MEDIUM AND HEAVY-DUTY CHARGING INFRASTRUCTURE

Market Overview, Charging Needs Assessment, and Incentive Program Design Strategy

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Contents

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1. Introduction

As the energy transition accelerates, transportation electrification will continue to be a critical component of economy-wide decarbonization. Looking beyond light-duty electrification, the need for greenhouse gas emission (GHG) reductions from medium- and heavy (M/HD) vehicles will need to be met with government and private sector action. States across the country have committed to increasing the sale of zero-emission M/HD vehicles and phasing out their internal combustion counterparts over time.

To facilitate a statewide transition to clean M/HD vehicles, the Colorado government developed and released its Clean Truck Strategy in 2022, which serves as the foundation for their M/HD electrification initiatives and the underlying impetus for this report [1]. To shore up funding gaps for M/HD charging infrastructure and spur growth in the nascent M/HD charging market toward the state's goals of 35,000 zero-emission M/HD vehicles on the road by 2030, the state of Colorado intends to develop an incentive program to defray the costs of charging infrastructure for these vehicles. Once launched, Colorado will be one of the only states in the country to offer such a program, cementing its position as a leader in the clean M/HD vehicle space.

In this report, we combine three research tasks:

1) a Colorado-focused analysis of the MHD charging market,
2) an M/HD charging needs analysis for Colorado, and
3) a strategic analysis to inform the development of Colorado's M/HD charging incentive program.

This research is meant to inform CEO's near and mid-term planning and programming for supporting the deployment of electric MHD charging infrastructure required to fulfill Colorado's broader MHD goals.

M/HD Vehicle Impacts

The transportation sector is the single-largest contributor to climate change across the United States economy, generating 27 percent of all national greenhouse gas emissions in 2020, a greater share than both the power and industrial sectors [2]. M/HD vehicles represent a subset of the transportation sector populated with trucks, buses, and vans often used in commercial or public service. In this report we define M/HD vehicles as those with a gross vehicular weight rating over 8,500 pounds. While they make up only 10 percent of all vehicles on the road, M/HD vehicles disproportionately contribute to air pollution and environmental degradation. In fact, they generate more than 60 percent of all nitrogen oxide and particulate matter emissions from on-road vehicles [3]. In addition, this vehicle-borne pollution most negatively impacts frontline environmental justice communities, who through discriminatory housing and zoning policies often find themselves adjacent to freight corridors, port infrastructure, and other M/HD transportation routes. M/HD electrification thus would have a positive, outsized impact on air quality, public health, and environmental justice in the state of Colorado.

To mitigate the negative impacts of M/HD emissions and advance its overall climate goals, the Colorado state government has taken several legislative and executive actions. Per a law enacted in 2019, Colorado has committed to reducing statewide greenhouse gas emissions 50 percent by 2030 and 90 percent by 2050, based on 2005 levels [4]. Going further, in January 2023 Colorado senate democrats introduced a bill that would formally commit the state to reach net-zero by 2050 [5]. As transportation comprises a large share of the emissions pie, around 25 percent of all statewide greenhouse gas emissions, assertive climate policy, particularly around M/HD vehicles, will be required to achieve these goals [6].

Colorado Policy Context

Governor Polis issued Executive Order B 2019 002 mandating the creation of a transportation electrification working group, the establishment of the Colorado Zero Emission Vehicle Program, the allocation of all remaining Volkswagen funds to transportation electrification, and the development of a state clean transportation plan [7]. Colorado, along with 15 states and Washington, DC, then signed a Memorandum of Understanding in 2020 to accelerate the electrification of trucks and buses, with the goal of achieving 100 percent clean M/HD vehicle sales by 2050 [8]. The state has since developed a clean truck strategy and, in 2023, adopted the Advanced Clean Truck Rule (ACT) which requires M/HD vehicle manufacturers to make available an increasing number of clean buses and trucks starting in model year 2027 [9]. Documentation published by the Colorado Department of Public Health and Environment has affirmed that adoption of such a rule would increase the sale of electric M/HD vehicles, substantially reduce NO_x pollution, and bring greater areas of the state into air quality attainment [10].

In working to design a statewide incentive, the Colorado Energy Office has responsibility for supporting the deployment of M/HD charging infrastructure. The Colorado Department of Public Health and the Environment is working in parallel to design a sister incentive for the purchase of electric trucks and buses. These two departments and incentive programs will be paired together to ensure applicants engage in a seamless, connected process as they move from vehicle procurement to infrastructure installation with the support of two collaborative agencies.

Prior to this work, the state government commissioned other research reports to chart the transition to zero-emission M/HD vehicles in Colorado. For example, MJ Bradley &

Associates conducted a study in which they 1) detailed the national and Colorado M/HD vehicle markets, 2) evaluated potential M/HD electrification policy levers, 3) collected perspectives from relevant stakeholders, and 4) provided a cost-benefit analysis of policy options with regard to their impact on society and electricity rates [6]. In looking beyond electrification, the Colorado government has also conducted studies on the prospect for the deployment of M/HD hydrogen vehicles and fueling infrastructure across the state [11].

Report Roadmap

This report is broken out into three substantive chapters that each cover one of the study's research tasks, and a conclusion chapter.

Chapter 2: State of the Market provides an analysis of the M/HD charging infrastructure market in Colorado that details the relevant actors and stakeholders and their respective relationships to one another. For this analysis we both synthesized existing research and drew upon primary sources such as interviews with market participants, marketing materials from market actors, implementation guides, and others.

In *Chapter 3: Charging Needs Assessment,* we summarize the results of an analysis of the needed charging infrastructure and its related costs in Colorado from 2023 to 2030. The analysis employs Atlas's INSITE-M/HD tool, a technoeconomic model of charging investment need and a geospatial-based analysis for electrifying priority freight corridors in Colorado.

Chapter 4: Strategies for M/HD Charging Incentive Program Design outlines findings of research and analysis of M/HD charging incentive program design. In this analysis, we rely on information learned in the prior two chapters, along with qualitative analysis of existing charging incentive programs drawn from interviews of key program implementers and program documentation. The chapter provides a summary landscape of charging incentive programs, an overview of the programmatic elements of MHD charging incentive design and a high-level set of program design recommendations.

Chapter 5: Conclusion contains high level discussion and summary of key findings from each research task and suggestions for future research.

Existing Literature

As electric M/HD vehicles have moved from the theoretical to practical commercial products, there has been a substantial increase in research focus on this market. Likewise, as governments have begun to adopt regulations requiring increased electric MHD vehicle deployment there has been a related increase in interest for understanding the infrastructure needs associated with those rules. However, while there is considerable literature available on the state of M/HD charging market and an emerging literature on

M/HD charging infrastructure needs analysis, we are unaware of any prominent examples of economic or policy analysis of M/HD charging infrastructure incentive programs.

This section summarizes the state of the literature most relevant to this report, while identifying important gaps that remain. While this section is meant only as a survey of extant scholarship related to the topic of this report, we also use the market literature summarized here to inform and augment primary sources analyzed in Chapter 2.

MHD Market Literature

In the 2021 *Colorado Medium- and Heavy-Duty (M/HD) Vehicle Study,* Moynihan et al. conducted an in-depth analysis of M/HD zero-emission vehicle (ZEV) adoption in Colorado, which found that adoption of M/HD ZEVs would have a substantial impact on GHG emissions and air quality in Colorado and could offer significant fuel and maintenance savings [6]. Specifically, the study finds that a transition to 100 percent zero-emission M/HD vehicles by 2040 could result in statewide greenhouse gas reductions of 1.1 million metric tons, while every modeled scenario anticipates combined annual fuel and maintenance cost savings per vehicle of over $2,100 between now and 2040. However, the study also reports that meeting M/HD ZEV deployment goals requires substantial policy support. The study finds that charging infrastructure deployment can accelerate the ZEV deployment process and that the state of Colorado has a critical role to play in planning for and funding infrastructure development.

Battery Electric Truck Operational Viability

Assessing the viability of battery electric truck usage across vehicle types and use-cases is a major focus of prior literature on M/HD truck electrification. Moultak et al. (2017) described the near-term likely opportunities for electric M/HD trucks as limited to uses where vehicles travel short distances around a central base location (such as urban delivery, vocational fleets, etc.) because those use cases minimize technology limitations of early electric trucks, such as a more constrained battery range and minimal access to en-route charging infrastructure [12]. Mihelic et al. (2018) came to similar conclusions, finding that electric trucks will initially be limited to operations with short, predictable daily miles traveled and where vehicles will return to the same location to charge each day [13]. Later studies have echoed the finding that shorter urban routes based at a single depot are ideal electrification use-cases. In *Making Zero Emissions Trucking Possible,* Farrag-Thibault et al. add that urban operations with longer idle times and stop-and-go driving also favor electric drive trains [14].

