When sizing for an EV fleet, all existing and potential routes should be considered so that the proper battery size and charging equipment can be made available. This will limit the need to limit EVs to certain routes. And until battery technology advances further, longer routes may still need to be served by diesel or other propulsion types.
Compared to existing diesel fleets, there is not yet any established and secure parts, service, and support for the full lifecycle of vehicles from startup OEMs.	Major OEMs are entering the market and beginning to provide full lifecycle service support. Recently announced partnerships, including ones involving Cummins, Toyota, and Paccar, indicate positive movement.
Space/organization of increased number of spare parts that comes with multiple types of vehicles.	While there is some overlap between EV and diesel versions of trucks (such as Freightliner Cascadia and e-Cascadia), there are also substantial differences. In most instances, EV will require fewer spare parts as there is no engine, potentially no gear box, far less wear and tear on brakes (due to regenerative braking), and no need for complicated diesel emission reduction systems. If new EVs are from the same OEM as previous ICE vehicles, the need for additional parts storage will be minimal. Fleets that make wholesale conversions will not need to address this challenge.
EVs need to be able to handle all terrains and all temperatures; cold weather can drop vehicle range up to 25%.	Road grades and temperature extremes reduce range. These conditions must be factored into planning. The City of Columbus, for example, pilot tested vehicles in January and July in order to have a good sense of climate and terrain. As battery technology improves, ranges for these conditions will improve and use cases covering highly variable terrains and the coldest temperatures will find EVs a good investment.

4.2.12. Utility Service

Distribution channels for diesel fuel are well established and reliable. Much of the concern around switching to electricity for fuel is focused on the variability in pricing, power interruption and peak charges.

Table 21: Utility Service

Fleet Perspective	Mitigation/Alternative
Electricity prices may be more variable than conventional fuel-hedged contracts especially when utility peak demand charges are unknown in advance and may change as EV fleets scale.	Commercial electricity rates are subject to contracts like other commodities and utilities have some flexibility with pricing structures. Peak demand charges are variable, but not typically unpredictable.

Fleet Perspective	Mitigation/Alternative
Power interruption with an EV fleet, even for short periods of time, would have a strongly negative impact on operations and profitability.	Backup power is an important consideration when considering EV fleets. Power outages are rare but impactful. Options include fuel-based electricity generators sized for minimum power needs. A greener option is backup batteries charged by off-peak power or by on-site solar panels. Battery power could generate revenue if electric utilities need to buy back power during peak power demand events such as heatwaves.
Once a company converts to EV, it is vulnerable to needing substantial power at times of more expensive peak demand. For example, Class 8 vehicles that run at night and need to charge during the day when demand and cost is high.	Backup batteries that store off-peak, less expensive power and discharge it during the day when power from the utility is more expensive can address this need. Backup batteries also serve as resilience in case of a power outage.

4.2.13. Battery Recycling

Batteries in electric vehicles manufactured today rely on lithium, cobalt, nickel, and manganese. These precious metals are often difficult and/or environmentally destructive to mine and currently less than half of the materials in the batteries can be recycled. The two most common ways of recycling today are pyrometallurgy relying on heat and hydrometallurgy relying on strong acids – neither particularly environmentally friendly nor affordable. As EVs explode in popularity, however, OEMs are finding ways to satisfy consumers desire for an appropriate end of life cycle back into future batteries.[82] The first way is to repurpose batteries that can no longer hold sufficient charge as a powertrain towards battery storage. Repurposed batteries can find useful second lives in support of solar power or wind power generators to store excess energy created during productive periods that would otherwise go to waste. These batteries would then discharge during evening hours or on cloudy or calm days helping stabilize renewable power generation.

Table 22: Battery Recycling

Fleet Perspective	Mitigation/Alternative
Limited options for replacement batteries.	EVs will come with warranties which reflect the needs of the consumers. Secondary markets, which have yet to develop, will need to be able to address battery replacement. Hopefully OEMs will consider the lifecycle value proposition when designing and manufacturing their trucks.
Understanding the upstream and end of life use for batteries. For lead acid there is already a market for recycling.	When batteries are no longer useful for transportation, they still have life as battery storage – where the charging and discharging cycles are less intense and where stability is less critical. Beyond that, some passenger EV manufacturers are already thinking through the end-life of batteries and how to dismantle them to retrieve the valuable materials still inside.

4.3. Notable Freight Projects and Initiatives

The following electric vehicle charging infrastructure projects are ongoing and were highlighted as key freight electrification efforts during outreach meetings.

- **Volvo LIGHTS:** A three-year collaboration between the South Coast Air Quality Management District in Southern CA, Volvo Trucks, and 14 other organizations to develop practices necessary for the commercial success of heavy-duty battery electric vehicles.
- **Ryder System:** A partnership with Ryder, ABB, and In-Charge that will allow Ryder's customers to take advantage of new electrification technologies.[83]
- **Southern California Edison:** ABB partnered with the utility to provide charging systems for Class 8 trucks at SCE's Irwindale, CA facility.[84] The utility recently took delivery of a Freightliner eCascadia, which it uses to move heavy equipment between the Irwindale facility and service centers and storage yards.[85]
- **Electric Island:** Daimler Trucks North America (DTNA) and Portland General Electric Company (PGE) are collaborating to test charging technologies near DTNA headquarters in Portland, Oregon. The Electric Island facility will support nine charging stations and power delivery greater than a megawatt by spring 2021, with plans for additional technology such as solar generation and on-site power storage in development.[86] Ultimately, they hope to work out some of the challenges of zero-emission electricity generation and examine the vehicle-grid interaction.

5. Technological Considerations

The ecosystem for gasoline and diesel vehicles is well established and robust. As relayed through fleet feedback enumerated in **Section 4**, the EV ecosystem is still heavily evolving. This section reviews several technical elements involved in transitioning a commercial fleet to electric.

5.1. Drivetrain

Traditional diesel engines burn fuel in an internal combustion engine (ICE) by compressing an air-fuel mixture until it ignites, producing mechanical energy to spin a crankshaft and transmit power via a transmission to an axle and the wheels. Battery-electric vehicles (EV) store energy in a battery and use it to power an electric motor, which in MD/HD applications is typically connected to the drive wheels via a simplified 1-4 speed gearbox. The simplified gearbox results from the electric motor having high torque at a low speed.

Hydrogen Fuel Cell vehicles store compressed hydrogen gas in a tank, which is then converted into electrical energy in the fuel cell and stored in a battery, which then uses the same EV system to power the drive wheels. Both EV's and Hydrogen Fuel Cell vehicles can recover braking energy by using the electric motor to act as an electric power generator to slow the truck and recharge the battery. A simplified overview of these systems is shown in **Figure 11**.

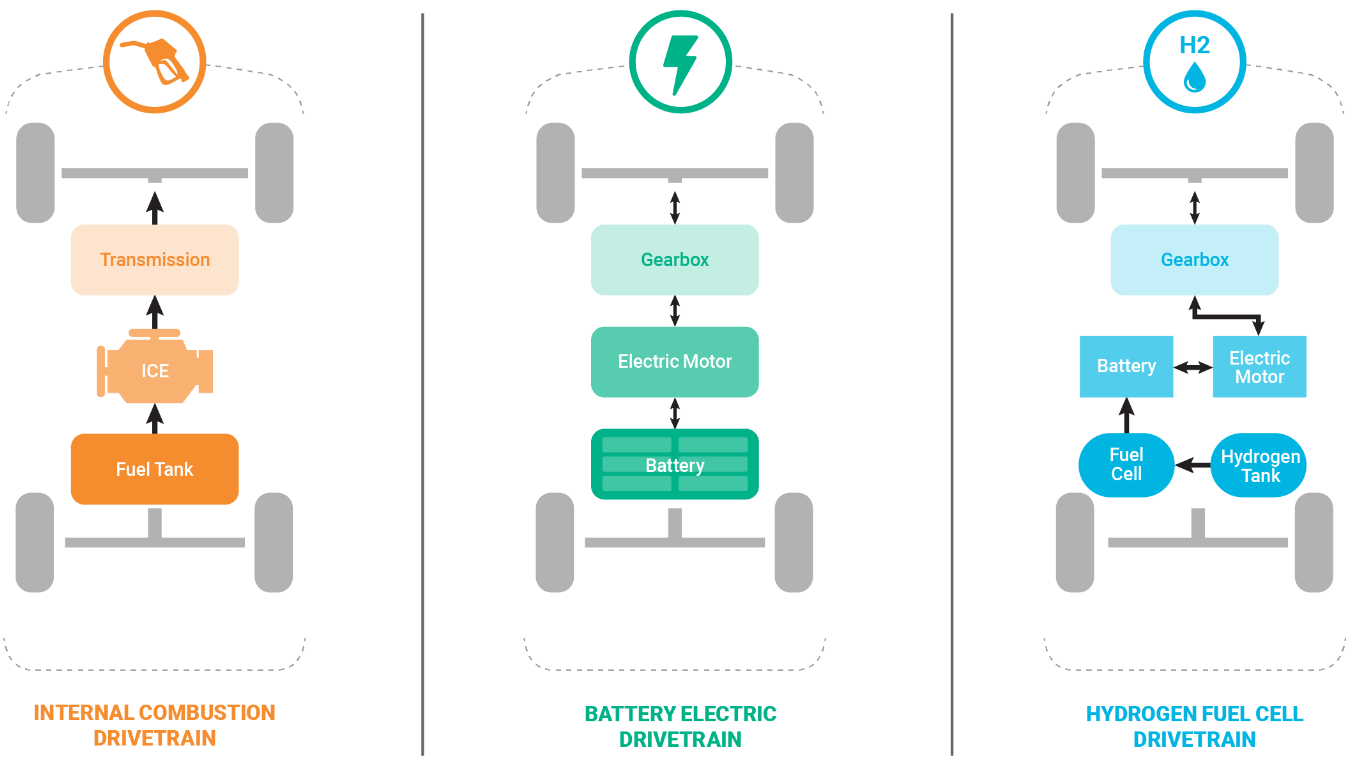


Figure 11: ICE and Alternative Fuel Drivetrains

5.2. Batteries

The rapid reduction in electric powertrain costs have been driven primarily by the reduction in battery cost (**Figure 12**) and increases in energy density (see **Figure 13**). Energy density represents the amount of power that can be stored in the same weight making improvement in energy density important to reducing battery weight. Battery pricing between suppliers and automotive OEMs is considered proprietary and not in the public domain. By producing their own battery cells, vehicle manufacturers can move into new products (like mid- and heavy-trucks and/or buses) more rapidly than their competitors.

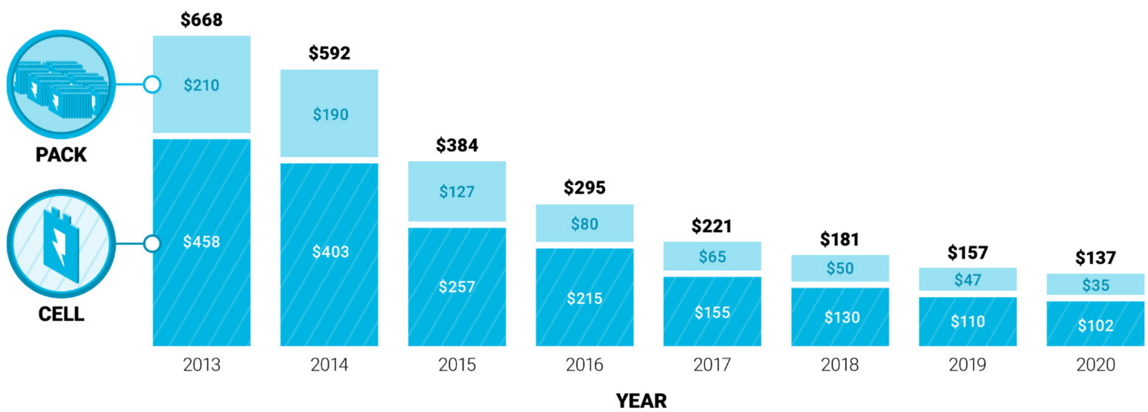


Figure 12: Volume-Weighted Average Pack and Cell Price Split[87]

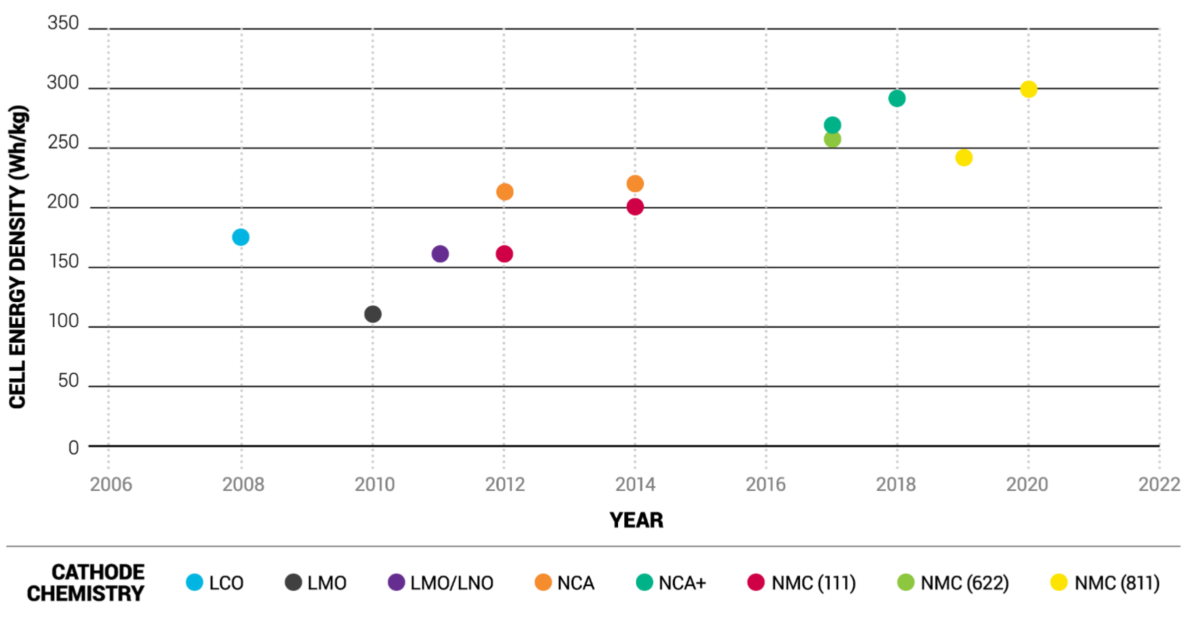


Figure 13: Battery Energy Density[88]

Today's batteries support lithium ions in a liquid or gel material for the anode, or positive side. Solid-state batteries replace the gel with a solid structure for the ions, improving safety and energy density while reducing weight all at the same time. However, the manufacturing procedures for solid state batteries are complex and expensive, and they may not reach market for another 10 years.[89] The weight savings alone are significant, because they mean that trucks can carry more cargo while simultaneously getting better fuel efficiency and weighing less overall, thereby causing less damage to roads and bridges.