While the key enabling factors for electrification identified in early literature have remained similar, more recent studies, drawing on rapid advances in technology, have updated expectations on how rapidly various truck segments could electrify. In a series of reports that drew on real world experience, Roeth et al., found that most medium-duty vehicles (such as step vans and box trucks) along with terminal tractors are 100 percent operationally electrifiable in the near- to medium-term (Roeth 2022a/b/c) [15, 16] [17]. Moreover, they found that as many as 50 percent of harder-to-electrify regional Class 7 and 8 tractors could be electrified with current technology (Roeth et al., 2022) [18]. In a broad-based study using telematics data from trucks in California and New York, Lund et al. (2022) found that about 65 percent of medium-duty and 49 percent of the heavy-duty trucks into those states are electrifiable in the near-term [19] .

While much of the literature remains focused on vehicles that operate out of a depot and return to charge every night, focus has also shifted to the use of electric trucks in long-haul operations. Phadke et al. (2021) finds that viable long-haul battery electric trucks are on the horizon, but stresses the need for policy support , such as binding zero-emission vehicle sale requirements and targeted subsidies indexed to batter price and cumulative sales, to both push technology and develop the charging infrastructure to support those trucks [20].

Charging infrastructure for electric trucks

While most published literature focuses on the electric trucks themselves, charging infrastructure to support those trucks is a key factor in the research on M/HD electrification. Lund et al. (2019) offers a deep dive on available charging options for electric M/HD vehicles which examines both standard cord and connector (plug-based) options along with alternatives such as catenary electric or wireless charging. Like vehicle-focused studies, the report concludes that most charging infrastructure will be deployed in depots. Moreover, the report notes that much of the demand for electric charging for M/HD can be met by existing charging technologies widely used by light-duty vehicles (L2 and DCFC) [21]. However, the report also acknowledges the need for megawatt level charging as the market matures, a finding that is echoed by Walkowicz et al. (2019) when reporting out from a workshop on the research needs for extreme fast charging, and Bourlaug et al. who find that megawatt level charging is critical for mid-shift charging of heavy-duty long-haul trucks [22] [23]. Additionally, there is general agreement across these reports that charging management strategies enabled by software or onsite energy resources will be crucial for managing energy costs in some applications.

The existing literature on M/HD charging does provide some insight on the barriers inherent in deploying charging infrastructure. However, research here is more limited than those focused on vehicles. Generally, the literature identifies common themes in infrastructure deployment barriers. For example, both *Road Freight Zero: Pathways to faster adoption of zero-emission trucks* (World Economic Forum 2021) and *Medium- and Heavy Duty Electrification: Weighing the Opportunities and Barriers to Zero Emission Fleets* cite capital cost, depot space availability, and grid capacity as substantial barriers to deployment of depot-based chargers [24] [25]. In addition, both reports also identify utilization risks—that not enough trucks will materialize to justify investment—as an additional barrier to the deployment of public opportunity or en-route charging.

M/HD Charging Needs Analysis

Charging needs analysis for electric M/HD vehicles is a very new area of research with few published paper or reports. Atlas's modeling tool (INSITE) and methods employed in this report are based on prior work estimating nationwide infrastructure needs for M/HD vehicles conducted as part of a broader effort to estimate infrastructure needs and costs for both light and M/HD vehicles. In that study, McKenzie et al. found that the nationwide infrastructure needed to meet a 100 percent electric M/HD sales target in 2040 would require between $100 and $166 billion in investments by 2030 [26].

In a broader analysis of Colorado's charging infrastructure needs that focused primarily on light-duty vehicles, Hsu et al. conducted a simplified analysis of needed investments for supporting M/HD vehicles in the state. The analysis covered Class 4-8 trucks and was limited to 50kw and 350kW stations. Hsu et al. found that by 2030, 85 public 350 kW chargers and 1,570 50 kW depot chargers would be needed to support 2,021 Class 4 through 6 trucks. An additional 598 (public) and 2,350 (depot) chargers would be needed to support 2,480 Class 7 and 8 trucks. The authors estimated the total cost for this infrastructure would be $363.6 million [27].

The California Energy Commission's *Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment* offers a similar analysis for charging needs in California. The report authors used NREL's recently developed HEVI-LOAD for its M/HD analysis [28]. The HEVI-LOAD model takes aggregated estimates of energy needs and disaggregates energy recovery need to time and location using vehicle travel pattern data across several vehicle types. Location and time of use for charging load is used to compute required numbers of 50kW or 350kW chargers to satisfy load requirements. When applied to California energy need and travel pattern data, the HEVI-LOAD tool projected 141,000 50 kW chargers and 16,000 350 kW chargers are necessary to charge 180,000 M/HD vehicles. The analysis did not estimate costs.

Lessons and Gaps

There is substantial agreement in the literature about how and where electric trucks are likely to deploy first and emerging evidence on the opportunities for deep transitions in the medium-term, even in harder to electrify segments. Moreover, except for novel "future" charging modes such as catenary charging or wireless charging, M/HD charging technology is relatively well understood, as it generally carries over technology from the light-duty market. The barriers to charging infrastructure deployment are less well explored, but the literature does lay out a common set of likely barriers that M/HD charging deployment will face. While there has been some study of the market landscape for charging provider business models, the industry is changing so rapidly that much of it is either out of date or lacking in depth. Lastly, given the recency of electric truck developments, there is little research that looks at the M/HD charging market from a Colorado perspective, meaning that research thus far may not perfectly represent the conditions as Colorado M/HD vehicles electrify.

M/HD Charging infrastructure needs analysis is a nascent area of study, though several different methods have been employed in different geographic contexts. While methods do differ in implementation and source data, extant methods all rely on estimated energy consumption of M/HD vehicles as the basis for establishing infrastructure need. While prior studies have estimated M/HD charging need in Colorado, they are either based on differing assumptions of electric M/HD vehicles adoption than envisioned by Colorado's goals or lack sufficient depth to inform a Colorado M/HD charging incentive program.

2. State of the Market

M/HD fleet electrification will be challenging, and the markets, business models, and financing structures for electric trucks, buses, vans, and tractors are still maturing. An understanding of the various interconnected actors in this space, from fleet operators to charging providers to electric utilities, is vital to establishing a well-designed EV infrastructure funding program. Likewise, knowledge of the numerous enabling factors as well as barriers to electrification for MHD vehicles is crucial to ensuring widespread adoption and deployment.

M/HD fleets across Colorado are diverse in their operations, vehicle mixes, and business models, much like the state's varied utility and charging vendor ecosystem. This chapter, State of the Market, provides a comprehensive analysis of the sector state of play, detailing the M/HD fleet landscape across Colorado, the stakeholders engaged in the market, and both the enabling factors and key barriers to the electrification of this segment. Furthermore, we break down the M/HD charging modes, power requirements, operational use cases, and charging business models that currently apply to the medium- and heavy-duty sector. And in looking toward program development, this section takes a deep dive into what is holding the M/HD fleet market back in its electrification journey and details the key factors and changemakers that have the potential move it forward. intro

Methods & Data

For this analysis we employed a mixture of synthesis research of existing academic and grey[1] literature and original qualitative research of primary sources. We employed several search methods to identify relevant secondary research material, including keyword and exact phrase searches of general search engines and academic journal databases along with citation mining of identified sources. The bulk of existing literature comes from non-academic sources. Along with these secondary sources we conducted similar searches for primary documents such as marketing materials, guides, and other relevant materials. We also gathered qualitative data through semi-structured interviews with select stakeholders and market actors working in M/HD sector on the ground in Colorado and across the country. Interviewees included charging service providers, fleet operators, financial institutions, vehicle manufacturers, freight trade and advocacy organizations, and utilities. Finally, we conducted two case studies with organizations that have or are in the process of deploying charging infrastructure for M/HD vehicles. We weave together data from these

[1] Grey literature includes reports from governments, trade associations, research institutes, and other authoritative but non-academic sources.

varied sources to provide a robust picture of the M/HD market as it is developing on the ground and how it will likely continue to develop in the near future.

M/HD Charging Market Overview

The M/HD charging market is a submarket of the overall EV charging market, which until recently has been focused primarily on serving private light-duty EVs. There is substantial overlap in technology use and the supplier side of the market. However, the M/HD charging market is differentiated from the light-duty charging market both by the generally higher energy and power demand of M/HD vehicles and their typical commercial or public service usage.

Conceptually, the M/HD charging market can be broken down into three broad participant categories:

- Electric M/HD vehicle owners and operators
- Charging equipment and infrastructure supply ecosystem
- Utilities or other electricity suppliers

Electric M/HD vehicle operators are the buyers in the market who need access to charging (either onsite or elsewhere) to fuel their vehicles. Thus far, the consumers of these products are mostly larger fleets, with heavy representation from the transit bus segment. Other public and municipal fleets are also early adopters of electric M/HD vehicles (and thus are buyers of charging equipment). Deployment has been limited in the private sector, with early grant-funded pilots mostly confined to middle-mile logistics or last-mile delivery. However, governmental mandates and funding, environmental social governance priorities, and economic factors are expected to substantially increase the number of vehicle operators (across industries and fleet sizes) that will pursue fleet electrification.

The charging equipment and infrastructure supply ecosystem encompasses the diverse set of sellers that are involved in the manufacture, distribution, planning, design, sale, and deployment, operations, and maintenance of M/HD charging solutions. Market actors in this ecosystem may focus on one aspect of supplying charging equipment or be vertically or horizontally integrated. Many M/HD charging providers are companies that started in the light-duty sector and are now expanding their offerings to M/HD charging, while other companies have emerged in the last few years to specifically provide solutions in the M/HD space. Dealers and vehicle original equipment manufacturers (OEMs) have also stepped into the role of charging provider (often through third-party agreements) to ensure that charging infrastructure is available to vehicle buyers. This supply ecosystem includes vendors that offer charging equipment and installations coupled with alternative financing such as charging and trucks as a service offerings.

Electricity suppliers sell the power that fuels M/HD EVs. The major actor in this space is the electric utility, which plays a vital role in the successful deployment of M/HD charging infrastructure and equipment. While not typically involved in the direct supply of charging equipment, utilities are directly involved in the M/HD charging market. Most importantly, utilities are responsible for providing the power and energy needed to charge M/HD vehicles, which can prove complicated, costly, and time consuming. Moreover, in part because transportation electrification represents an opportunity for utilities to increase the amount of electricity they sell and (in some cases) to utilize grid assets more fully, some have become key partners in developing charging infrastructure and providing funding for make-ready infrastructure, charging equipment , and valuable advisory services. While most M/HD EVs will be supplied with energy from utility grids, some charging equipment suppliers have integrated electricity supply into their service models using onsite renewable generation and battery storage.

Other Involved Parties

Though not necessarily traditional market participants, funding providers are key players in the early M/HD charging market. In this developing market where costs and uncertainty are high, funding and financing providers, including incentive programs, grant-making agencies, and utility programs, are key enablers of project success. The ability to access funding from one or more funding providers is very frequently a make-or-break factor in M/HD charging deployment.

In addition to the direct market participants and funders, there are a number of additional actors who are often involved in the development of M/HD charging projects, including:

- Property Owners and Managers—many logistics facilities are leased by the fleet operator, meaning that landlords must be involved in project development
- Public Site Hosts—in the case of public, en-route, or other opportunity charging, chargers must be hosted. Where charging providers and vehicle operators do not secure their own locations, suitable hosts such as existing truck stops must be contracted
- Truck Dealerships—Truck dealers are often the entity with the closest and most direct relationship with the fleet operator and often sell charging equipment bundled with trucks
- Original Equipment Manufacturers—Like dealers, OEMs have relationships with fleets and have expertise in the charging infrastructure needs for their vehicles
- Green banks and sustainable finance lenders—Can provide financing and loan guarantees for M/HD projects
- Electricians and Contractors—Perform the actual electrical and construction work necessary to deploy chargers. Includes both specialized and non-specialized providers.

- Technical Assistance Providers—Provides third party planning support and facilitation.

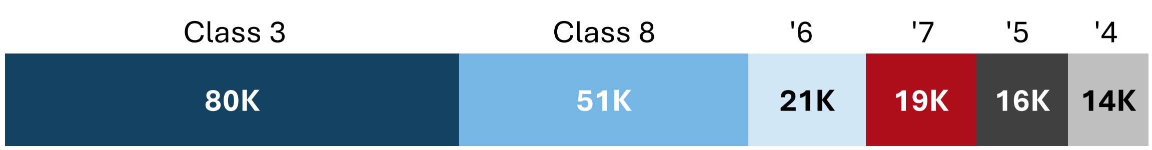
Colorado M/HD fleets and electrification

By the Advanced Clean Trucks Rule[2] definition, M/HD vehicles include all vehicles over 8,500 lbs. gross vehicular weight rating—encompassing everything from a Ford Transit van to a Freightliner Cascadia tractor truck [29]. Across the M/HD classification are heavy-duty pickup trucks, cargo and step vans, box trucks, vocational vehicles, buses, construction trucks, and tractors, among others. The diversity of M/HD vehicle types is exceeded by the fleet operator landscape, which is rife with complexity in services rendered, operation types, and structures.

M/HD Vehicles in Colorado

Analysis of S&P Global vehicle registration data shows there were just over 200,000 Class 3-8 vehicles[3] registered in Colorado in 2019, the most recent year for which we have data. Figure 1 shows the breakdown of registrations by Class in Colorado. Among Class 3-8 vehicles about 4 in 10 are Class 3. The next largest category is at the other end of the weight spectrum, with Class 8 vehicles accounting for about 1 in 4 Class 3-8 vehicles. Middle vehicle classes 4-6 are substantially less common. While we do not have direct data on the number of Class 2b vehicles, MJ Bradley estimated that there are approximately 300,000 Class 2b vehicles on the road, making them by far the largest class category of M/HD vehicles on the road in Colorado [6].

Figure 1. M/HD Vehicle Registrations by Class (excluding Class 2b)



Class 2b and 3 are the largest class categories of M/HD vehicles because they are most likely to be non-commercial pickup trucks used as personal vehicles. While it there is no source for a precise estimate of the number of vehicles in those classes that are not used for commercial purposes, the percentage is undoubtedly high, particularly for Class 2b pickup trucks, which are popular personal and recreational vehicles. For Class 3 vehicles

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[2] The Advanced Clean Trucks Rule is a California regulation that require automakers to produce increasing percentages of zero emissions Class 2b-8 vehicles. Adopting this rule in Colorado is part of the Colorado Clean Truck Strategy. See: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

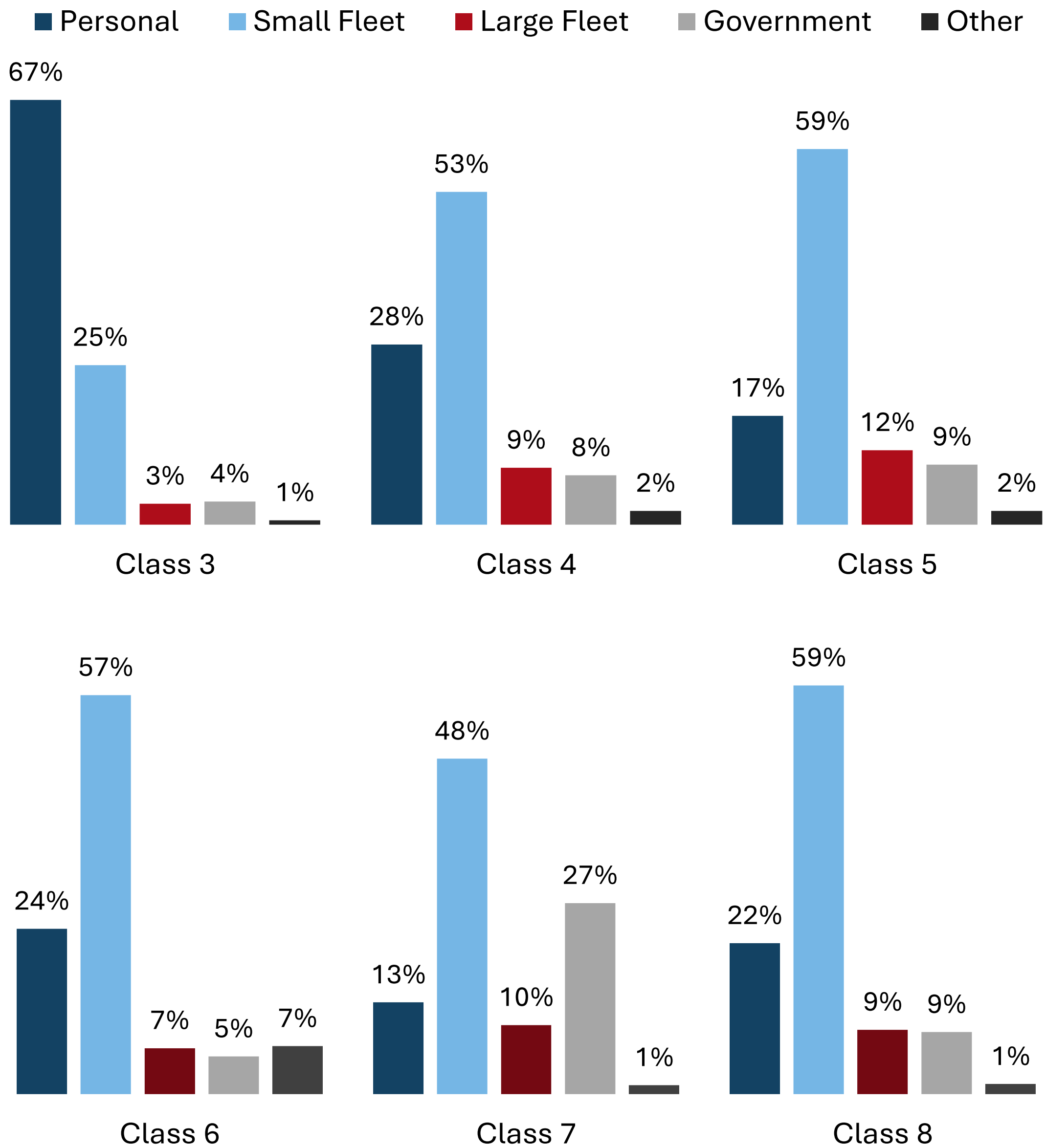
[3] Because these data do not distinguish between class 2a and 2b vehicles, we do not include any class 2 vehicle figures in this analysis.