Electric trucks typically require much larger batteries that in turn may require higher power charging than most electric light duty vehicles. Higher power charging may be needed if the vehicle requires on-route charging. This places a burden on the battery – the less an electric vehicle needs to be fast charged the better for all system elements. Current typical Direct Current Fast Chargers (DCFCs) range from 125kW to 250kW with 350kW beginning to be available. Units with more capacity up to 1MW will likely be needed to handle the demand of batteries large enough to satisfy the range requirements of long-haul trucking. High power chargers are a necessity for mid- and heavy-duty trucks that need to be charged on-route since the drivers do not have the time available to wait for long charging times. If in a rural location, high-power infrastructure may not be available. Battery-boosted charging power is feasible but cannot satisfy the need if truck traffic is high causing the charger batteries to get depleted.

5.3. Battery Re-Use

Heavy-duty fleet vehicles have batteries that may have useful life even after they are no longer suitable for transportation. It is feasible that they could be repurposed as stationary battery storage for a micro-grid system to increase resiliency, add value, and flatten demand from the grid – particularly in a region where high-power charging is delivered to HD trucks. During off-peak times, the battery can be charged, "filling in" excess generation capacity, while the battery can be used to meet demand during peak times, "flattening" the demand curve. While grid-scale energy storage is growing rapidly, this manner of utilizing the batteries after their vehicle life is still in the early stages of development.

5.4. Automated Trucks

Because of the high cost and shortage of drivers, particularly for long-haul, autonomous driving development is underway to improve truck safety and efficiency. Autonomy can support several use cases, such as accurate vehicle docking to load/unload cargo, stopping over an inductive charging pad, or vehicle platooning. While electrification is not a requirement for autonomy, most of the commercial demonstrations of fully autonomous vehicles are electric vehicles. None are commercially available at this time, though a number are in various stages of testing.

5.5. Electric Vehicle Supply Equipment (EVSE)

Fleet depots are often crowded, and safety of drivers and charging equipment need to be taken into consideration when evaluating new sites or making changes to an existing one. The various charging design philosophies each have unique use cases, advantages, and disadvantages and all will be important as charging technology matures.

- **Wireless:** Wireless charging is being tested for in-road applications and is more commonly used at depots that don't require driver interaction. While progress is being made on wireless charging research in the 20kW-100kW DC range, this will not be fast enough for large trucks. Wireless charging generally requires a standardized receptor under (or on top of) the vehicle. Trucks have a variety of undercarriages and tops that are consistent with their work-function. They also have large capacity batteries that require high power chargers that limit wireless options.

- **Plug-in:** CCS cables on the market today can handle up to 0.5MW charge rates, and Mega Charging System (MCS) systems under development can charge at rates up to 4.5MW.[90] Tesla is also reportedly developing a charger to power its Semi at rates of up to 1.6MW. Chargers that provide about 50kW or more require active cooling systems to prevent the cable from overheating, adding complexity to the system.

  With the higher power requirements that come with DCFC, some people are concerned about safety of charging, especially in bad weather. However, local building codes require chargers be certified by a national certification lab. These labs ensure strict electrical safety and proper manufacturing standards. In addition to these stringent requirements, all charger designs incorporate a communication protocol that ensures the cable is not energized without a secure and safe fit. If this connection is interrupted mid-charge, the charger de-energizes the cable and the cord is safe again. While accidents are still possible, these measures greatly reduce the risk of harm to anyone operating a high-voltage EV charger.

- **Pantograph:** SAE J3105 is the standard for overhead pantograph charging currently in use for many bus fleets and capable of charging at rates of 600kW and above. This seems to be a satisfactory approach for buses that have "clean" roofs but will have limited usefulness in heavy-duty trucks; particularly if they are tractor-trailer vehicles.

- **In-Road Charging:** The difficulty in charging and hauling large batteries has led to an interest with in-road charging—where cables and charging equipment are placed in the roadway and the vehicle acquires a charge while driving. This is an innovative solution as it shifts the burden from the vehicle (and its need to carry a large battery) to the roadway. Catenary systems effectively do the same thing but with wires suspended overhead. The main challenge for this strategy will be to organize manufacturers to produce vehicles that can operate on an inductive road using a charger standard. It also shifts the responsibility for managing power distribution to the governments that control the roads. This approach will probably not be adopted in the near term except in a few extremely high traffic-density locations.

  Also referred to as dynamic charging, research pilots are underway in France, Sweden and Israel for transit buses and heavy-duty trucks, but with falling battery prices and the availability of other charging methods, at $1m+ to $4m per mile for the infrastructure, dynamic charging is not economically feasible for most.[91]

- **Automated features:** The EVSE can obtain data from the vehicle that informs the charger when charging is complete, turns off the charger, and sends a message to the driver that charging is complete. This can be helpful in a truck-stop where other trucks may be waiting to charge. The EVSE driver interface can also provide an invoice to the driver and email it to the trucking company. In the future, connecting and disconnecting the EVSE to/from the vehicle may be automated.

5.6. Battery Swapping

It is possible to replace a depleted battery in a battery electric vehicle with a fully charged one. In existing design configurations, batteries are usually stored in the center chassis for protection, so accessing them to replace them is not trivial. They are usually highly customized to the shape of the chassis and operating requirements of the vehicle, and no unified design exists or is likely to. A few automakers, such as the Chinese company Nio, have embraced battery swapping in passenger vehicles, but the passenger vehicle industry has trended away from this technique and rapidly charging energy-dense batteries seems to be the way forward. Even so, battery replacement remains an appealing option when these constraints can be overcome and may find its niche in applications such as drayage and long-haul trucking where manufacturers and/or larger fleet operators could build out battery swapping networks that addressed specific needs.

5.7. Power Requirements for Depots

Long-haul freight has significant power and battery requirements, and even the DCFCs adequate for topping up passenger vehicles, do not deliver enough range per charging minute to work for freight operations. However, according to the U.S. DOE and Argonne National Lab,[92] the highest impact and biggest short-term need is not single-vehicle megawatt (MW) charging, but lower (still relatively high) rate charging for multiple vehicles in the same location. Regardless of use case, terminal tractors, drayage, last-mile, local, and regional haul (and to some extent, long-haul) all charge at a depot during an off-peak time for their use case. This results in many vehicles charging over a longer time.

A typical urban last-mile depot would require 2- 3MW of power to charge all its delivery vans overnight with load management. A lack of load management results in significantly higher power requirements and could result in prohibitive demand charges for fleet operators and/or require utilities to build additional infrastructure. The impact of load management on power requirements is significant and can be seen in **Figure 14**. Notice how in the bottom portion of the figure the same number of vehicles are charged in the same amount of time using less power capacity. Careful urban and regional planning in coordination with utilities is especially important when freight sites are clustered near one another.

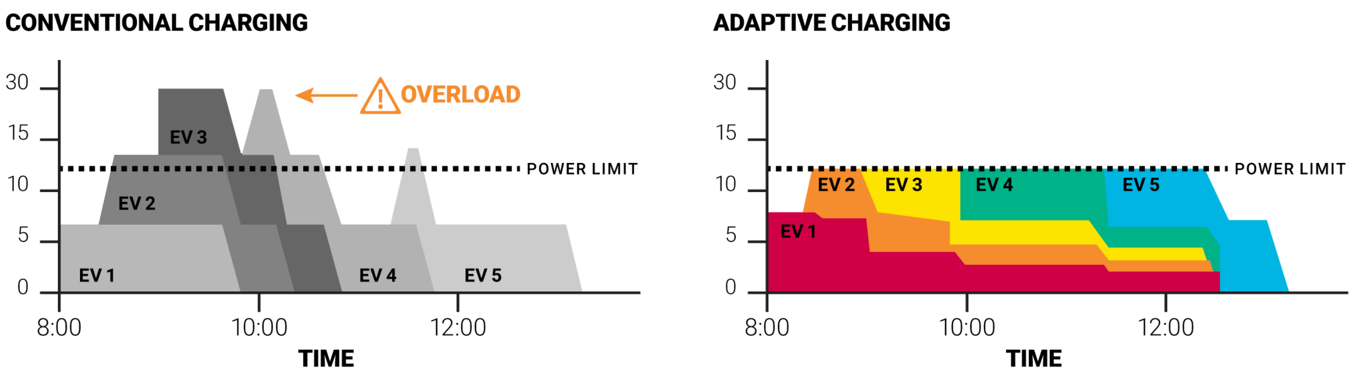


Figure 14: Adaptive Charging Reduces Maximum Power Requirements[92]

5.8. Electric Utility Infrastructure

Coordination between electrical utilities, government planners, and freight suppliers will be critical as transportation electrification accelerates. While utilities likely have sufficient generation capacity for near-term vehicle electrification, coordination can help facilitate energy needs for the longer-term transition. Additionally, different utility rate structures, programs, and operational flexibility needs to be understood and considered as part of vehicle electrification and implementing charging infrastructure.

It is important to consider the demand for electricity across all use cases and more than just commercial freight vehicles. As an example of the challenges that lay ahead, the load for a typical distribution center serving last-mile urban delivery today is about 500kW without electric trucks. Electrified Class 6 trucks serving the same facility would consume about 1.25MW charging in eight hours overnight. This assumes 100 Class 6 trucks that each consume 100kWh / day, and all recharge in the same 8-hour period. Class 8 trucks for the same facility would consume 1.5MW overnight, or 2-3MW if used continuously with 45 minutes to charge.[93] As vehicle electrification increases, so does the need for additional energy from the utility.

Depending on the location and the intended use of the facility, most utilities may be able to accommodate a single site with 1-2MW of demand. Utility customers request service when building new facilities and when expanding. Entities implementing electric vehicle charging need to go through the established utility processes to ensure adequate service is available or can be upgraded to accommodate required charging infrastructure. Utilities currently upgrade the grid based on the forecast of anticipated growth in customer load to serve their increasing energy needs. At this stage, because utilities need to balance investments with rates customers pay for service, they are not generally including additional consumption expectations based on vehicle electrification. There is too much uncertainty in timing and amount of vehicle electrification that will occur to be able to justify rate increases to all customers. This means that utility infrastructure for vehicle electrification is being done reactively rather than proactively and could result in delays when utility system upgrades are required. Fleet owners need to work with their utility to optimize charging infrastructure locations to minimize costs where possible. Fleets both large and small will need to adjust their risk management considerations and facility engineering to accommodate the characteristics of power generation, which are significantly different than those of diesel fueling.

Electrical load management and battery-oriented grid storage can be controlled behind the meter and peak reduction can be enforced by demand charges and time-of-use charges on the utility side as described in **Section 3.3.4**. Both are possible today with existing technology.

Utilities are also looking into offering programs to interrupt or reduce charging when the grid is strained. EVs can help address grid challenges by generating energy on site or storing electricity with use of an energy storage system. The energy needed during peak periods can be drawn from on-site generation or the battery energy storage rather than from the grid. Additionally, when prices are lower, the depot batteries can be charged. This lowers the cost of electricity for EV owners and reduces peak demand for the utility.

The commercial industry should expect to see utility rate structures evolve as fleets transition to electricity. Initially they will be fit into existing industrial structures or preliminary charging structures, as seen in California. Over time, as in the case of Georgia Power, electric vehicle charging will become a rate class unto itself, with different tiers for different needs. State legislators, public utility commissions, and utilities will need to work together to determine who will pay for the necessary electrical infrastructure upgrades to support high power vehicle charging.

Regardless of the front end, the fundamentals remain the same. Trucks will need space, amenities, and a lot of power. Power service is the expensive part with long lead times. Once this is solved, faster chargers can be installed comparatively cheaply. It is easier to put in a new charger with on-site storage and/or a different connector than it is to upgrade the infrastructure behind the charger.

5.9. On-Site Storage, Solar Generation and Microgrids

5.9.1. On-Site Storage

As the cost of batteries decreases, on-site battery storage is an increasingly affordable option for reducing the costs of electricity. On-site storage allows a property to draw electricity from the grid during off-peak times and store it on-site for later use, often with the goal of avoiding demand charges. It’s also a potential use for older vehicle batteries that no longer maintain enough of a charge to use in operation but are valuable for other purposes.

5.9.2. Generation

On-site electricity generation can also help offset electricity costs during peak demand times. Solar is one of the most promising sources of local, renewable generation for local generation due to their relatively inexpensive costs and the fact that much of their energy production coincides with daytime peak demand, making it a good candidate for peak leveling to reduce demand charges and improve grid stability. Panel prices have come down significantly in the last 10 years while efficiency has gone up, making them more attractive for large-scale use. Other types of distributed generation can also serve to provide power during peak periods or when the larger grid is not available. **Figure 15** depicts a set of wind turbines used at a PITT OHIO facility to generate electricity, which is then used in conjunction with rooftop solar to power their electric forklifts.

Figure 15: Wind Turbines at a PITT OHIO Terminal[94]

5.9.3. Microgrids

A microgrid is a small subsection of the grid that can operate on its own using local generation during a power outage. It typical integrates renewable solar or wind generation, batteries, distributed generators, and can power building operation and charging infrastructure. Microgrids are typically designed to reduce critical load.

Proterra has developed a charging solution that directly interfaces with utility-scale 35kV lines. It can charge vehicles at rates of 75-500kW, enabling the same hardware to power personal vehicles and buses. Their system is bi-directional, enabling smart-grid and vehicle-to grid applications, as well as on-site battery and solar integrations. Tesla’s V3 Superchargers can charge their personal vehicles at 250kW each, and their initial site in Las Vegas, Nevada has on-site solar panels for local generation and batteries for demand management. However, there is little discussion from Proterra or Tesla about the power provided by the panels or what the payback period is. To optimize local solar generation, on-site stationary battery storage will be needed.

5.9.4. Broadband Internet

Widespread access to broadband internet will be required to fully leverage the benefits of electrification, such as remote management and peak flattening. These features are key advantages of electrifying for fleets and enable lower electric rates and reliability. However, many areas today do not have access to reliable, fast internet, especially in areas outside of major cities. Providing internet access to these places will be another critical prerequisite for enabling the full advantages of electric vehicles.

6. Goods Movement Use Cases

Electrification of over-the-road (OTR) freight, including associated terminal operations, is being driven by the technical and economic viability of goods movement use cases. As noted previously, based on feedback from fleets, these use cases are being grouped into four categories for discussion:

1. Terminal and off-road
2. Last-mile
3. Local freight and drayage
4. Regional and long-haul

For each subsector, routes, drive/duty cycles, and vehicles themselves are unique. Even within subsectors, especially last mile, unique factors drive vehicle specifications. This is true with diesel vehicles today and will continue to be the case regardless of which alternative fuels gain market share. Charging requirements also vary widely even within each subsector, depending on specific routes, payloads, terrain, climate, and other factors. Refrigerated trucks may also operate in any of the categories listed above.

As vehicle technologies, Total Cost of Ownership (TCO), and charging system capabilities for commercial EVs rapidly evolve their market viability follows. Understanding these dynamics allows governments and utilities to better support private stakeholders, shape policy and appropriately plan charging infrastructure investments. It also helps private companies determine the best transition plan for their specific operation.

6.1. Terminal Off-Road

CURRENT STATUS

Terminal tractors are the best use case for electrification of any commercial EV today. They don't need to idle while stationary and provide immediate power on demand. This saves energy and drives facility pollution loads down. Low speed, start-stop operation is ideal for electrification since Battery Electric Vehicles (EVs) are at their most efficient in this drive cycle. Because they are tethered to home base, charging infrastructure is relatively straight-forward and usually can be handled at lower rates of charge, often Level 2, or a mixture of Level 2 and fast charging. These vehicles often don't operate on public roads, and therefore don't need to be DOT compliant, which can make them easier to deploy.

Many terminals across the country are beginning to add EV terminal tractors. Most deployments have been partially funded by incentives to offset the upfront costs; however, some operators have purchased EV terminal tractors on their own. Even absent incentives, EV yard tractors offer an annual fuel savings that helps drive a positive return on investment in 5-6 years. It is important to note that the upfront cost to purchase these vehicles can still be higher than the industry can tolerate. Their durability, low operating costs, and long-lifespan points toward financing as a logical tool to facilitate faster deployment. Because EV terminal tractors are so new to the market, data on resale value is not sufficient yet.

PLANNING

To anticipate, plan for and accelerate turnover of diesel terminal tractors to electric, the government can work with utilities and other stakeholders to facilitate investments in distribution electric grid infrastructure serving terminal operations. In some cases, where terminals are clustered, these grid investments will be significant. The investments may also serve the needs of other OTR freight subsectors, discussed below. As examples, there are multiple industrial parks in Central Ohio that are devoted to warehouses. Additional investments and policies are discussed in **Section 8**.

6.2. Last-Mile Delivery

CURRENT STATUS

Within this subsector, the best fits for electrification today is lower speed, stop-and-start drive cycles and lighter loads. Urban downtown routes show the most benefit. Suburban service also makes sense. Applications will evolve toward higher speeds and heavier loads as EV batteries become less expensive, lighter and more energy dense. The performance advantages of EVs, especially torque and acceleration, are well suited to last mile drive and duty cycles.

In some states, companies are beginning to deploy EVs for last mile. Many of these deployments are supported with incentives. With the right drive and duty cycle and appropriate financing, some EV last mile delivery vehicles have achieved total cost of ownership parity with conventional vehicles today. The benefits are greater with longer vehicle use lifecycles, as EVs have and operations and maintenance cost advantage.

PLANNING

Providing charging needed by fleets in this subsector will require a combination of solutions. Large and many medium size fleets will want to ensure sufficient charging through Electric Vehicle Supply Equipment (EVSE) installed at their facilities.

Some medium and independent last-mile delivery vehicles may prefer to share charging facilities with other freight subsectors, including terminal tractors and regional freight. In many cases, the higher end of Level 2 (up to 19.2 kW) likely offers a sufficient rate of charge for vehicles domiciled for at least 8 hours. As this sector grows, governments, utilities and private stakeholders should work together to provide larger, multi-port high-power charging located close to logistics centers where freight vehicles of all types come, go, and congregate. These facilities would need to offer numerous, high-power, fast charging ports that could require a combination of significant distribution utility upgrades and onsite battery storage.

To extend delivery ranges without requiring vehicles to be equipped with large battery packs, last mile delivery vehicles also could share use of some fast-charging assets in downtown, city, and suburban locations with taxis, TNCs and other personal mobility users. For larger vehicles, access may require separate, but co-located charging ports offering higher-power rates of charge. For fleets to rely on this set-up there will need to be charging management, a reservation system or near-real time understanding of the charger status.

6.3. Drayage and Local Freight

CURRENT STATUS

Within this range (<250 miles per day), drivers run one or multiple routes between home base and a destination within a single workday. Today, battery technology is insufficient to equip a heavily loaded truck with sufficient range for a single trip at longer distances. However, technology advancements can be expected to make this achievable on a commercial scale within ten years at a total cost of ownership acceptable to the industry. Based on this framing of the drayage and local freight subsector, trucks would not require stops for on-route charging, except in an emergency. Thus, local freight EVs would not be a market driver for extremely high-power and high rate-of-charge facilities needed to serve the regional, and especially, long-haul subsectors.

Today, deployments of full EVs in drayage or local freight operations have primarily been demonstrations, either heavily subsidized by governments or as part of truck OEM research and development projects. These vehicles have been used for shorter routes. To commercialize 100+ mile range vehicles required for much of this subsector, batteries must become more energy dense, and less expensive per kWh of delivered energy. Full scale commercialization of this and other sectors may also require affordable solutions to recycling of battery components, not just single reuse of in-tact batteries. All this likely will require different battery chemistries than those used by the industry today.

PLANNING

Based on how this category is defined, local freight trucks will require charging only at or close to termination points. Charging facilities will generally be housed "behind-the-fence" at trucking or intermodal terminals because demands for total power and rates of charge can be kept lower, avoiding the kinds of extremely costly grid infrastructure upgrades and charging equipment that on-route charging will require. However, as we see deployments of more EVs in local freight, it likely will make sense to provide some shared fast charging infrastructure in areas with clusters of these vehicles.

6.4. Regional/Long-Haul Freight

CURRENT STATUS

The key factor driving planning for these combined subsectors is that both regional and long-haul will require some amount of on-route charging.

- **On-route fast charging:** For fast charging this would likely be at a rate of charge of at least 1 MW or more. This would permit charging times at least comparable with time needed to fuel today's diesel trucks. Facilities will need to offer numerous ports to prevent long queues and wait times. Charging several trucks simultaneously at these rates will require investments on the utility distribution infrastructure side combined with substantial energy storage to flatten demand peaks and valleys.
- **On-route Level 2 charging:** Beyond on-route fast charging, one additional possibility is development of facilities at highway rest stops – commercial and government-owned. During mandated rest periods, truck drivers would charge while parked. They would schedule these charging sessions as passenger vehicle drivers do today with commercial Level 2 and fast charging stations. Power supply needs at facilities still would be substantial, but peaks and valleys could be flattened more easily due to staggered start and stop times and longer charging durations. Rates of charge would be significant but probably more on par with current DC fast charging facilities at 150 kWh. Accommodations might be needed for emergency fast charging at high cost.

Batteries will need to be lighter, denser, and less expensive for trucks to offer ranges needed for electrification of regional and long-haul vehicles to be economical.

PLANNING

Investments in distribution grid infrastructure and deployment of more zero carbon electricity sources, and/or carbon capture and storage at scale is needed for this sector to electrify successfully. Public-private partnerships involving state and federal governments, utilities and their regulators, the trucking industry, manufacturers, retailers, commercial truck stops and owners of potential truck parking facilities, and a wide range of technology solution providers will be needed.

This segment requires the most planning and coordination for successful deployment. For Terminal, Last-Mile, and Local Freight/Drayage, charging is done exclusively on private land and fleet owners can electrify by coordinating with their landlord and local utility company. Long-haul is dependent on the availability of public chargers.

To begin thinking about where public charging should be placed and how much may be needed in Ohio, the six largest cities by population in Ohio, plus Pittsburgh, PA, and Indianapolis, IN were mapped. These areas are likely to be the endpoints for long-haul freight operations and will presumably have depot charging before public charging is needed. Cincinnati / Dayton and Cleveland / Akron were combined for this analysis due to their proximity. Once these cities were selected, a 50-mile radius buffer was placed to identify gaps between them.

The truck parking map seen in **Figure 9** was then used to identify areas that large trucks could physically access within the gaps. These 10 candidate areas can be seen in **Table 23** and **Figure 16.** Some gaps have multiple viable sites (designated as site A, B, and C), while others only have one at this time. This list of sites was provided to the local utility company to determine if enough grid capacity is available at each location to supply 1, 5, and 10 MW of power. As expected, each site has different levels of power available and different costs and timelines for bringing higher levels of power. A fuel station looking to provide electric charging should be aware of these potential costs and timelines since they can be expensive and take years to deploy.

There are still some gaps, including US 23 in the northern portion of the state and US 33 in the southeastern portion. These gaps come primarily from a lack of large truck parking sites along the corridors. Near Cleveland, Cincinnati, and Dayton, there are many warehouses and it is assumed that a truck nearing "empty" there will be able to charge at its destination.

Table 23: List of Candidate Truck Parking Areas for Electrification

Area	Site	# of Truck Parking Stalls	Operator Name	Address	Electric Provider	Additional Load
1		323	Petro	1 Petro Place Girard, OH 44420	Ohio Edison	1 and 5MW capacity available now with 3-4 month lead time. 10MW would require new subtransmission line with ~3 year lead time and typical direct costs of $3.5-4.5M
2		73	Love's	976 OH-97 W Bellville, OH 44813	Ohio Power	1MW capacity available. 5 and 10MW capacity not available.
3	A	92	Ohio Turnpike	Wyandot Service Plaza (EB) Ohio Turnpike Genoa, OH 43430	Toledo Edison	Capacity available now for 1 and 5MW additional load. Required equipment for 1MW costs ~$155k. Possible 10MW capacity exists within 4 miles.
	B	92	Ohio Turnpike	Blue Heron Service Plaza (WB) Ohio Turnpike Genoa, OH 43430	Toledo Edison	Capacity available now for 1 and 5MW additional load. Required equipment for 1MW costs ~$155k. Possible 10MW capacity exists within 4 miles.

Area	Site	# of Truck Parking Stalls	Operator Name	Address	Electric Provider	Additional Load
4		111	Love's	14553 OH-49 Edon, OH 43518	North Western Electric	Capacity available now for 1 and 5MW additional load. Cost to upgrade substation ~1.5mi away for 10MW load would cost ~$1M.
5	A	158	TA	5551 St, OH-193 Kingsville, OH 44048	Cleveland Electric Illuminating	1, 5, and 10 MW would each require extensive upgrade of existing distribution system, 6-12 month lead time.
	B	80	Love's	2 Love's Dr Conneaut, OH 44030	Cleveland Electric Illuminating	Capacity available now for 1MW additional load with 10-12 week lead time. 6-12 months required for 5 and 10 MW.
	C	~100	Shell	780 OH-7 Conneaut, OH 44030	Cleveland Electric Illuminating	New truck stop built after truck parking study was completed. 1MW available now with 10-12 week lead time. 5 and 10MW require subtransmission line extension with 6-12 month lead time.
6	A	144	TA	12403 US-35 Jeffersonville, OH 43128	Dayton Power & Light	1MW capacity available now 5MW would require ~$40k investment 10MW would require $250-275k investment
	B	141	Loves	13023 US-35 Jeffersonville, OH 43128	Dayton Power & Light	1MW capacity available now 5MW would require ~$100k investment 10MW would require ~600k investment
	C	152	Flying J	9935 State Rte 41 Jeffersonville, OH 43128	Dayton Power & Light	1MW capacity available now 5MW would require ~$300k investment 10MW would require ~325k investment
7	A	101	Love's	25727 Durac St Circleville, OH 43113	Columbus Southern Power	1MW capacity available. 5 and 10MW capacity not available.
	B	55	Pilot	25600 US-23 Circleville, OH 43113	Columbus Southern Power	1MW capacity available. 5 and 10MW capacity not available.
8		35	Pilot	61700 Southgate Rd Cambridge, OH 43725	Ohio Power	1 and 5MW capacity available. 10MW capacity not available but could be upgraded.
9	A	145	TA	1775 Bellefontaine St Wapakoneta, OH 45895	City of Wapakoneta	1MW capacity available now. 5 and 10MW could be added in the future.
	B	130	Love's	2241 Fair Rd Sydney, OH 45365	Dayton Power & Light	This site is ~20 miles south of the ideal area and would not capture traffic from US33, but 5MW are available with limited investment.
10		197	Petro	9787 US-40 West New Paris, OH 45347	Dayton Power & Light	Currently at capacity limit. Upgrades are in progress but cost several million dollars and are at least 4-5 years out.

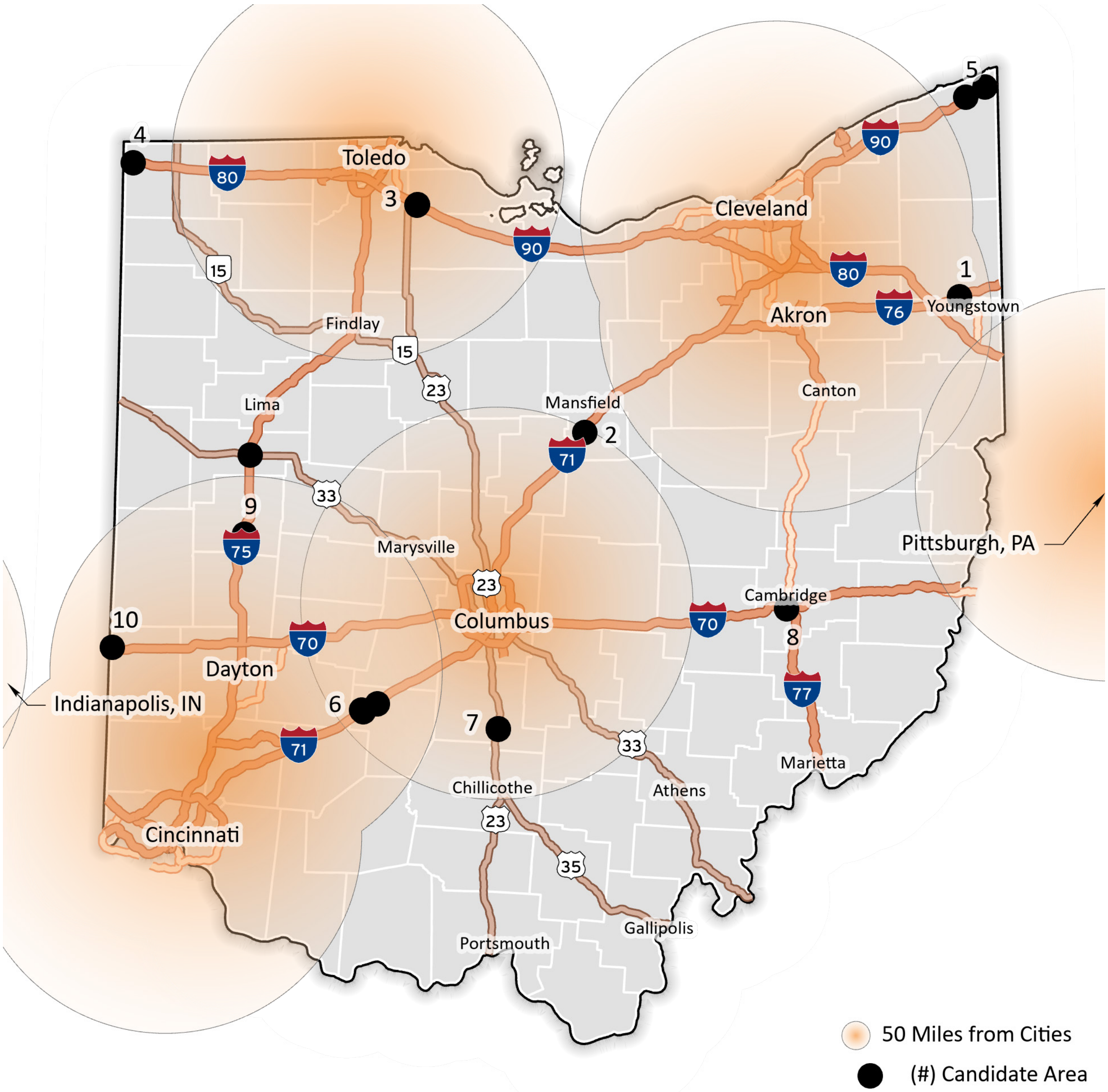


Figure 16: Map of Candidate Truck Parking Areas for Electrification

Coordination among electrical utilities, government planners, and freight suppliers will be critical as transportation electrification accelerates. While utilities likely have sufficient generation capacity for near-term vehicle electrification, coordination can help facilitate energy needs for the longer-term transition.