(for which we have data), 67 percent (see Figure 2) are classified as personal vehicles. Though because that classification only indicates that the vehicle is registered to an individual, it is likely that some percentage of those 'personal' vehicles are used for a small commercial enterprise.

M/HD Fleets in Colorado

The S&P Global registration dataset includes an indicator of ownership type that includes personal (individual), small fleet (<10), large fleet (>10), government, and other (rental, dealer, etc.) which is visualized in Figure 2. Except for Class 3 (where personal registrations are likely to be non-commercial vehicles), *small fleet* dominates each vehicle class and *large fleet* makes up only around 10 percent of Class 4-8 vehicles. This breakdown reveals a private M/HD fleet industry that is dominated by small fleets. Individually owned vehicles make up the second-highest category in 4-6 and Class 8 vehicles, though those are more likely to be used for commercial purposes than Class 3 vehicles. Class 7 vehicles are more represented in governmental vehicles because a large fraction of buses are Class 7. While the data show that 59 percent of Class 8 vehicles in Colorado are owned by a small fleet, it is likely that a substantial portion of those vehicles are fleets of one, registered to an incorporated independent owner-operator.

Figure 2. Class 3-8 Vehicles by Ownership



When considering the market for charging M/HD vehicles, the distinction between a personal vehicle and one that is used for commercial purposes is an important one. Non-commercial MD pickup trucks dominate the M/HD fleet in Colorado, but they are more akin to light-duty vehicles in that they are used for personal transportation and recreation rather than a business purpose. Like light-duty vehicles, these trucks will mostly charge at home and will use public charging that is geared towards light-duty uses. However, because Class 2b and 3 pickup trucks are marketed as towing vehicles, they will need pull through charging that can accommodate a truck and trailer (more so than Class 2a pickup trucks).

Overall, the makeup of fleets in Colorado looks similar to that in other states. Urban-based fleets in Denver or Boulder fulfill similar functions with comparable duty cycles to those in other metropolitan contexts. Likewise rural fleets in Colorado are like those in other rural communities across the country. This means that lessons learned from across the country will generally apply well to fleets in Colorado. However, Colorado's topographical and meteorological conditions do present some distinct challenges for electrification that, while not unique to Colorado, do differ substantially from areas not in the Mountain West. These conditions can pose additional challenges for electrification such as longer than typical driving distances, steep grades, colder weather, heavy snowfall, and changing weather conditions.

M/HD fleets are very diverse, serving functions in nearly every industry and governmental activity. The diversity of fleet activities and industry structure defies easy classification, but at a high-level, M/HD fleets can generally be grouped into three broad categories:

Table 1. High Level Fleet Categories

Category	Example Fleet Types	Example Fleets
Goods movement (logistics)	freight trucking retail/foodservice distribution delivery	Old Dominion Freight Line Sysco DHL
People movement	transit shuttles motorcoaches	Regional Transportation District Ace Express Coaches Kiowa School District
Other services	utility vehicles construction refuse collection rental	Colorado Springs Utility Waste Management Ryder Trucks Xcel

Moreover, fleets can also be classified by their ownership and structure, such as:

- Public—Government owned and operated vehicles
- Private—Vehicles owned and operated by the business they serve
- Contract—Independent fleets contracted to a single or small collection of businesses or government
- For-hire and delivery—Fleets (or often owner-operators) hired on a per-load or less-than-load basis rather than on a long-term contract
- Rental—Fleets of vehicles that can be hired out short term for use by other companies or individuals

Fleet Factors that Affect Charging Needs

While fleets are diverse in their operations, considerations for charging needs are comparatively simple. The number and power level of chargers, as well as required onsite electrical capacity, come down to just four factors that may differ from fleet to fleet.

Vehicle Efficiency: Generally, M/HD vehicles use more energy than light-duty vehicles. However, there is substantially more diversity in energy use per mile among M/HD vehicles than light-duty. For example, a Class 3 delivery van may require as much as 70kWh to travel 100 miles, whereas a Class 8 tractor trailer may require 300kWh to travel the same distance. All things equal, fleets that run smaller, more efficient vehicles will require less charging capacity than those that run larger, less efficient vehicles.

Other conditions that affect vehicle efficiency and that may differ between fleets include:

- Load weight (heavier cargo can impact efficiency)
- Typical operational speeds (higher speeds are less efficient)
- Route topography (climbing hills takes more energy)
- Power take-off needs (some vehicles use traction battery power to operate equipment, such as loaders and pickers)
- Average climate (colder temperatures reduce powertrain efficiency)

Operating Parameters: Energy use is generally a function of both efficiency and operating distance. All things equal, vehicles that travel shorter distances between charging events will require less charging capacity than those that travel further. Operating distances are generally related to the type of work the fleet performs. For example, a regional haul tractor may travel several hundred miles on a single shift, hauling a full truckload of goods between cities, whereas a construction truck may travel at most 50 miles to a job site. For some fleets, operating distances will also vary by service area. For example, service and delivery fleets will generally travel shorter distances in dense urbanized areas and longer distances in suburbs and rural areas due to the distance between route stops.

Dwell Duration: Charging capacity need is a function of the required energy recovery (based on distance and efficiency) and the amount of time the vehicle can remain stationary while charging (known as dwell time). Recovering the same amount of energy in a shorter period requires more power, and thus electrical capacity. Fleet vehicles with long operating hours, particularly those in *slip seat* operations (where drivers alternate shifts on a single vehicle within the same day) may have short windows of time when they are able to stay plugged in. Other fleet vehicles may be used in much shorter operations, with as much as 14 hours of downtime between each shift. Recovering 100 kWh of energy in 10 hours can be accomplished with a basic 11kW level 2 charger, but recovering 100 kWh of energy in one hour requires a 100kW+ DC fast charger. Longer dwell times also enable greater optimization of charging by energy management software which can substantially decrease needed onsite energy capacity.

A special case of dwell duration are vehicles that do not operate out of a homebase or are otherwise not regularly domiciled at a location with charging access. This is the default mode for long-haul trucking but is also common among owner-operator vehicles. As these vehicles often must charge at third-party locations, charging time cannot necessarily be matched with long periods of vehicle downtime. Because minimizing downtime is key, very high-power levels are desirable.

Operational Predictability: This factor does not directly affect energy recovery needs but can have substantial impact on the number and power of necessary charging equipment. Fleets with very predictable routes and dwell durations, and that operate vehicles with ranges capable of managing more than one day of operations at a time will be able to better share charging equipment between vehicles by alternating or otherwise scheduling charging. Fleets that can share equipment and infrastructure will be able to support the same average daily energy recovery need with a smaller charger deployment.

Enabling Factors for Electrification

The enabling (and motivating) factors for electrification can be broadly described as technical, economic, and organizational. These factors intersect with fleet types, operations, and use cases, rendering some fleets easier to electrify early than others.

Technical factors are a make-or-break category which include:

- Vehicle fit for purpose—Are there electric vehicles on the market that can handle the daily duty cycles required by the fleet's business case? Vehicle technology is advancing rapidly, meaning many fleets already have electric options suitable for their operations. Notable exceptions are for long-mileage and very heavy-duty applications such as long-haul trucking.
- Charging equipment availability—Does charging equipment exist that can sufficiently charge the vehicle based on its energy needs and dwell time? Like vehicle technology, charging technology is advancing, with equipment capable of charging at greater than megawatt speeds coming to the market in the near term.
- Compatible operations—Are fleet operations conducive to the use of available vehicles and charging equipment? As a corollary to the prior two bullets, fleet operations that are compatible with existing technology are critical enablers of electrification. In the near term, this means return-to-base operations and duty cycles that are within the battery range of the vehicle in worst case conditions.

Economic factors are also important considerations for identifying early-to-electrify fleets, as they determine whether a given project is likely to be viable.

- Well-capitalized fleets—Fleets that have access to low-cost capital are best positioned to benefit from electrification because returns on fleet electrification rely on operational savings outweighing higher initial capital cost. This is easier to achieve when the average costs of upfront capital are low. Well-capitalized fleets are also usually better positioned to absorb the risk of switching to an emerging technology.