In this instance, it is important to consider the demand for electricity across all use cases and more than just commercial freight vehicles. As an example of the challenges which lay ahead, the load for a typical distribution center serving last-mile urban delivery today is about 500kW without electric trucks. Electrified Class 6 trucks serving the same facility would consume about 1.25MW charging in eight hours overnight. This assumes 100 Class 6 trucks that each consume 100kWh / day, and all recharge in the same eight-hour period. Class 8 trucks for the same facility would consume 1.5MW overnight, or 2-3MW if used continuously with 45 minutes to charge.[95] As vehicle electrification increases, so does the need for additional energy from the utility.

Depending on the location and the intended use of the facility, most utilities may be able to accommodate a single site with 2-3MW of demand. Utility customers request service when building new facilities and request increases to existing service when expanding. Entities implementing electric vehicle charging need to go through the established utility processes to ensure adequate service is available or can be upgraded to accommodate required charging infrastructure.

As the number of facilities with charging needs grow in number and geographic proximity, more intensive planning efforts are needed to ensure reliable and dependable electrical power. Utilities currently upgrade the grid based on the forecast of anticipated growth in customer load to serve their increasing energy needs.

At this stage, because utilities need to balance investments with rates customers pay for service, they are not generally including additional consumption expectations based on vehicle electrification. There is too much uncertainty in timing and amount of vehicle electrification that will occur to be able to justify rate increases to all customers. This means that utility infrastructure for vehicle electrification is being done reactively rather than proactively and can cause significant delays for when required upgrades can be made for charging infrastructure.

7. Key Insights and Policy Options

7.1. Freight EV Transition Strategic Framework

The viability, pace, and ultimate success of transitioning the freight sector to EVs will require collaboration across all levels of government, the utility sector, the freight/logistics industry, OEMs, equipment providers, and the financial sector. In this section we identify policy item to track at the federal level as well as practical ways the state, local governments, logistics industry, and utility providers can support the transition to an electrified future.

7.1.1. Federal

Historically and currently, the federal government has played specific and fairly limited roles in goods movement. These roles have included:

- **Research, Development and Demonstration:** The U.S. Department of Energy and other agencies have funded research, loans, and grants to help accelerate development and commercialization of promising vehicle technologies. A few commercialization programs have included real-world demonstrations and data collection.
- **Incentives:** These have included tax credits and grants for some cleaner vehicles, fuels and fueling infrastructure. Some credits have come, gone, and sometimes come back again. Unpredictability has hindered market growth of fuels, fuel infrastructure and technologies. Grants have been administrated or made available by USEPA, USDOE, USDA, and various portions of USDOT. Grants have made positive impacts, but bureaucratic complexity is a downside. The federal government may be considering simpler approaches, such as point-of-sale vouchers and rebates.
- **Standard Setting:** In recent years, fuel economy and emissions standards have included medium and heavy-duty vehicles. The Renewable Fuels Standard (RFS) uses market mechanisms and volume targets to drive renewable fuels into transportation. The EPA administers these rules and programs.
- **Education Programs and Tools:** These have been instituted by Clean Cities, various DOE labs, EPA, USDA, and others. These programs have been valuable in educating the market, but inconsistently applied and utilized.

Federal funding is currently available for EV charging infrastructure on the national highway system through existing DOT funding and finance programs, although many of these programs are oversubscribed.[96] The Biden Administration is working to greatly expand the federal role in clean transportation as part of an overall climate and economic reinvestment agenda.[97] Members of Congress and interested parties are advancing additional proposals, some aligned with and others that would expand on the Administration's agenda. Some of these policies and programs seem likely to be enacted in some form.

These federal efforts could help Ohio close the gap with states that have accelerated freight electrification efforts. Given the importance of Ohio's manufacturing and logistics sectors, federal policy is likely to provide relatively greater benefits to Ohio than many other states.

Another potential advantage for Ohio is their significant number of FHWA–designated alternative fuel corridors, with 352 miles designated for electric fuel corridors, and 1,265 miles still pending – as shown in **Figure 17**. These designations are meant to ensure alternative fuel vehicles can refuel along the corridor at regular intervals. For electric vehicles the distance between charging stations must be 50 miles or less.

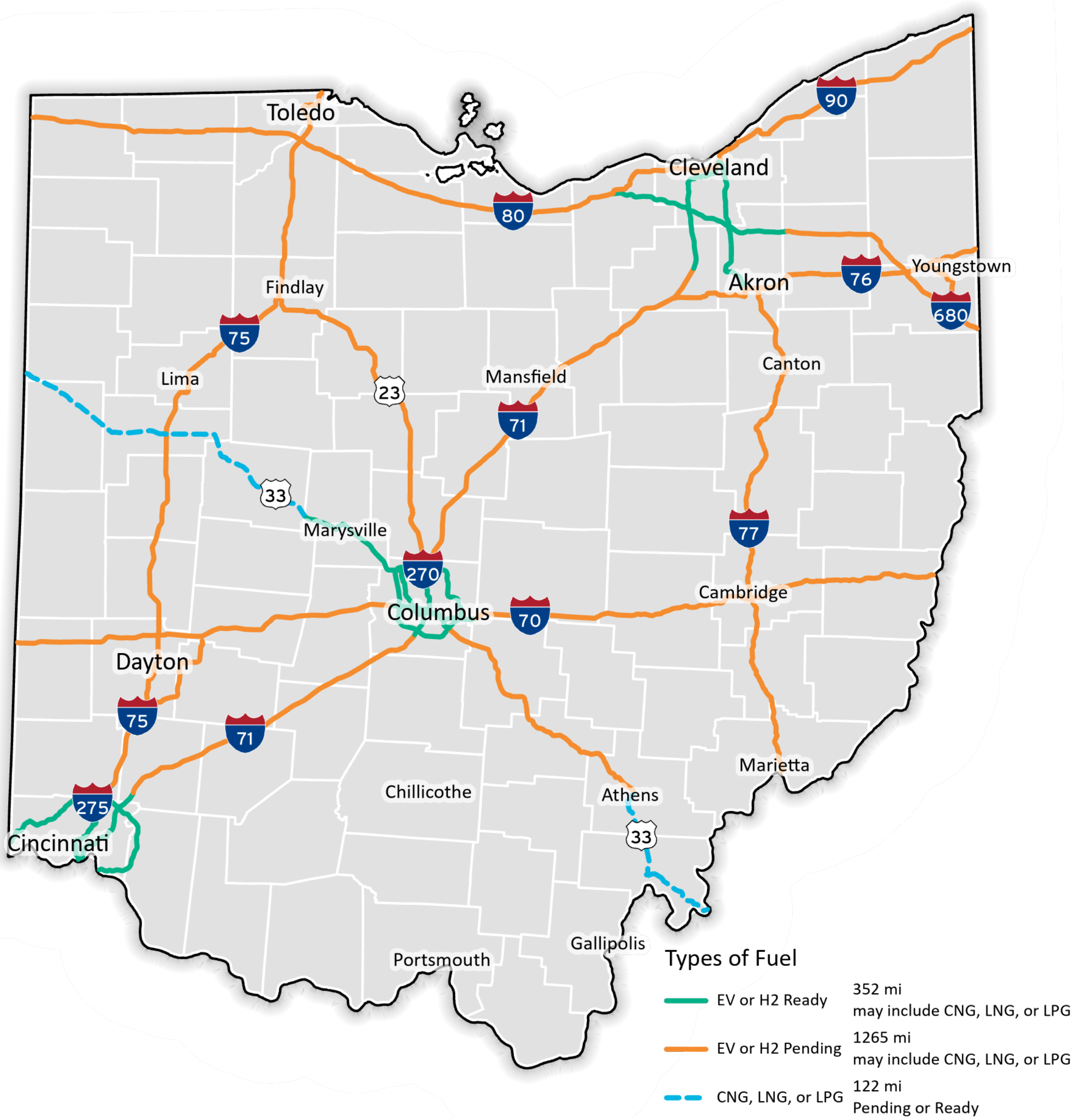


Figure 17: Alternative Fuel Corridors in Ohio

Table 24 identifies some of the potential federal policy actions that may be used to advance EVs in the next few years.

Table 24: Framework for Federal Support of Ohio's EV Freight Movement

Type	Agency	Recommended Policy
Vehicle Incentive	USEPA	**Diesel Emissions Reduction Act:** Update to fund only advanced vehicles, not diesels, and convert the program from grants to simple, point of sale vouchers and significantly increase funding
Vehicle Incentive	USDOT	**Congestion Mitigation and Air Quality (CMAQ) Program:** Create new Buy America policy governing FHWA, restoring CMAQ as a source of funding for clean vehicles, while driving American jobs into sector. Increase CMAQ funding to states with guidance to create voucher or rebate programs and utilize the Public Private Partnership (PPP) provision of CMAQ to include awards to private fleets. Provide funding needed to regional or state agencies to serve as public sponsors.
Vehicle Incentive	USDOT	**Financing Tools:** Direct state DOTs to use existing financing tools for clean vehicles and infrastructure projects. Provide more federal resources and/or new programs for that purpose. Consider how green bonds (bonds that have environmental benefits) can be integrated into a broader financing strategy. Allow stacking of financing and vouchers/grants.
Charging Incentive	USDOT	**EV Charging:** As part of new infrastructure bill, provide funding to state DOTs for EV charging stations, including charging for commercial and government medium to heavy-duty fleets. Allow terminal and public fleet charging to be eligible.
Taxation	IRS	**Federal Excise Tax:** Eliminate the 12% federal excise tax on purchases of new clean, advanced commercial vehicles.
Taxation	USDOT	**Highway Taxes:** Develop and implement pilot program to tax advanced commercial EVs based on VMT, rather than energy consumption.
Demonstration	USDOE	**Vehicle and Charging Demos:** Expand competitive grant funding for advanced vehicle and charging demonstration programs. Include technologies at early stages of commercialization. Allow localized and multi-state projects.
Demonstration	USDOE	**Vehicle/Grid/Building Integration:** Fund vehicle to building (V2B) and vehicle to grid (V2G) integration demonstrations in a variety of utility markets. Include freight vehicles in these demos.
Standards	USDOE	**High-Power Charging:** Facilitate industry stakeholder process to adopt single standard for high-powered charging. Tie government funding for charging infrastructure to adherence to the standard.
Standards	USEPA and USDA	**Renewable Fuels Standard:** Expand and reform the standard to include all lower net CO2 transportation technologies, including EVs, not just the four renewable fuel categories currently included (biomass-based diesel, cellulosic biofuel, advanced, biofuel, and total renewable fuel). Tie credit values to science-based carbon intensity scores.
Standards	USDOT	**Trucking Regulations:** Ensure hours of service regulations are in line with developing trends in automation and electrification.
Standards	USDOT	**Fuel Surcharges:** Allow carriers to gain at least a partial windfall based on the difference between the cost to fuel EVs and other advanced vehicles and the market prices of diesel fuel that otherwise would be used, and upon which the surcharge is based.

7.1.2. State

The State of Ohio has many tools and strategies to use across multiple departments to help prepare Ohio for freight electrification and advanced transportation technologies. These tools include direct incentives, financing, taxation, codes and standards, procurement specifications and direct purchases, study, education and convening authority.

- **Codes and Standards:** The Ohio Department of Commerce could update the state building code, encouraging local jurisdictions to require that some parking spaces at new or expanded logistics facilities be hardwired to prepare for future installation of EV charging equipment.
- **Study, Convene and Educate:** The state could examine and use its convening forum in several areas. These include sustainable taxation of roads, how to fund utility distribution grid upgrades needed for freight electrification, strategies to address disproportionate community impacts of pollution from freight/logistics operations, leveraging community colleges and others to provide training to heavy-duty vehicle technicians.
- **Data Analysis:** The state has access to valuable data which could be used by all levels of government to facilitate and manage the transition to electrical fleets.
- **Purchasing:** The Ohio Department of Administrative Services could expand efforts to develop procurement specifications for EV charging equipment and vehicles by including higher-power equipment and heavier-duty vehicles. The state could create criteria for purchasing medium and heavy as well as light duty EVs for its own fleet and encourage local governments to consider these purchases.
- **Vehicle Incentives:** The Diesel Emission Reduction Grant (DERG) program utilizes $10 million per year in federal CMAQ dollars to provide grants to replace older diesel vehicles. CMAQ offers the benefits of broad eligibility and flexible rules. DERG could be reformed and streamlined to increase the pace of fleet turnover per program dollar. Vouchers and rebates are emerging as best practices. The Public Private Partnership (PPP) provision of CMAQ opens this source to commercial fleets. Any new state programs could be aligned with DERG and potential federal sources. Consider housing newly streamlined programs under ODOT or OAQDA, where they also could be more easily integrated with existing and potential new financing tools.
- **Infrastructure Incentives:** The OGA is considering state incentives for EV charging. These incentives could include freight electrification. Administration could be combined with new federal sources, if created.
- **Financing:** Ohio has a variety of financing tools. The OAQDA can facilitate financing and forgiveness of some taxes for clean vehicles and infrastructure through its Clean Air Improvement Program (CAIP). OAQDA is actively considering additional, potentially larger, financing programs. ODOT itself has financing tools that could be utilized to help develop clean vehicles and charging infrastructure.
- **Taxation:** Mass transition to EVs would endanger the gas tax as a mechanism to fund Ohio's roads. The state could study solutions. Since other states and the federal system face the same risk, Ohio could join with other states to seek common solutions.