- Favorable operations—While technical vehicle range constraints place a cap on the operational distances that are easily electrifiable, project economics for electric M/HD vehicles improve as average usage increases. This is because the return from electric vehicles come from operational cost savings in fuel and maintenance costs, which add up faster the more miles a vehicle is driven or otherwise utilized. All things equal, higher mileage applications (within daily range constraints) or applications where vehicles spend substantial time idling will present a more favorable case for electrification. Additionally, operations that allow for fleets to avoid high demand charges and take advantage of lower cost time of use electricity rates will increase economic viability.

- Incentive Program Availability — Access to government and utility incentive can attract investment. If and where availability of incentives target specific fleets and vehicles (such as specific incentives for school buses) those fleets will be more likely to electrify earlier.

Technical and economic factors are not the only important considerations for early M/HD electrification. In most cases, the impetus for early electrification will come from organizational drivers.

- Governmental commitments — The state and many jurisdictions in Colorado have instituted or are considering zero emissions targets for fleet operations (i.e., GoEV Cities). While technical constraints will still steer these transitions and focus will be put on economics, these commitments make public fleets (or private fleets contracted to public agencies) more likely candidates for early electrification.
- Private commitments and ESG — Most large publicly traded companies that run fleets have ESG goals (driven increasingly by requirements from institutional investors) that include reducing vehicle emissions. In addition, public facing companies whose brand will be associated with vehicles they run are increasingly conscious of the impact that electric vehicles can have on their brand image. Public perception for these companies serves as a strong motivation to electrify where possible.

These factors combine to create a profile of likely first mover fleets, most of which have already taken action towards electrification in locations inside and outside of Colorado.

Table 2. Example Fleet Types

Category	Example Fleet Types
Public Fleets	Transit Buses School Buses Refuse and Solid Waste Trucks Heavy-Duty Work Pickup Trucks Service Vehicles
Private Fleets run (or contracted) by large companies	Medium-Duty Vans for Parcel & E-Commerce Delivery Investor-Owned Utility Service Vehicles Food Service M/HD Fleet Trucks Rental M/HD Fleet Trucks Food and Beverage Distribution M/HD Fleet Trucks Refuse M/HD Fleet Trucks Local Service M/HD Fleet Trucks

Charging Infrastructure and Equipment

The basic technology for charging M/HD vehicles does not differ substantially from that used for light-duty vehicles. Low-power (<19.2kW) alternating current charging uses the same J1772 standard as light-duty vehicles. Higher power direct current (DC) charging has to date primarily employed the CCS connector standard used for fast charging by most non-Tesla vehicles. The recently publicized Megawatt Charging System (MCS), which is specified to provide up to 3.5 MW of power, is poised to take market share, at least among vehicles that require heavy charging loads. New megawatt charging technology will, however, continue to coexist with the CCS standard for DC charging of M/HD vehicles.

The key differences between M/HD charging and those of typical light-duty vehicles come down to power level and configuration. Higher-power (11kW+) level 2 chargers are much more common for M/HD vehicles than light-duty vehicles. Moreover, while a DC charger is considered a “fast charger” for light-duty vehicles, an M/HD vehicle might require charging with a high-power DC charger for long periods of time just to cover a single day of driving. In addition to higher power requirements, M/HD chargers require more space, longer cords, and increased planning to accommodate large vehicles, and due to space constraints at depots, may be installed in overhead configurations uncommon for light-duty charging, or designed to be better shared between multiple vehicles.

In addition, due to the high power needs, predictable charging patterns, and reliability requirements of fleet charging, M/HD charging solutions are more likely to incorporate integrated power management, renewable generation and energy storage. These additions increase capital cost of the system itself but can avoid substantial grid upgrade costs and delays. In addition, managed charging and onsite energy resources can also be employed to reduce the impact of demand charges and otherwise optimize the ongoing electricity costs.

Because the basic technology is similar, infrastructure and equipment providers for M/HD charging are primarily the same firms that supply the light-duty charging market. Charging system equipment providers are a mixed industry, with some suppliers vertically integrated with downstream charging services,[4] and others equipment-only suppliers that may be solely focused on charging equipment or a part of a larger company with diversified offerings. A growing number of companies are focused on full M/HD charging system solutions and technical assistance, incorporating smart energy management, microgrid controllers, and distributed energy resources.

M/HD Charging Service Provider Business Models

Like on the equipment side, EV charging service providers that started in the light-duty sector have begun to stand up fleet charging divisions that offer services for M/HD charging. However, as the market ramps up, there are new entrants offering novel services or specializing in niches such as corridor truck charging and charging/trucking as a service, or logistics industry-focused charging deployments.

To date, nearly all deployed M/HD charging has occurred at a depot or other M/HD facility. Deploying charging infrastructure and equipment at any location requires engineering design, construction, electrical work, permitting, equipment procurement—generally everything necessary for any major construction project that adds substantial energy load to a site. While fleets may manage this process themselves through a traditional construction process, integrated solutions from charging providers have become more common in recent years. In addition to managing the infrastructure deployment, providers generally also provide ongoing software, maintenance, and repair contracts for the equipment they provide. In many cases, charging providers will manage funding and incentive applications, and even help fleets with route planning, capacity assessments, and charging strategy.

Limited evidence from discussions with fleet operators indicates that the decision to contract with a full-service charging provider, [5] rather than managing the process in-house,

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[4] Downstream services may include networking services offered by EV charging providers beyond work relevant to the charging hardware itself.

[5] Charging provider that provides end-to-end services from planning to execution, operations, and maintenance.

appears to be dependent on the size and capacity of the fleet operator deploying chargers. Larger fleets with many facilities are more likely to build internal capacity to deploy and manage their own charging. On the other hand, smaller fleets with few locations may not find it profitable to build capacity to manage a more limited deployment, making a full-service option more attractive. However, integrated charging solutions can be attractive even to larger fleets, with early-adopter electric transit bus operators indicating a desire for more integrated solutions than were available at the time of their conversion [30].

Charging as a Service

Most charging service providers have adopted charging-as-a-service products that operate alongside their more traditional operator-owned offerings. These services bundle the integrated charger deployment services, ongoing service/maintenance, and software fees with an equipment lease. These services reduce or eliminate the upfront cost of charger deployment in exchange for a monthly per-stall cost or a per-kWh fee. While most of these products are offered by established charging service providers, in at least one instance, an industrial logistics real estate company has started offering charging as a service as an add-on to tenants. Additionally, while most charging-as-a-service solutions are predicated on the customer having space where chargers may be installed, several service providers also install charging offsite for use by one or multiple fleet customers.

Charging as a service for M/HD fleets is a young industry and there is very little data on uptake of this service model. However, as-a-service offerings have proven popular in other industries, notably technology and software. Moreover, the fact that a substantial proportion of charging service providers have adopted the model speaks to industry confidence in the viability of the business model. As-a-service models are attractive to fleets that wish to outsource fueling their vehicles so that they can focus on their traditional operations. Multiple industry sources interviewed for this report indicated that charging as a service is an important and lasting part of the charging infrastructure and equipment supply ecosystem, and that it may be particularly attractive for smaller fleets who lease property and may wish to avoid the risk of long-term infrastructure investments in locations they do not own or may not occupy in the long term.

Trucks as a Service

In addition to charging as a service models, some companies are standing up electric trucks as a service offerings. The business models represented in this space are diverse, but common bundled features include truck leasing, charging as a service, maintenance, and other fleet management services. In some cases, truck as a service models resemble traditional full-service leases with the addition of electric fueling infrastructure solutions. OEMs selling electric M/HD vehicles such as Mack Trucks, Lion Electric, and OrangeEV, along with major truck leasing companies, have adopted this model.

In a departure from traditional truck leasing, a number of startup companies are experimenting with truck as a service models that move beyond full-service leases to include features such as access to centralized high power charging depots and even truck yards where vehicles can be both stored and receive a charge. Two notable companies experimenting with this model are WattEV and Zeem Solutions—both of which are currently operating in Southern California. Currently, the business models of these companies are strongly tied to the drayage truck[6] industry for Southern California ports (which have aggressive zero emission truck requirements). However, they may prove a sustainable model for the electrification of smaller truck fleets and trucks run by independent operators, which may have difficulty funding and securing a location and charging infrastructure to fuel their trucks.

En-route Charging

While depot-based or nearby centralized charging locations can serve trucks on shorter distance regional or local routes, they cannot support long distance inter-regional trucking, nor can they support local trucking operations for vehicles that do not have access to depot charging options.

While the truck technology necessary to operate on long routes is limited and demand for en-route M/HD charging is currently low, there has been some movement to begin building the high-power charging outposts needed to electrify truck transport on longer distance routes or where depot charging is otherwise unavailable.

Early efforts are fragmented and mostly confined to the West Coast. In one example, TerraWatt, a well-funded startup, is building charging depots in California with plans to expand along Western freight corridors. TerraWatt will provide a combination of subscription-based and one-off semi-public charging but will limit its sites to commercial vehicles. Another example is Portland General Electric (PGE)'s pilot, a high-power, modular M/HD charging site in Portland, Oregon known as Electric Island, which was developed in partnership with vehicle manufacturer Daimler North America [31]. This pilot site is fully public and is not limited to truck traffic. PGE also plans to install additional sites in its service territory as part of the West Coast Clean Transit Corridor.[7] A final example is a partnership project between Volvo, California truck dealers, and a charging service provider, that is building a network of charging locations along freight corridors in California to encourage sales of Volvo's electric trucks.

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[6] Drayage trucks move containerized freight to and from ports and other intermodal facilities such as rail yards.
[7] The WCCTCI is a multi-utility partnership to support the electric vehicle charging infrastructure development along the Interstate 5 corridor. https://westcoastcleantransit.com/

Utilities

The utility landscape in Colorado is diverse. Two investor-owned utilities cover roughly 10 percent of the state's land area. However, because they serve densely populated areas, they account for about 60 percent of utility customers in the state. The remaining 40 percent of customers are split between 22 rural electric cooperatives and 29 municipal utility territories over the remaining 90 percent of the state's land area. According to the Southwest Energy Efficiency Partnership, municipal utilities provide 16 percent of the state's electricity, with rural electric coops providing 28 percent [32]. With so many utilities, there is significant diversity in the size, structure, funding, and capacity of utilities that may serve a fleet or charging provider customer who is looking to deploy M/HD charging in Colorado. The large number of utilities serving Colorado introduces complexity in the charger installation planning process and creates inconsistencies in customer experience across the state.

Figure 3. Colorado Utility Service Territories

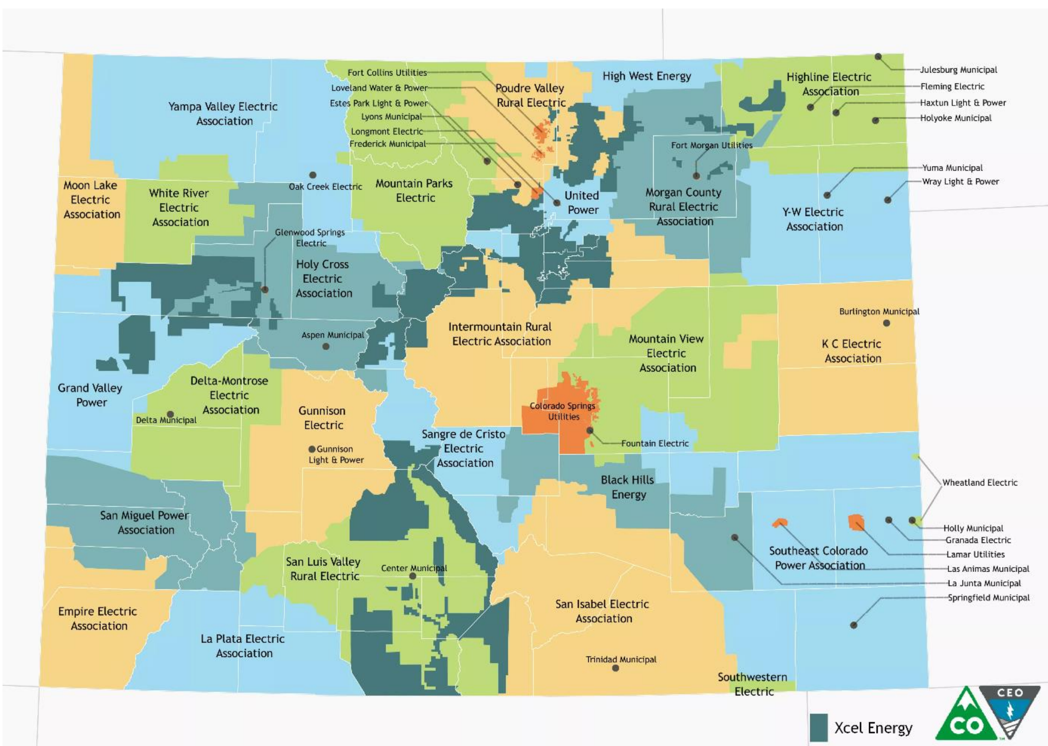


Image courtesy of the Colorado Energy Office

Xcel Energy Colorado

Xcel Energy is Colorado's largest investor-owned utility serving a total number of 1.5 million customers. As part of their approved Transportation Electrification Plan (TEP), Xcel has developed a fleet electrification advisory services program (FEAP), as well as an electric vehicle supply infrastructure (EVSI) deployment program (transformer to the facility), which could provide service at little to no expense to the customer. In addition to those offerings, they also provide utility-owned level 2 (L2) chargers, a 10-year charger leasing program, a bring-your-own charger program, as well as equity adders for charging equipment for low-income and high-emissions-burden communities.

Participants in the fleet advisory service program receive a rebate based on costs incurred in the planning process. Costs incurred in the infrastructure deployment program are normally fully covered through an approved utility construction allowance of $350 per kW, provided they install a minimum of four ports. Likewise, the utility requires participants to select charging equipment from a preapproved hardware and vendor list. Xcel maintains a full-time transportation electrification team and provides each participant in the infrastructure installation program a specified project manager to help guide them through the four-stage process: design, build, implement, and optimize. Xcel also works directly with dealerships and OEMs to ensure they are well informed on their incentive offerings and can pass along accurate information to vehicle buyers.

Black Hills Energy

Black Hills Energy is Colorado's second investor-owned utility, serving a total number of 98,000 customers. Like Xcel, Black Hills Energy has also implemented a transportation electrification plan. The utility offers a charger rebate program for light-duty vehicles (ReadyEV), in addition to EV time-of-day rates. While they do not yet have an M/HD electrification strategy, they are working to educate fleet owners and community members around the value and benefits of electrification and the role of the utility in that process. Like Xcel, Black Hills Energy is an investor-owned utility, and therefore has some flexibility to rate base upgrades to its distribution grid to support M/HD charging.

Rural Electric Cooperatives and Municipal Utilities

Beyond the two investor-owned utilities, there are 22 electric cooperatives across the state that serve a large swath of rural Colorado. Every electric cooperative is a unique entity each in a different stage of the transportation electrification (TE) journey. However, every co-op has at least one EV charging station in its territory, and some have developed electric school bus and transit bus programs, with others experimenting with residential time-of-use (TOU) rates. Notably, the generation/transmission cooperative, Tri-State, is investing millions of dollars to support offtake members to install EV charging infrastructure. To date, rural electric cooperatives have not established specific electric M/HD vehicle initiatives, and the inability to raise funds to conduct upstream grid upgrades serves as a major barrier to fleet electrification in these rural areas. Likewise, rural cooperatives tend to have lean staffing resources and less capacity to manage specific TE projects.

Colorado also has an ecosystem of 29 not-for-profit municipal utilities regulated by local boards, such as those in Fort Collins, Estes Park, and Colorado Springs. These entities range in size from hundreds of thousands of customers to a few hundred across a wide range of topographies (flat eastern plains to mountainous western slope). Given the diversity across municipal utilities, each is in a different situation regarding EV charger installation across its service territory. Those with greater financial and staffing resources, like Colorado Springs Utilities, are moving to electrify light-duty and small truck fleets, but many of these entities are resource-constrained with just a handful of lineworkers across the company.

Common Barriers to M/HD Charging Project Development

High cost of electric M/HD vehicles, limited vehicle and model availability, uncertain operations costs, unfavorable utility rate structures, risk, maintenance requirements, and workforce development needs are all cited as barriers to M/HD electrification among reports, news articles, trade publications, and interviews with industry leaders. In parallel to these vehicle-related concerns are the barriers to deploying the high-cost, high-power charging infrastructure and equipment needed to supply those vehicles with a charge.

Powering Chargers

The importance of early and ongoing engagement with utilities is a common theme in M/HD charging procurement guides, research reports, and in interviews with charging providers, fleets, and the utilities themselves. Charging equipment of course needs power to operate, and freight facilities or other truck depots, yards, and parking facilities are usually not outfitted with sufficient electrical capacity to handle the additional electrical load necessitated by M/HD charging. Fleets that do not engage with utilities early in the process may find themselves with electric vehicles that they cannot charge, and thus cannot use. However, the process of securing additional power to charge electric vehicles is not necessarily simple, and capacity upgrades can come with substantial costs and long lead times.

The first key barrier to powering chargers is the availability of electrical capacity at the site and on the local distribution grid. A truck yard may only have enough existing capacity to support a small office or maintenance facility. Warehouse-adjacent facilities may have substantial electrical capacity, but that will be sized to meet building loads and not EV charging requirements. While a few low-power L2 chargers may fit within a facility’s existing capacity footprint, larger, or higher-power installations generally do not.

If there is sufficient capacity on the local feeder circuits that supply the facility and nearby electricity users, upgraded or new service may only require a new transformer for interconnection. If the facility is not already served by an appropriately sized distribution line, a line extension may also be necessary. In the case that a facility requires substantial additional power, or when the local distribution grid is already congested, charger installation can even require substation upgrades or new substation construction.