Table 25 identifies specific actions the state can take, many of which do not require capital expenditures.

Table 25: Framework for State Government Support of Ohio's EV Freight Movement

Type	Agency	Policy Options
Data	ODOT	Provide latest trends on EV adoption by zip code, city, and county to local and regional agencies.
Data	ODOT	Ensure state vehicles have telematics capable of reporting state of charge and other key indicators.
Fleet	ODOT	Evaluate state fleet and duty cycles to determine which vehicles may be appropriate for EV conversion.
Planning	ODOT	Plan freight-oriented EV corridor charging: gap identification, power supply analyses, priority locations for private sites.
Guidance	ODOT	Provide visible leadership to cities, counties, and MPOs by convening coordinating meetings between government, utilities, and private freight stakeholders. Conduct statewide EV freight analysis on a recurring basis by making EV a key part of statewide freight plan updates.
Guidance	ODOT	Provide guidance to local governments on permitting, ROW easements, standardized Electric Vehicle Supply Equipment (EVSE) layouts and specifications, ideal locations for freight EV charging.
Education	ODOT	Identify point person within ODOT who is responsible for knowing about freight-related EV grant funding, learnings from other jurisdictions, and who would lead state efforts on transportation electrification.
Education	ODE	Technician Training: Support programs in partnership with Ohio's community colleges, leading universities, Jobs Ohio, OEMs, and fleets. Include MD/HD EV training in curriculum. Include EVSE training in partnership with electrical trades. Link graduates of these programs to jobs in the sector.
Incentive	ODOT	If FHWA creates *Buy America* policy applicable to CMAQ funding of clean vehicles, reform DERG to eliminate bureaucratic requirements, and roll the funding into the new state voucher program above. Relocate administration from OEPA to ODOT, or OAQDA. Same list of eligible vehicle types.
Incentive	OAQDA	Consider a "green bond" financing (investment) program that includes freight vehicles and charging. This can be managed by OAQDA. Utilized existing ODOT financing tools.
Promotion	JobsOhio	Promote Ohio's capacity and resources for OEMs (e.g. TRC).
Procurement	ODAS	Maintain and publicize to Ohio agencies EV chargers that are on the state's universal term contract list.
Procurement	ODAS	Add and publicize to Ohio agencies EV vehicle models that are on the state's universal term contract list.
Promotion	ODOT, Ohio EPA	Identify and promote top location targets for charging.
Promotion	JobsOhio	Identify and promote vehicle battery recycling efforts.
Grid	PUCO	Study level of investment, and policy and mechanisms needed to fund needed upgrades in grid infrastructure to supply power to freight EVSE, include freight terminals, truck stops and other appropriate locations. Address EV charging rates including demand charges. Plan for grid resilience in the face of storms or other unforeseen events.

Type	Agency	Policy Options
Taxation	ODOT	In coordination with FHWA, pilot test new ideas for funding road and bridge construction that could include VMT-based taxation rather than taxation based on fuel (or electricity) consumed.

7.1.3. MPOs/Counties/Cities and Towns/Counties/MPOs

Metropolitan planning organizations play critical convening and education roles. Most importantly, they can undertake coordinated region-wide planning that creates a bridge between statewide and municipal levels. Counties can also support progress, especially in more rural parts of the state. Ohio local governments play an important role in freight electrification, especially given their business connections and specifically for the last-mile segment, as part of their broader transportation electrification effort. In some instances, items shown as potential city ordinances may be more easily handled at a statewide level.

Table 26: Framework for MPO/County/Local Support of Ohio's EV Freight Movement

Type	Policy Options
Fleet	Set local fleet electrification goals.
Fleet	Analyze opportunities to add EVs to local government and other fleets, including federal grant opportunities.
Fleet	Ensure vehicles have telematics capable of reporting state of charge and other key indicators.
Charging Prioritization	Conduct assessments of public access charging needed to serve regional fleet needs, especially last mile delivery involving multiple stops at retail sites, businesses, and residences.
Charging	Support matchmaking of site hosts, OEM suppliers and dealers (including EVSE), utilities, permitting agencies, incentive programs, and funding opportunities.
Education	Publicize to member agencies EV vehicle models that are on the state universal term contract list.
Education	Educate members on needed local policies and encourage adoption.
Education	Educate elected officials and staff on fleet electrification and grid impacts
Education	Provide forums to consider electrification of government fleets and strategies to incentivize electrification of private fleets.
Education	Provide opportunities for governmental staff to be educated on goals and processes of EV transition.
City Ordinance or regulation	Adopt building code requiring wiring and proper site design for EVSE during construction or significant renovation
City Ordinance or regulation	Prohibit non-EVs from parking in designated EV spots.
City Ordinance or regulation	Prohibit restrictions by commercial and residential property management and others on installation of EVSE, if owner assumes financial responsibility.
City Ordinance or regulation	Adopt rules clearly governing process for installing EVSE in public ROW.
City Ordinance or regulation	Streamline and shorten permitting processes for installation of EVSE in any location. Link permits to effective design (e.g. pull-through charging at truck stops, mix of charging levels, charging connectors, etc.)

Type	Policy Options
Municipal Procurement	Require thorough review of feasibility to integrate EVs and other low net CO2 alternatives into government fleets. Use lifecycle cost accounting to determine feasibility.
Curb Space	Conduct and follow through on studies addressing curb space, loading zones, and district-specific emission caps.
Data	Gather and maintain regional EV data to facilitate planning and grant applications.

7.1.4. Logistics Industry: Shippers, Carriers and Third-Party Logistics Providers

Goods movement is an interdependent ecosystem of shippers that must receive and send raw materials, components, and finished products. They depend on carrier fleets operating throughout this chain of shipping and receiving. Third party providers manage warehouses, terminals, and other facilities. Progress toward freight electrification will require shared efforts to set goals, identify barriers, conduct demonstrations, share data and lessons learned, and work with state and local government actors to devise, test and validate solutions.

Table 27 identifies a few items fleets can consider as they plan and implement their transition to electric vehicles.

Table 27: Framework for Logistics Industry to Support Ohio's EV Freight Movement

Category	Policy Options
Demonstration	Undertake projects to put equipment into service, gain operating experience, gather data, and obtain results that can be validated and shared.
Replication	Share lessons learned with others.
Messaging	Ensure EV roll outs generate driver enthusiasm by confirming new equipment works as intended and issues are resolved ahead of time – as much as possible.
Financing	Consider innovative financing (bond or investor financing, longer leases) that enable carriers to take advantage of positive return on investments that take longer than typical 3-year lease contract terms.
Operations	Evaluate the use of networked chargers to manage demand as fleets scale.
Contracting	Ensure contracts with EVSE vendors provide sufficient maintenance and support.
EV Charging Rates	Leverage the value of battery storage technology to lower charging costs in a demand-based utility rate structure.
Utility Coordination	Work with utilities early in the process to assess potential needs and costs for distribution grid upgrades for EV charging.

Figure 18 steps through the high-level decision-making process for fleet EV implementation and can serve as a tool for fleets considering this transition.

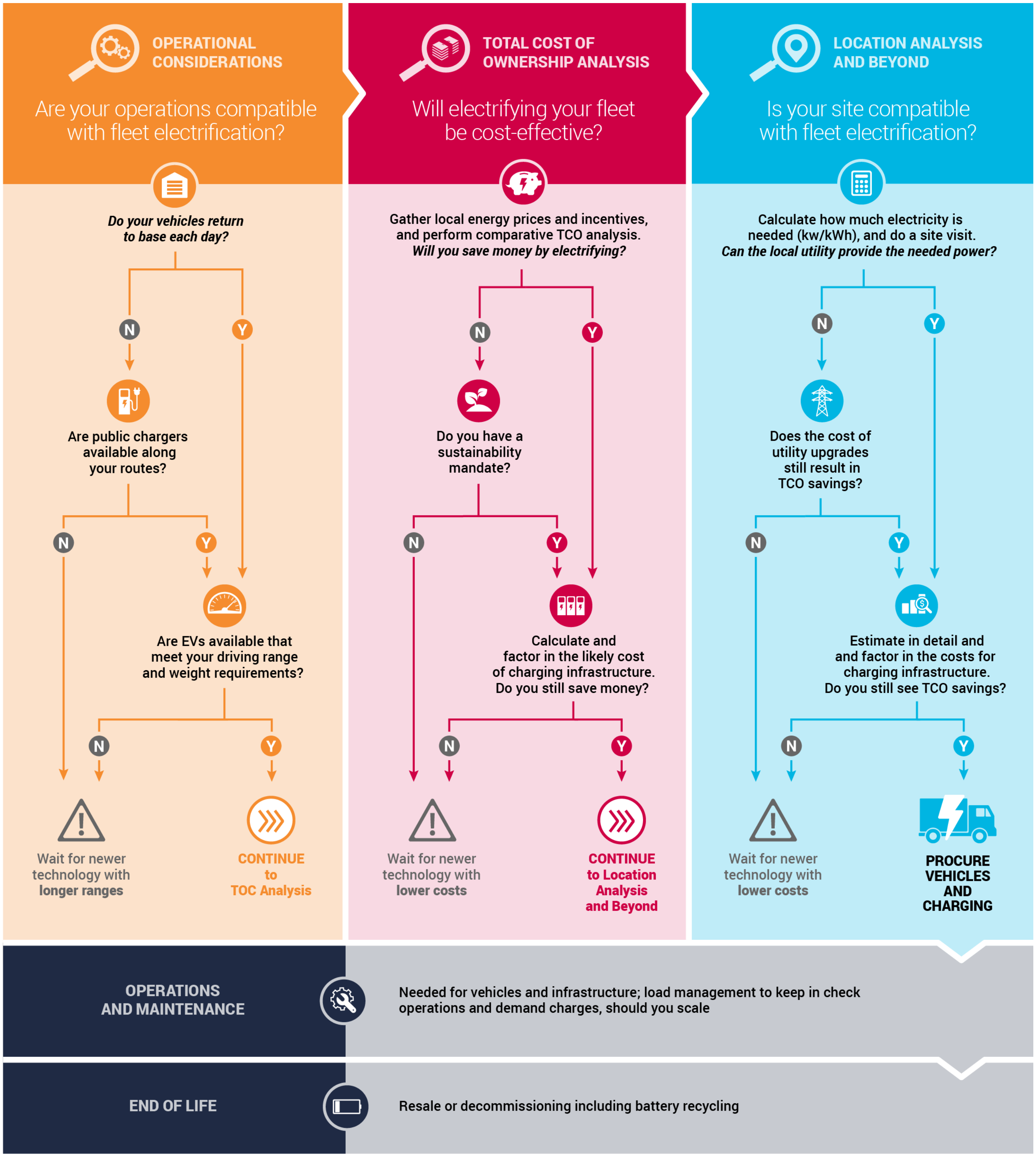


Figure 18: Fleet Electrification Implementation Flow Chart

7.1.5. Utilities

As illustrated earlier in this report by **Figure 10**, Ohio has a diverse set of utilities. Four are large private investor-owned companies regulated by the Public Utilities Commission of Ohio (PUCO). Several are controlled by municipal governments. Others are private cooperatives, serving mostly rural communities. All utilities, regardless of type, will be called upon to serve the needs of the goods movement industry as it transitions to EVs.

Even with this complexity, the investor-owned utilities (IOUs), working with regulators at the PUCO, are in a position to create the financial structures to provide massive upgrades to distribution grid, battery storage infrastructure, and potentially microgrids to power an electrified freight sector. IOUs and regulators also can create rate systems to help overcome the significant barrier of demand charges as currently structured.

Ohio's IOUs will not solve these problems alone. Utilities and state regulators across the country are considering how to solve problems, and there may be a federal role.

As IOUs develop financial solutions, municipal and co-op utilities may be able to use these as models. However, these non-regulated utilities don't have the deep pockets and rate bases needed. They will need help from state or federal resources. Financing may play a role. Below are initial steps both IOUs and their non-regulated counterparts can begin to take. The PowerForward docket, concluded in 2019 may be a useful model to follow.

Table 28: Electric Vehicle Charger Incentives and Funding Sources

Source	Type	Eligibility	Notes
AEP Ohio	Utility	AEP Ohio Territory	• Past Funding: Level 2 public, MUD, workplace, DCFC, $10 million total from 2017-2020 • Potential Future: Filed, pending PUCO action, $4M annually recurring, DCFC, Level 2 public, MUD, and workplace
Dayton Power & Light	Utility	DP&L Territory	Potential Future: Filed, pending PUCO action, $5.1M, DCFC, Level 2 public, MUD, and workplace
Duke	Utility	Duke Territory	Potential Future: Filed, pending PUCO action, $15 million, DCFC, Level 2 public, MUD, and workplace
Municipal and Co-Op Utilities	Utilities	Any site type	Potential Future: Subject to approval by utility boards

Table 29: Framework for Utilities to Support Ohio's EV Freight Movement

Category	Policy Options
PUCO Coordination	Collaborate with PUCO to proactively plan for grid investments to support commercial EV transition.
Rate Structure	Evaluate rate structures, including providing off-peak EV rates to commercial users.
Battery Storage	Enable battery storage so fleets can charge vehicles during peak times at lower cost and with less strain on grid.
EVSE Incentives	Provide flexible incentives for EVSE which do not preclude use cases.
EVSE Sites	Identify and promote low-cost sites for EV fleet expansion (e.g., under-utilized grid infrastructure).

7.3. Workforce

The freight and logistics and the automotive sectors each support over 100,000 jobs in Ohio. Gaining a reputation for supporting the electrification transition will help attract more manufacturing investments and spur parallel investments in automation transforming the freight industry. Because EVs have about 40% fewer parts and are generally easier to assemble than internal combustion engine (ICE) vehicles, there will likely be fewer auto-manufacturing jobs in the future.[98] However, it is important to note that EV and other advanced automotive technologies have the potential to replace many lost ICE vehicle manufacturing jobs.

To offset diesel manufacturing unemployment during this transition, the United States is looking to on-shore more of the semiconductor chip, lithium-ion battery, and other emerging automotive technology supply chains. Currently, there are notable shortages with the semiconductor supply, causing several automakers to cut back on vehicle production.[99] These supply chains are absolutely critical for current and future EV production and the competitiveness of Ohio (nationally) and the United States (globally) in the automotive industry moving forward.

Attracting these advanced technology supply chains to Ohio will create many scientific, technical, and manufacturing employment opportunities. The battery manufacturing process contains three distinct assembly steps, with the initial cell production step typically occurring overseas in China, South Korea, and Japan.[100] Then, these battery cells are imported into the United States and assembled into battery modules and packs before they are installed into vehicles. On-shoring the battery supply chain from the material acquisition of lithium, cobalt, and other key raw earth materials to assembly will adequately replace obsolete ICE vehicle positions. In addition, the semiconductor supply chain offers many high-demand employment opportunities. With costly shortages in the market, semiconductor availability is a critical factor for the production of EVs and other electronics. The United States is already taking action to secure and on-shore this supply chain by investing $22 billion dollars in domestic manufacturing and research.[101]

Given the importance of the automotive industry to Ohio's economy, there is greater impetus than ever to capitalize on this transition and utilize the automotive resources and infrastructure already established here.

7.3.1. Advanced Vehicle Supply Chain and Manufacturing

Over the next decade, 29 major global automakers are investing at least $300 billion into EVs.[102] Ohio, a long-time leader in automotive manufacturing, is well-positioned to reap the benefits from EV technology and manufacturing. With existing automotive manufacturing and end-to-end supply-chain infrastructure in the state and Midwest region, Ohio has a competitive advantage and can spearhead the EV transition. The economic impact of EV manufacturing in Ohio alone is projected to create 2,000 jobs, putting $135 million more dollars (in annual wages) into the Ohio economy.[103]

To reduce capital expenditures and prohibitive up-front costs, EV manufacturers should tap-into the existing manufacturing infrastructure across Ohio. Retrofitting a shuttered ICE automobile plant for EV production has the potential to same time and turn profits sooner.

7.3.2. Electric Vehicle Maintenance and Technician Workforce Development

Because EV design and technology differ significantly from ICE vehicles, mechanics and service technicians will need knowledge of EV upkeep, maintenance, service components, and parts to support the transition to vehicle electrification. In 2018, there were 27,470 automotive service technician and mechanic jobs in the United States, which underscores the tremendous opportunity for workforce development in this area.[104] As EVs flood the commercial and consumer markets over the next decade and onward, automotive technicians will need training and continuing education in EV maintenance. Continuing education and technician training already occur in Ohio; there are post-secondary vocational programs, community colleges, online instructional resources, and automotive-specific institutes or programs that can supplement their current training and continuing education curricula with EV content. Grants can be used to expand these programs and provide an opportunity to procure equipment to ensure students get sufficient hands-on experience.

7.3.3. Electric Trades EVSE Workforce Development

The continued adoption of EVs relies on the installation of accessible EV charging infrastructure. Because Ohio is the fifth largest home to electricians in the United States, there is an even greater workforce development incentive here.[105] Through EV charging installation and maintenance, the electric trades will become newly integrated with the automotive sector, generating increased employment opportunities to support this transition.

By leveraging the Electrical Industry Training Centers and International Brotherhood of Electrical Workers in Ohio, the electrical trades can use their existing organizational networks to prioritize training in EV charging installation. Further, any apprenticeships can require a certain amount of field experience in EV charging planning and installation to ensure workers are prepared for the growing demand. Because electrical professions often require certification, EV charging installation training and knowledge could be integrated as a mandatory component to become certified.

7.4. Equity

Disadvantaged communities have traditionally borne the brunt of expanding logistics as freight operations such as distribution centers and intermodal hubs tend to be built near low-income and minority communities. These communities are also frequently environmental non-attainment zones. Concentrating air polluting activities near low-income and minority communities causes negative health outcomes, lower quality of life, and disrupted communities. Noise pollution is also a serious concern around most freight facilities since terminals and ports with diesel equipment are loud and often operate around the clock. Electrifying these operations will improve air quality and reduce noise pollution and is an immediate tangible benefit of electrification.

A program by the State of Massachusetts[106] is extending subsidies for businesses to purchase electric medium and heavy-duty trucks. The state is incentivizing the program more heavily when trucks will be operating in primarily low-income areas. Programs like this can be tracked to determine if there are lessons learned or opportunities to apply certain elements in Ohio.

Appendix A. Overview of Key Research

A.1. McKinsey Center for Future Mobility

This report analyzes three critical assumptions about Total Cost of Ownership parity for electric trucks compared to diesels. They examine fuel and electric efficiency, cost of batteries, and cost of fuel and electricity. They find that urban use cases are more sensitive to changes in these parameters than long-haul, and that access to charging is less critical than for passenger vehicles because the use patterns are more predictable. They recommend depot charging to unlock predicable rates and availability. They claim LD trucks were cost comparable in 2017, with urban last mile becoming competitive between 2017-2021, regional hub and spoke deliveries 2017-2023, and long-haul freight 2023-2031. Despite the predictions about cost competitiveness, they acknowledge that widespread adoption will take much longer.

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry

A.2. ATLAS Public Policy

This assessment attempts to demonstrate critical factors for cost competitiveness of freight EVs compared to diesel. They find there are two critical elements required for the success of EVs: low-cost charging and up-front vehicle incentives. Low-cost charging is primarily achievable through private depot charging where there is no middleman and the fleet can manage demand. Public charging is more expensive because it requires higher rates of charge and a middleman charge station operator who will need to be paid as well. Vehicles that have higher utilization have a greater opportunity for cost savings but are more susceptible to variations in the price of electricity. State-level purchase incentives affect price parity but are not essential for the success of freight EVs. Maintenance costs are not an important determinant of cost competitiveness of EVs.

https://atlaspolicy.com/projects/accelerating-the-adoption-of-electric-trucks-and-ev-charging-infrastructure/

A.3. Electrifying Freight: Pathways to Accelerating the Transition

A report published by the Electrification Coalition, released in 2020, analyzes the barriers to electrifying the MD- and HD markets and discusses ways to overcome them. They identify the 12% federal excise tax as disproportionately affecting electric heavy-duty vehicles, which have a higher purchase price. A typical price differential of $100,000 - $250,000 between a diesel and equivalent EV would add an additional $12,000 - $30,000 in FET alone, which the fleet operator must pay up front. Other barriers include uncertainty around resale value, maintenance, and performance. They also point out that many depots where charging would take place are leased, and the fleet operators cannot install the electric service that would be required to charge a fleet of trucks. Uncertainty and delayed releases of electric vehicles mean procurement as usual for fleets, who need to meet rising demand with available technology.

In order to overcome these barriers, they recommend removing the federal excise tax for zero-emissions Class 8 vehicles, streamlining the electric permitting process, implementing fleet emissions standards, decoupling scrap requirements from incentive programs, and having OEMs and states lead workforce training.

https://www.electrificationcoalition.org/electrifying-freight-pathways-to-accelerating-the-transition/

A.4. ACEEE Electrifying Trucks

A report published by the American Council for an Energy-Efficient Economy, discussing benefits of electrification of the MD- and HD sectors. They find overall energy reduction of 24-40% depending on vehicle class and use case from electrification, as compared to diesel fuel. They also find the payback period for an electric Class 8 truck is about 5.5 years longer than a diesel, compared to just 3.3 years longer for Class 4 and 5 vehicles. They identify fleet barriers as purchase price, lack of adequate on-site charging, and a general lack of high-power charging. They recommend expanded funding for transitioning, even in California, and improved data collection about vehicle inventory and use.

https://www.aceee.org/white-paper/electrifying-trucks-delivery-vans-buses-18

A.5. West Coast Clean Transit Corridor Initiative

A report published by HDR in partnership with CALSTART, focused on the states of California, Oregon, and Washington identifies barriers and opportunities to electrifying MD and HD sectors along I-5 from California to Washington. They identify various barriers, mostly focused on charging infrastructure and including long lead times, lack of funding, land constraints and a dependence on site-specific details such as distance to interconnect and local capacity. They recommend planning early, encouraging the power utility to take a leadership role, and developing programs that will benefit utilities and fleet owners together.

https://www.westcoastcleantransit.com/

A.6. Medium-Duty Electric Truck – Cost of Ownership

The North American Council for Freight Efficiency releases a 2018 Guidance Report on electric trucks focused on MD trucks. This unbiased report details the multiple factors fleets should consider in selecting commercial EVs, with special consideration on the cost and benefit factors in estimating return on investment.

https://nacfe.org/report-library/guidance-reports/

A.7. 2019 Annual Fleet Fuel Study

A study released by North American Council for Freight Efficiency in 2019 provides a deep dive investigation into the adoption of freight efficiency products and the practices that support. This study examines 21 of the major North American Fleets. This study looks at Class 8 tractors and trailers which includes day cabs and sleepers in both regional and long-hail applications.

https://nacfe.org/annual-fleet-fuel-studies/

A.8. Run on Less

In 2019, the North American Council for Freight Efficiency released their Run on Less study showcases the best-of-the-best, cross country roadshow for the advancements in freight efficiency. The report highlights the best possible use of the technologies, operational practices, and driver capabilities.

https://runonless.com/regional-report

A.9. Argonne Megawatt+ Working Group

A group that meets to discuss development of greater-than-megawatt charging, their meetings are available to view online. They discuss existing efforts to develop fast charging for freight applications, including: short-term needs, adaptive charging, existing connectors, new connector development, and grid storage and solar options to reduce peak demand.

https://bluejeans.com/playback/s/6kGY9w9GA29Dls3vK7DcW5G1RRBNX4CVa8bSU5gK6vQDlOzB6GLCFkfjMzmULJM7

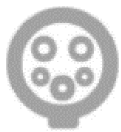
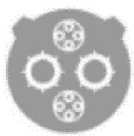
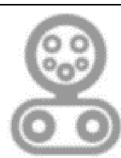
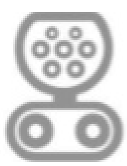
A.10. National Renewable Energy Laboratory Electrification Futures Study

This study models demand-side adoption scenarios for transportation electrification. It is the second in a forthcoming series of reports to explore the impacts of electrification on the U.S. energy market. Of the scenarios NREL examines, they find that the transportation sector has the largest shift toward electrification by 2050, with 76% of VMT in 2050 being electric.

https://www.nrel.gov/analysis/electrification-futures.html

Appendix B. Charger Type Overview

Table 30: Existing EV Charger Types

Charging Station Level (Electric Current Type)	U.S. Connector Type	Power	Fill Time for 100kWh Battery (80% Fill)	Voltage	Best Commercial Use Case Example
Level 2 (AC 1-phase)	 SAE J1772	• > 3.7 kW • ≤ 22 kW	• 7 kW = 12.5 hours • 22kW = 4 hours	208/240V	MD and HD vehicles that sit parked for 5+ hours at a time
Direct Current Fast Charging (DCFC)	 CHAdeMO	• > 22 kW • ≤ 43.5 kW	• 2+ hours	277/480V	MD and HD vehicles with shorter routes/smaller battery packs that have a natural pause in their duty cycle of around 2 hour or more; MD and HD vehicles with a longer route / larger battery packs that can charge over several hours
DCFC Combo (AC, DC fast charging) *Note: Combined Charging System (CCS1) combo 1 connector is currently used in North America, but the CCS2 combo 2 may be used in North American MD/HD applications.*	 J1772 CCS1  J3068 CCS2	<450 kW today; up to 1 MW projected	• 40+ minutes (today) • 15+ minutes (future)	Industrial voltage levels (speak with your utility)	MD & HD vehicles that have a natural pause in their duty cycles (e.g., while waiting at a loading dock) that is less than 2 hours
Inductive charging (DC)		Inductive charging equipment uses an electromagnetic field to transfer electricity to a plug-in electric vehicle without a cord. In HD applications, inductive charging is often used for in-route charging on bus routes with 150-300 kW charging capability.			

Appendix C. Demand Charge Comparison

Electric Loads come from a presentation by Mike Rowland on Advanced Energy.[107] Assumptions from his example are spelled out in **Table 31**. The Ohio PUCO calculator was used to calculate electric bill and demand charges using the standard commercial rate on 10/05/2020. No commercial vehicle charging rate is available in Ohio. The calculator does not account for time-of-day charges, infrastructure build-out fees required to support this level of charging, or additional fees that could be imposed to cover maintenance for roads and bridges.

Table 31: Parameters for Demand Charge Comparison

	Number of trucks	Battery size, per truck (kWh)	Recharge period (hrs)	Power used per hour of charging (kW)	Peak Demand (kW)	Monthly Usage (kWh)
Non-Electrified Depot	100 Class 6 or 30 Class 8	N/A	N/A	N/A	500	375,000
Class 6 Electric	100	100	8	1,250	1,750	675,000
Class 8 Overnight	30	400	8	1,500	2,000	735,000
Class 8 Slip-Shift[a]	30	400	0.75	3,200	3,700	735,000

[a] *Charging in groups of six throughout the day*

The demand charges in **Figure 19** that are not in Ohio come from a 2017 NREL analysis of the maximum utility demand charge in each utility area. They analyzed all demand charges available at the time and provided a summary of the highest rate, regardless of how long it applies or how many customers are subject to it. Aggregating by state, then, gives a maximum of maximums and an average of maximums, and is not indicative of typical demand charges paid by customers.