Each of these issues adds increasing cost and time to M/HD charger deployment. Utility industry sources note that lead times for utility interconnection, where no substantial upgrades are required, can take from six months to two years. However, lead times for delivery and installation for new transformers (depending on size) could be ten months (for pole-mounted systems) out to five years (for primary transformers at substations) given current supply chain constraints. Often, such timelines are out of sync with fleet vehicle purchase and procurement. Uncertainty around utility interconnection adds risk to fleet electrification timelines and makes it difficult for fleet operators to move through the process.

While a fleet operator or charging provider can expect at least a minimum amount of lead time to interconnect and power new M/HD chargers, there is little geographic information available on electrical capacity, nor estimated timelines for grid upgrades. This means that a capacity barrier that may be fatal to near-term charger deployment will remain unknown until the utility has assessed the site. Multiple industry sources, including fleet operators and charging providers, expressed need for more transparent capacity maps for use in high-level planning and site selection processes.

Capacity limitations are a heavily binding constraint on M/HD charging deployment. In the near term, fleets will likely defer electrification where capacity limits impose long timelines on charging infrastructure and equipment deployment. Fleets with multiple locations will prioritize electrification in places where grid capacity is more robust. Highly motivated fleets may opt to deploy onsite renewables and battery energy storage to enable operations ahead of or instead of utility capacity build out, however this will come at considerable expense. This self-generation and storage strategy is currently being embraced by charging service providers building high power en-route charging.

In addition to the time constraints that can derail electric M/HD deployment projects, capacity upgrades come at an additional cost to the already high cost of onsite electrical equipment, charging equipment, construction, and the vehicle itself. Investor-owned utilities Xcel and Black Hills Energy have flexibility to rate base some of these costs, which can reduce or eliminate the upfront costs of these upgrades to customers and allow the utility to earn a rate of return on their investments. However, this is not true for the other 51 municipal utilities and rural cooperatives across the state. Not-for-profit municipal and rural utilities are limited in their ability to use ratepayer funds to pay for electrical system upgrades for single beneficiaries. For customers in those territories, adding substantial capacity upgrade costs to project budgets, along with increased timelines, is likely to render many projects uneconomic, even with grant and incentive funding.

Outside of investor-owned utility strategies of rate basing grid capacity expansion costs, there are few, if any, meaningful proposals that address the cost issue of grid enhancements to support transportation electrification. This is an unsolved problem that deserves further research and attention both in Colorado and nationally as the M/HD electrification transition takes hold.

Funding Chargers

Cost is of course a barrier to the deployment of M/HD charging infrastructure and equipment, especially for smaller operators with fewer resources. Unlike liquid fuel, where using public infrastructure is common, especially for smaller fleets and owner operators, public infrastructure is not available outside of very limited markets on the West Coast. Moreover, due to longer recharging times and uncertain public charger availability, many fleets are unable to rely upon public charging if they are to meet their duty cycle obligations and return to base within a specified, narrow timetable. Without incentives or other rebate programs, installing the necessary wiring, conduit, panels, and charging hardware can be prohibitively expensive. M/HD infrastructure costs can range from $25,000 for 20kW of charging to upwards of $1 million for 500kW. And, as certain projects could require megawatts of electricity, these costs will be considerable, and out of reach for many fleet operators.

Tax credits, grants, and incentive programs and policies are specifically intended to help overcome these cost barriers. However, as designed, many funding programs are inaccessible or infeasible for many fleets or M/HD charging developers.

In many cases funding providers require fleet operators to provide a vehicle purchase order before any construction may begin. If poorly implemented, this model can exclude charging-as-a-service providers which may have otherwise enabled a fleet to electrify by financing infrastructure at a cost the fleet operator could not otherwise obtain. Likewise, given the asynchronous timelines for vehicle purchase and delivery compared with infrastructure development and site interconnection, purchase order requirements may leave many fleets with idle vehicles languishing in depots without power. Other incentive requirements have also hampered fleets from accessing funds, such as ten-year “in-the-ground” infrastructure requirements. Fleets on a typical five to seven year commercial site lease may not be able to commit to that obligation.

There are generally good public or ratepayer interest reasons for these funding program design features, but many are maladapted for effective deep electrification in the M/HD vehicle sector. New or reauthorized programs that relax these requirements, or that offer funding lanes to cover use-cases that might otherwise be excluded from program requirements, could have a substantial impact in improving fleet access to available funding.

Installing Charging Infrastructure

Space is a substantial constraint for many fleet depots and other M/HD facilities. Electrical equipment and charging equipment can have large footprints, particularly for high-power applications, and fleet depots are not configured to have the additional space necessary to accommodate them while still maintaining space to park and maneuver large trucks. Business models are predicated on the number of vehicles currently on site, and revenue or operational efficiency can suffer if fewer vehicles can park at the same depot. The construction related to the installation of chargers at existing depots may also result in interruptions in their business operations and hinder fleet productivity. While solutions are available to elevate charging equipment above vehicle storage, those structures increase the cost of deploying charging infrastructure and may be impractical.

Land ownership is an additional barrier to deploying charging infrastructure. Leasing property is common in commercial fleet applications. Unlike those that own the land where their vehicles are domiciled, fleet operators on leased land will need to engage with depot property owners or property managers to secure their support and buy-in for any electrification project to succeed. As such, required property easements or modification may deter landlords from moving forward with electrification and can deny a tenant’s request to install chargers. Moreover, much of the cost of deploying infrastructure is unrecoverable in the case where a tenant may not occupy a space in the long term, making many fleets hesitant to make these improvements to land they do not own. Finally, in some cases utilities may balk at the prospect of investing in service upgrades at a property when there is a risk the tenant will leave and anticipated revenues from charging will leave with them.

While the landlord-tenant relationship issue is recognized in both literature and by industry sources, there is little data on how hard or durable a barrier this issue is. One source interviewed for this report noted that negotiating with property owners has been a challenge for deploying infrastructure, particularly when it came to return of premises conditions that would require the removal of newly installed electrical infrastructure. However, it is possible that these concerns will temper as the market matures and it becomes clear that future tenants will also desire charging for their vehicles. Landlord reticence may also be mitigated by ‘right to charge’ laws such as those in California that require landlords to allow commercial tenants to install charging equipment [33].

The more challenging aspect of this barrier may stem from fleets' reticence to invest heavily in improvements for property they do not own. Charging as a service may prove to be a solution to this problem by enabling chargers to stay with the property instead of the fleet upon lease termination. At least one major property manager of industrial logistics assets is pursuing this model directly through the creation of an internal charging-as-a-service division. Understanding of this barrier will evolve as the market matures and more fleets and charging providers come in contact with more landlords and property managers, making this an important topic for future study and ongoing monitoring.

Dealer Engagement

Vehicle manufacturers, and in particular, dealerships, often serve as the initial gateways for operators into the electrification process. However, if dealerships are not well informed about charging infrastructure needs, information gaps in this initial contact cause problems down the line for charger and vehicle deployment. If not initially informed by a dealer, these managers may not know to contact their utilities, the infrastructure installation and preliminary timelines necessary to energize the vehicles, nor fully understand the next steps in the electrification process. At the same time, a poorly informed dealer may sell a fleet operator charging hardware that is incompatible with or unnecessary for their chosen electric M/HD vehicles, lack the necessary knowledge regarding available funding or incentive programs, or otherwise dissuade prospective owners from purchasing an EV altogether.

Permitting Charging Installation

Often considered a "soft cost," permitting, along with fees and regulations, are an integral component of the fleet electrification process that must not be overlooked. Fleets must be sure to engage with the relevant permitting bodies and secure the appropriate permits before beginning any construction work or installation. Sites slated for DC charger deployment must undergo a zoning review conducted by the local authority, often cited as the lengthiest part of the permitting timeline, in addition to a building and electrical permitting and inspection process. In some cases, permitting processes can take up to a year, particularly if utility upgrades and buy-in are required, and fleets must build those considerations into the planning process. In terms of best practices, jurisdictions having authority (JHAs) should update zoning ordinances to define EV charging stations as accessories to existing sites in order to mitigate any zoning review requirements, as well as clarify in law that EV charging stations are full parking spaces as they relate to parking minimums. Likewise, JHAs should encourage and allow concurrent reviews and inspections for all required permits to streamline the process and avoid duplicative efforts. To best support permit applicants, JHAs should engage in pre-permitting meetings with prospective DCFC installers, ensure all qualifications and requirements are clear and transparent, and make all documents and applications readily available and submittable online [34] [35].

Conclusion

The market for M/HD charging infrastructure is nascent, and much uncertainty exists on how it will develop as demand for M/HD charging increases. Several M/HD market segments, particularly those that are depot based with predictable operations that lend themselves well to early electric M/HD vehicle models, are primed to electrify, especially with governmental or utility incentives. Other use cases without such favorable operations or without access to capital could potentially electrify, but face more difficult project economics and may require more substantial subsidy in the near term. Moreover, the high-power needs of depot charging can prove a challenge if there is not suitable electrical capacity where trucks need to recharge.