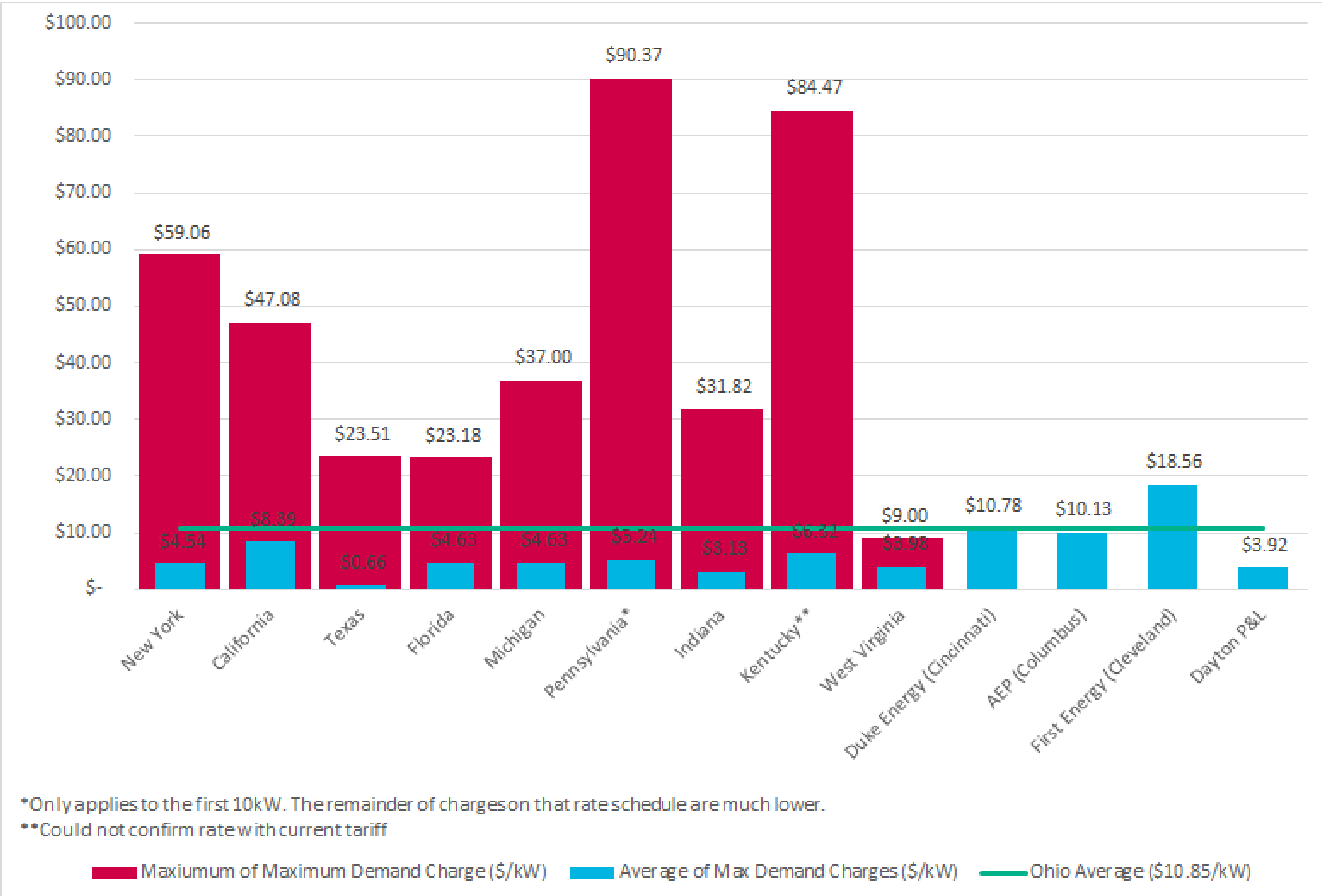


Figure 19: Demand Charges in Ohio and the U.S.[108]

Table 32: Demand Charge Comparison for an Electrified Depot in Ohio

		Duke Energy (Cincinnati)	AEP (CSP) (Columbus)	First Energy (Cleveland)	Dayton Power and Light
Electric Rate Used		**DP (Commercial)**	**CSP-GS2 Pri (Com)**	**CEI-GS**	**DPL-Pri (Com)**
Non-Electrified Depot	total bill ($)	$24,152	$26,837	$32,229	$23,031
	demand charges ($/%)	$5,517 (23%)	$5,067 (19%)	$9,299 (29%)	$1,960 (9%)
	effective demand charge per kWh ($)	$11.03	$10.13	$18.60	$3.92
Class 6 Electric	total bill ($)	$52,887	$58,129	$73,720	$44,543
100 vans charging overnight	demand charges ($/%)	$18,927 (36%)	$17,733 (31%)	$32,474 (44%)	$6,860 (15%)
	effective demand charge per kWh ($)	$10.82	$10.13	$18.56	$3.92

Electric Rate Used		Duke Energy (Cincinnati) DP (Commercial)	AEP (CSP) (Columbus) CSP-GS2 Pri (Com)	First Energy (Cleveland) CEI-GS	Dayton Power and Light DPL-Pri (Com)
Class 8 - Charging Overnight	total bill ($)	$58,610	$64,387	$82,019	$48,846
30 trucks charging	demand charges ($/%)	$21,584 (37%)	$20,266 (31%)	$37,109 (45%)	$7,840 (16%)
	effective demand charge per kWh ($)	$10.79	$10.13	$18.55	$3.92
Class 8 - Slip-Shift	total bill ($)	$76,855	$84,338	$113,536	$55,418
30 trucks charging, 6 at a time, for 45 minutes per group, spread throughout the day	demand charges ($/%)	$38,796 (50%)	$37,492 (44%)	$68,627 (60%)	$14,505 (26%)
	effective demand charge per kWh ($)	$10.49	$10.13	$18.55	$3.92

Appendix D. Summary of Hours of Service Regulations

The following restrictions apply to property-carrying drivers.[109] Different restrictions apply to drivers carrying passengers.

- **11-Hour Driving Limit:** May drive a maximum of 11 hours after 10 consecutive hours off duty.
- **14-Hour Limit:** May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.
- **30-Minute Driving Break:** Drivers must take a 30-minute break when they have driven for a period of eight cumulative hours without at least a 30-minute interruption. The break may be satisfied by any non-driving period of 30 consecutive minutes (i.e., on-duty not driving, off-duty, sleeper berth, or any combination of these taken consecutively).
- **60-/70-Hour Limit:** May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.
- **Sleeper Berth Provision:** Drivers may split their required 10-hour off-duty period, as long as one off-duty period (whether in or out of the sleeper berth) is at least 2 hours long and the other involves at least 7 consecutive hours spent in the sleeper berth. All sleeper berth pairings MUST add up to at least 10 hours. When used together, neither time period counts against the maximum 14- hour driving window.
- **Adverse Driving Conditions:** Drivers are allowed to extend the 11-hour maximum driving limit and 14-hour driving window by up to 2 hours when adverse driving conditions are encountered.
- **Short-Haul Exception:** A driver is exempt from the requirements of §395.8 and §395.11 if: the driver operates within a 150 air-mile radius of the normal work reporting location, and the driver does not exceed a maximum duty period of 14 hours. Drivers using the short-haul exception in §395.1(e)(1) must report and return to the normal work reporting location within 14 consecutive hours, and stay within a 150 air-mile radius of the work reporting location.

Appendix E. Estimated EV State of Charge Levels

The average speed of heavy trucks on U.S. Interstates is between 50 and 60 mph,[110] so drivers can cover between 400 and 480 miles in eight hours, at which point they must take a 30-minute break (see Figure 20). If electric trucks can reliably and consistently offer 500 miles of range, as they are anticipating, then they can take the required 30-minute break, and then drive for a maximum of three additional hours before taking a required 10-hour break. At 60 mph, this is an additional 180 miles, which means that charging, even during the 30-minute break, would have to recoup at most 36% of range capacity to complete the journey. At this point, the driver is required to not be driving for 10 hours, ample time to recharge the battery to full capacity.

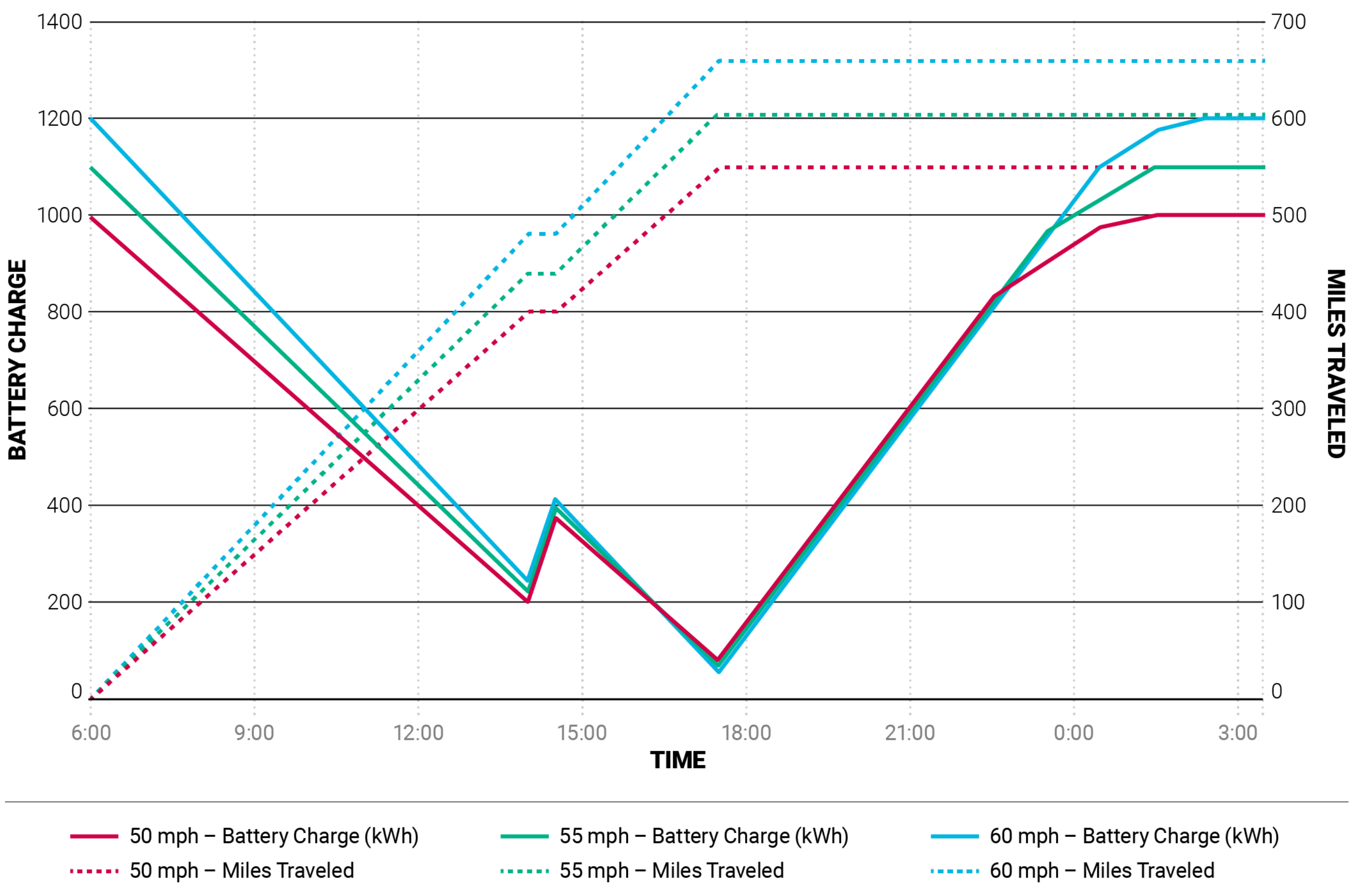


Figure 20: Estimated Mileage and State of Charge based on Average Speeds and Hours of Service Requirements

U.S. Class 8 trucking is dominated by Daimler (Freightliner and Western Star) with 40% market share and Volvo (Volvo and Mack) with 20% market share.[111] The current Class 8 eCascadia from Freightliner has a range of 250 miles.[112] The Volvo VNR Electric regional haul truck due out in 2021 has an expected range of 150 miles.[113] The Tesla Semi, expected in late 2021 will initially come in a 300-mile version, followed by a 500-mile range model.[114] In the next few years, electric trucks with sufficient range to accommodate a full day of Interstate driving are expected to be released. It should be noted that electric trucks may not be able to accommodate all use cases in the near term – dual drivers in sleeper booths, for example, can swap roles and cover significantly longer distances than solo drivers.

Appendix F. Industry Outreach Participants

Organizations that participated in benchmarking calls include:

F.1. Fleets

- **Bimbo Bakeries:** Bimbo is the largest bakery company in the world, comprised of numerous top-selling baked goods brands, and it is focused on all aspects from production, delivery and stocking shelves at stores. Bimbo North America runs 5,673 vehicles in fleet including 309 Class 8 tractors, 2,500 trailers, 1,500 dedicated third-party trailers, 650 box trucks, 3,500 step vans, and 38 yard tractors running routes from bakeries to distribution centers (DCs) and from DCs to stores for stocking products.
- **Continental Express:** Headquartered in Sydney, Ohio, Continental Express is the largest refrigerated trucking company in the state. They own 475 trucks and 1,000 refrigerated trailers, and they perform all maintenance in-house. The company is are primarily a regional carrier, with most routes within 500 miles of the home terminal, but they also have some long-haul routes.
- **DHL:** DHL Supply Chain is a division of DHL that is focused on contracted warehousing, HD trucking operations, and express services (last mile, final point delivery) on behalf of client companies. DHL Supply Chain North America operates Class 4-8 fleet vehicles associated with warehouse customer operations, including 1,500 dedicated trucks that are leased by DHL to provide dedicated transportation (FTL and LTL) for third-party clients.
- **FedEx Express:** FedEx's express transportation service is the world's largest transportation company in the world – operating in 200 countries and is focused on the movement of goods. Currently operating a fleet of 100,000 units across medium and heavy-duty vehicles. FedEx is 100% committed to fleet electrification and has moved beyond pilots to at scales deployments across the world.
- **Firefly Transportation Services:** A new company specializing in "yard spotting" and distribution center contracted services (i.e. companies with distribution centers contract with Firefly to bring in vehicles to run operations). Firefly runs facilities in Groveport, OH but also has clients throughout the country such as Chicago, Atlanta, etc. Note that Firefly Transportation Services was acquired by Lazer Spot, Inc. in March 2021.
- **Nagle Companies:** Based in Toledo, they operate about 50 refrigerated trucks, split between local operations and regional/OTR. They are interested in alternative fuel technologies so long as the technology is up to the task.
- **PITT Ohio:** Represents five Less than Truckload (LTL) carrier fleets operating in the Midwest with 800 Class 8 tractors, 2,000 trailers, a range of Class 6-7 units, and 100 light duty (Sprinter and Transit vans). Collectively PITT OHIO units run 8 million miles per month with many routes running "terminal to terminal."
- **R&L Carriers:** Fleet of 7,000 tractors and more than twice as many trailers doing pickup and delivery services between cities in regional haul operations with most drivers out and back home each day (i.e. not long-haul). Lighter than Load (LTL) but with goals of scaling most loads up to 80,000lbs to maximize profit of each delivery.
- **Sherwin Williams:** Private fleet of 800 Class 9 vehicles that delivers to Sherwin-Williams and Lowe's stores nationally. The fleet is broken up in regional drivers/routes, with a major route on I-70 between Indiana and Ohio. Retail stores have fleet of Ford Transit Connect delivery vehicles (~80 vehicles in Ohio).
- **UPS:** Large parcel delivery fleet with MD-HD vehicle operations, primarily in hub-and-spoke/return to base operations. Currently utilizing EVs in Class 6 step van on Ford F-59 platform but exploring up to Class 8 and down to electric bikes. Also using CNG (250M GGE of RNG) LNG, propane, hybrids, and efficiency technologies.

F.2. Utilities

- **American Electric Power:** They serve about 1.5 million customers in the state. They are also one of the largest utilities in the nation, with 26,000 MW of generating capacity and a transmission system that serves about 10% of the Eastern Interconnection. They have a large solar energy program and EV charging incentives in place for public chargers in their service areas. Recently, six American utilities, including American Electric Power, across the South and the Midwest announced a new EV charging network called the "Electric Highway Coalition." Once complete, the network is expected to stretch across 16 states and connect major highway systems from the Atlantic Coast, through the Midwest and South, and into the Gulf and Central Plains regions.[115]
- **Dayton Power & Light:** They serve more than 527,000 customers in west Central Ohio. A recent settlement agreement, if approved, will implement a rebate program for electric vehicles and electric vehicle supply equipment.
- **Duke Energy:** They serve 7.8 million customers in six states and have 51,000 MW of generation capacity. They have a large renewable energy program. They have their own fleet of about 4,000 LD vehicles and 6,000 MD and HD vehicles, and pledge to convert all the LD and half of the MD and HD fleet to zero-carbon by 2030.
- **First Energy:** They serve about 1 million customers in Northeast Ohio. They offer different incentives around the country, including purchase incentives for passenger EVs in Ohio.
- **Ohio's Electric Cooperatives**: There are 25 electric cooperatives that serve rural customers not covered by one of the investor-owned utilities or a municipality. Together, they cover over 380,000 homes and businesses in 77 of Ohio's counties. Some, but not all, offer purchase incentives for passenger EVs.

F.3. Charging Vendors

- **ABB:** A leading global technology company that energizes the transformation of society and industry to achieve a more productive, sustainable future. ABB offers a total electric vehicle charging solutions from compact, high quality AC units to reliable DC fast charging stations with robust connectivity, to innovative on-demand electric bus charging systems, we deploy infrastructure that meet the needs of the next generation of smarter mobility.
- **ChargePoint:** Operates the largest online network of independently owned EV charging stations across 14 countries. As of September 2020, they operated over 114,000 stations across the world supporting businesses, fleets and drivers across the light, medium and heavy-duty vehicle platforms. Together, they are responsible for approximately 3,015 MW of generation, including about 71 MW from renewable sources.

F.4. National Labs

- **National Renewable Energy Laboratory:** NREL advances the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies.
- **Argonne National Laboratory:** Argonne is a multidisciplinary science and engineering research center operated by the University of Chicago for the U.S. Department of Energy.

F.5. OEMs

- **Lion Electric Company:** An innovative manufacturer of zero-emission vehicles providing 5 all-electric vehicle platforms to the market: Lion6 and Lion8 Class 6 and 8 urban and regional truck solutions, LionA, LionC and LionD school buses, and the LionM transit bus. Lion designs, manufacturers and assemble all components of their vehicles from the chassis to the battery packs, to the cabin and powertrain.

- **Navistar NEXT:** Navistar is a leading manufacturer of commercial trucks, buses, purpose-built vehicles, and powertrain solutions. Navistar's NEXT eMobility team is reinventing the approach to transportation electrification and providing real-world electric fleet solutions from fleet advisory to construction support to charging, and telematics. Their current focus is on meeting the needs of the commercial fleets that return home at the end of operations.
- **Tesla:** Tesla was one of the first manufacturers to bring zero-emission vehicles to the global market. Tesla offers a number of light duty electric passenger vehicles and currently lead the segment in EV market sales. They are developing a light duty pickup truck and a Class 8 semi truck to be released in 2021. The headquarters is located in Palo Alto, CA with manufacturing facilities located in the United States, Netherlands, Germany, and China.
- **Volvo Trucks:** Volvo trucks has a long tradition of developing market leading technologies and solutions and as the need for zero-emission transportation grows their electric truck line are now coming to market. Their Volvo Lights project, $44.8 million project funded by the California Air Resources Board, is focused on the reduction of emissions from goods movement trucks and equipment. This three-year project will demonstrate the ability for heavy-duty, battery electric trucks and equipment to reliably move freight between the city's two major ports and warehouses throughout the region with less noise and zero emissions.

F.6. Trucking Industry Groups

- **Ohio Trucking Association:** An industry group focused on enhancing the public image and economic growth of its members by promoting safety, innovation, and professionalism.
- **NACFE:** North American Council on Freight Efficiency. A fuel-agnostic organization for fleets, manufacturers, vehicle builders, and other government and nongovernmental organizations coming together to improve North American goods movements.

F.7. Truck Stops

- **Trillium (Love's):** Love's Travel Stops & Country Stores maintains 500+ locations in 41 states, providing professional truck drivers and motorists with 24- hour access to electricity for charging, gasoline, diesel fuel, CNG, renewable CNG, and even hydrogen. Their fuel availability depends on fleet's needs and increasingly they are building out EV charging infrastructure and hydrogen dispensing across the U.S.

F.8. Ports

- **New York New Jersey Port Authority:** The port authority keeps the region moving by air, land, rail, and sea and are focused on reshaping the future for the region with innovative yet practical facilities and systems with an eye of reducing carbon emissions from transportation. They are running 36 shuttle buses at LaGuardia (LGA), Newark (EWR), and John F. Kennedy (JFK) airports, which is the largest all-electric fleet on the east coast. The Port Authority is also reducing the emissions of our fleet of light-duty vehicles by committing to electrifying 50 percent of the fleet – a total 600-700 vehicles – by 2023.
- **Toledo-Lucas County Port Authority:** The first port authority established in the state of Ohio, the port develops expertise and assets that drive and grow the region's transportation and logistics infrastructure.

F.9. Rail

- **CSX:** One of the largest rail freight operators in the country. They have electrified container cranes at facilities across Ohio and operate a large fleet of Class 2 trucks with rail wheels for access to rail facilities.

F.10. Commissions

- **Ohio Rail Development Commission:** The ORDC an independent commission within ODOT, represents the state in non-regulatory interactions with the railroad industry to fund safety improvements, support rail economic development, and coordinate with railroads for ODOT highway projects.
- **Ohio Turnpike and Infrastructure Commission (OTIC):** OTIC operates a 241-mile toll road from east to west across northern Ohio, including 14 service plazas. Four of these plazas have passenger vehicle DCFC right now, with plans for adding DCFC to the other ten. In 2019, they served about 52 million vehicles, including approximately 10 million heavy-duty trucks.

F.11. Ohio Planning Organizations

- **Ohio Freight Advisory Council:** Members of the newly-formed council are made up of ODOT and various planning organizations from across the state including the Mid-Ohio Regional Planning Commission (MORPC), the Miami Valley Regional Planning Commission (MVRPC), the Northeast Ohio Areawide Coordinating Agency (NOACA), the Ohio Association if Regional Councils (OARC), the Ohio-Kentucky-Indiana Regional Council of Governments (OKI), the Ohio Mid-Eastern Governments Association (OMEGA), and the Toledo Metropolitan Area Council of Governments (TMACOG).

F.12. Funding Program for AFV Vehicles

- **New York Truck Voucher Incentive Program:** A first-come, first-served incentive program that makes alternative-fuel vehicle purchases simpler and more affordable. NYTVIP is administered by the New York State Energy and Research Development Authority (NYSERDA) and combines funding from the New York State Department of Transportation (NYSDOT) and New York State Department of Environmental Conservation (NYSDEC) to use an innovative voucher design that reduces upfront vehicle cost for fleets. There has been $14.5 million in incentives and VW funds bring available funds up to $54 million for 300-400 new truck replacements.

Appendix G. Additional Figures

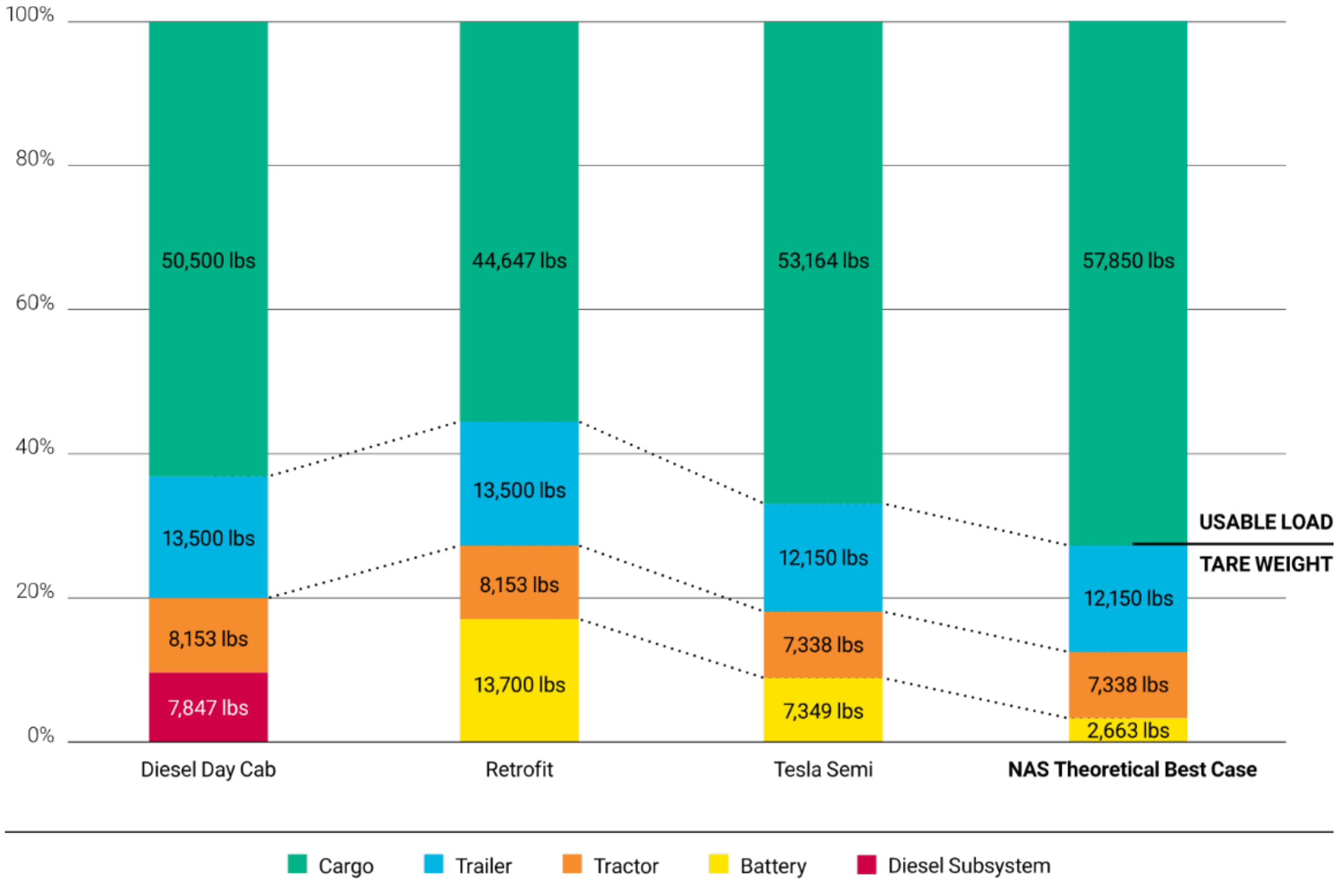


Figure 21: Usable Load Versus Tare Weight

This figure shows currently available technology for the Diesel Day Cab and Retrofit, from NACFE's Guidance Report on Electric Trucks.[116] Tesla information is based on 10% mass savings in trailer and tractor, as well as battery information from Tesla's 2020 shareholder meeting.[117] The NAS Theoretical Best Case, cited in NACFE, is an estimate of the best possible battery energy density based on chemical analysis of Lithium-Ion technology.

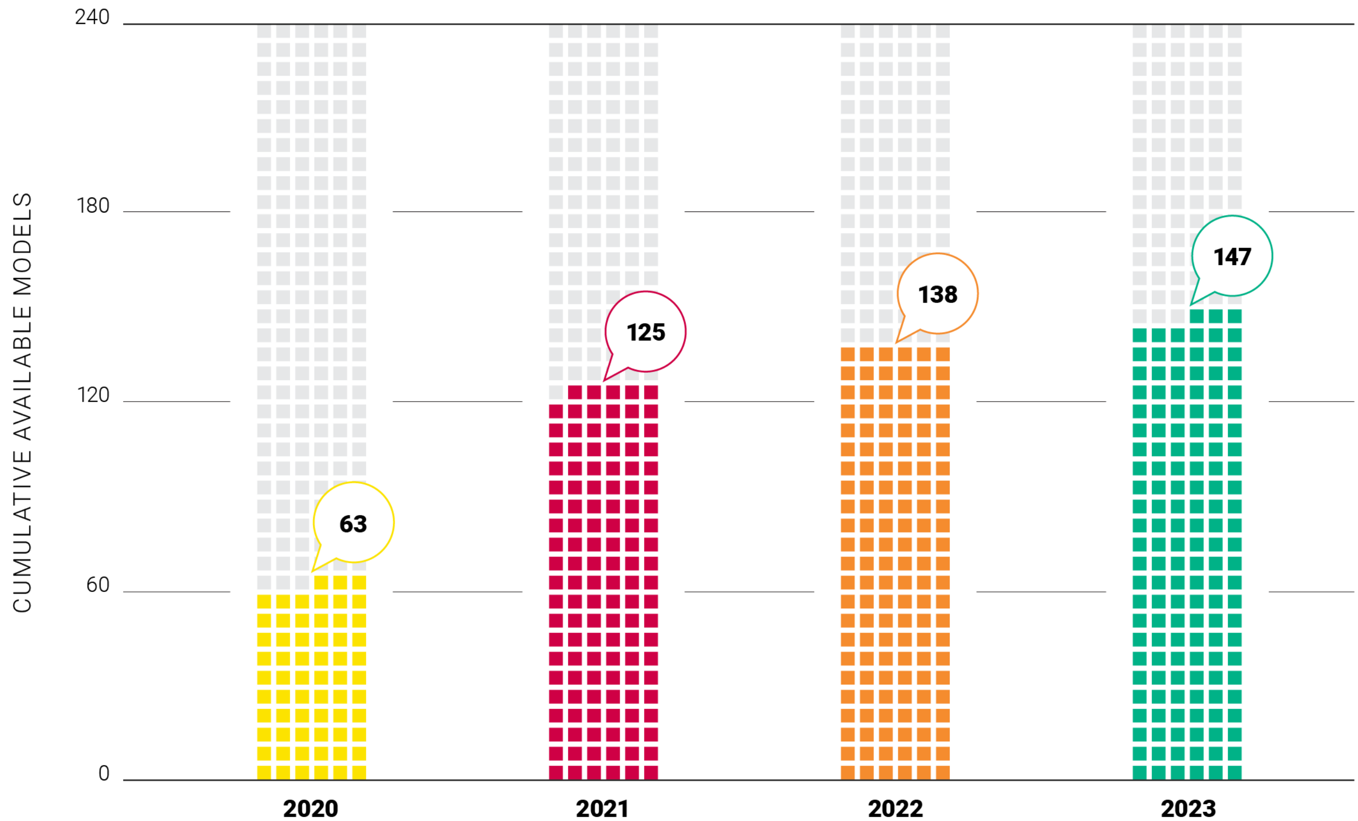


Figure 22: Electric Vehicle Model Availability

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