While the basics of charging M/HD vehicles do not differ substantially from light-duty vehicles, the sheer variety of M/HD vehicle use cases adds complexity to the market. This complexity along with challenges more particular to M/HD charging leave much room for innovation around charging service business models and financing arrangements. En-route charging of the type that could provide charging for vehicles that do not have a home base (such as long-haul trucks) has the least developed market. Several companies have already begun to develop business models to fill that need but given the high costs and uncertain road to profitability, will also require substantial policy support.

3. Charging Needs Analysis

To develop a well-designed funding program for M/HD vehicles in Colorado, it is important to understand not just the current state of the market as examined in the previous chapter, but also look ahead to understand Colorado's future M/HD charging needs in the context of broader electric M/HD vehicle adoption goals. This chapter details the results of that charging needs analysis conducted using the Atlas INSITE-MHD model, an energy-need based technoeconomic model of M/HD charger deployment, along with a spatial analysis of long-haul-focused corridor charging need.

The INSITE Tool

Atlas Public Policy's Investment Needs of State Infrastructure for Transportation Electrification (INSITE) tool is a technoeconomic[8] model designed to provide high- level estimates of annual charger investment needs for widespread M/HD electrification. The model integrates a high-level analysis of the number and power level of chargers needed to support a given fleet of vehicles with a cost model that estimates the associated capital (equipment and installation) costs.

For this analysis, the tool takes as an input modeled zero emissions M/HD vehicle sales (vehicle classes 2b – 8, excluding transit buses) supplied by Colorado Energy Office. These are consistent with Colorado's policy goals. The tool assigns those sales to one of ten vehicle segments (Table 3) based on class and use case and then estimates the energy recovery need of those vehicles based on operational parameters. The model then classifies truck segments into home, depot, public (or combination of home/depot and public) charging and estimates the number and power level of chargers necessary to recover energy needs, accounting for a significant slowdown in charging rate above 80 percent state of charge. Finally, the model translates those charging station requirements into investment needs by applying installation cost models of charging types to the number of needed charging types. Further information about the methods, data sources, and assumptions embedded in the INSITE-MHD model, and its application to this report can be found in Appendix A.

Table 3. INSITE Vehicle Categories[†]

Vehicle Use Case	Description

[8] Technoeconomic modeling combines a technological model (in this case a model of infrastructure need) with an economic model (in this case a cost model that estimates infrastructure cost).

Cargo Van	Mid-sized van designed for goods movement. Typically used for delivery service or other commercial applications
Motor Coach	Intercity or tour bus
Pickup Truck	Heavy-duty pickup truck marketed for hauling or towing heavy loads
Refuse	Vocational truck used for waste collection
Regional Truck	Catch-all category for middle- and last-mile freight trucks used for goods movement
School Bus	Buses used to transport K-12 students
Shuttle Bus	Short- distance passenger bus such as those used at airports or to connect to transit
Step Van	Large van built for easy driver ingress/egress. Typically used for delivery services
SUV	Large heavy- duty sport utility vehicle used for passenger transport
Terminal tractor	Specially configured tractor built to move dry vans or other trailers around cargo terminals and other warehouses

† Tractor trucks used for long haul operations are not modeled in INSITE

The results of the INSITE tool are the number of needed ports and associated investment need for each charging category. To simplify the analysis, INSITE-MHD models a limited number of charger power levels compared to the universe of available charging equipment, and therefore the results categories should be interpreted as representative rather than exact. High-level charging categories included in the model are listed and described in Table 4.

Table 4. INSITE Charging Categories

Category Name	Description
Home L2 **Class 2b3 vehicles**	AC chargers installed at a residence to support charging of personally owned Class 2b and 3 vehicles
Depot L2 (48 & 80 A) **Class 2b/3 vehicles &** **Class 4 – 8 vehicles**	AC chargers installed at depots configured to support Class 2b-Class 8 vehicles with relatively low energy needs. Subcategorized into 48- and 80-amp equipment variants depending on power recovery need. INSITE assumes no sharing for L2 chargers (one charger per vehicle)

Depot DC (50 kW & 150 kW) Class 4 - 8 vehicles	DC chargers installed at depots configured to support Class 4-8 vehicles. INSITE allows a single DC charger to be shared using load management up to 80% utilization during a 9-hour overnight charging window. This results in no more than two vehicles sharing a charging port.
En-route 350kW Class 2b - 3 vehicles & Class 4 – 8 vehicles	Very high-power DC chargers that support away-from-base charging needs for those vehicles that need supplemental charging or have no onsite charging. Because the footprint of Class 2b and 3 vehicles is similar to light-duty vehicles, en-route charging is modeled sufficient to meet incremental energy demand from these vehicles in high-utilization areas. Class 4-8 vehicles need more space and are therefore assumed to require purpose-built charging locations, with lower utilization during the study horizon.

Cost model

The INSITE tool's cost model captures the following capital expenditures required to deploy charging equipment:

- Charging equipment
- Electrical equipment (e.g., panels, switchgear, conductors)
- Grid upgrades at DCFC sites (not included at L2 sites)
- Related construction costs (e.g., bollards, supporting structures)
- Labor
- Project management, design, and permitting costs

The model excludes capital costs for land acquisition, greenfield site development, distributed energy systems, and any ancillary construction costs for structures not directly related to charging equipment (e.g., shade structures, restrooms). Because INSITE models upfront capital investment need only, the cost model excludes all operating costs such as rent, energy bills, maintenance, and repairs. Costs are in undiscounted 2022 dollars.

Table 5. Summary of Costs by Charging Type[9]

Charging Type	Per Port Cost
Home L2 Charging	$2,600 - $6,000 depending on home type†
Depot L2 Charging	$6,600 - $25,000 depending on power level and configuration††

[9] For full description of costs, cost model assumptions and data sources, see Appendix A

Depot DC Charging	$86,900 – $193,300 depending on power level
En-Route Charging	$254,900 – $360,000 depending on configuration††

† *Costs differ between detached, attached, and multifamily housing*

†† *Larger vehicles require costlier charging site configurations*

Due to the long lead times necessary for utility upgrades, funding for high-power depot and en-route charging must be committed well in advance of need for charging. Cost modeling accounts for this lag between committed investment and charging deployment by modeling depot charging and en-route charging needs two and three years in advance, respectively. In other words, the investment for those two categories in year one reflects energy recovery need in years three and four.

Cases

There is considerable uncertainty inherent in predicting the number, type, and cost of charging infrastructure needed to satisfy the charging needs of an increasingly electrified M/HD fleet. While the INSITE model is not equipped to capture uncertainty around dimensions such as infrastructure cost and vehicle adoption patterns, the analysis does address uncertainty in how M/HD operators might size their depot infrastructure builds. To capture this uncertainty, we present results in two cases:

- **Average Case**: This case bases energy need (and thus required infrastructure) on the average daily mileage for each vehicle class-segment. This scenario assumes that fleet operators will optimize their charging infrastructure deployment to closely match their typical usage and/or share charging infrastructure efficiently across their fleet.
- **Conservative Case**: This case increases energy recovery need by 30 percent to build in additional operational reserves within charging infrastructure installations. The case assumes that fleet operators will be conservative in their infrastructure sizing to accommodate considerably more energy recovery than their typical usage would require.

While it is unclear how conservative or aggressive fleet operators will be when making infrastructure investment decisions (especially as the market matures and fleets become more comfortable with EV technology), We expect that the true value is likely to reside between these two case bounds. Note that both cases assume a substantial operating margin in both home and public charging, and so cases do not introduce any differences for those charging modes. Both cases also assume that depot-charging vehicles are charged to full, including a significant slowdown above 80 percent state of charge.

Long-Haul Trucking

The INSITE model estimates charging needs based on the energy requirements of an inventory of vehicles registered within the geographic domain under study. This approach works for long-haul trucking when the geographic domain is national or a large multistate region. However, it is not an appropriate method for estimating the charging needs of long-haul trucking in Colorado because a substantial portion of long-haul trucks that operate and require charging are not actually registered in Colorado.

For this analysis, we model long-haul truck charging needs using a secondary spatial model that is described in the Electrifying Freight Corridors section.

Hydrogen Vehicles

The INSITE model does not support modeling investment required for hydrogen fuel cell vehicles. Any assumption of hydrogen fuel cell vehicle usage in this study would only reduce the number of EV charging infrastructure required without accounting for the cost of hydrogen fueling infrastructure that would take their place. Therefore, the results presented in this analysis reflect the investment needs for electric vehicle infrastructure in a scenario where all zero-emission M/HD vehicles are battery electric. To the extent that hydrogen fuel cell M/HD vehicles make up any portion of zero-emission M/HD vehicle deployments, as suggested by *Opportunities for Low-Carbon Hydrogen in Colorado: A Roadmap* [36], Colorado will require proportionately fewer chargers but will need hydrogen fueling infrastructure in their place.

INSITE M/HD Results

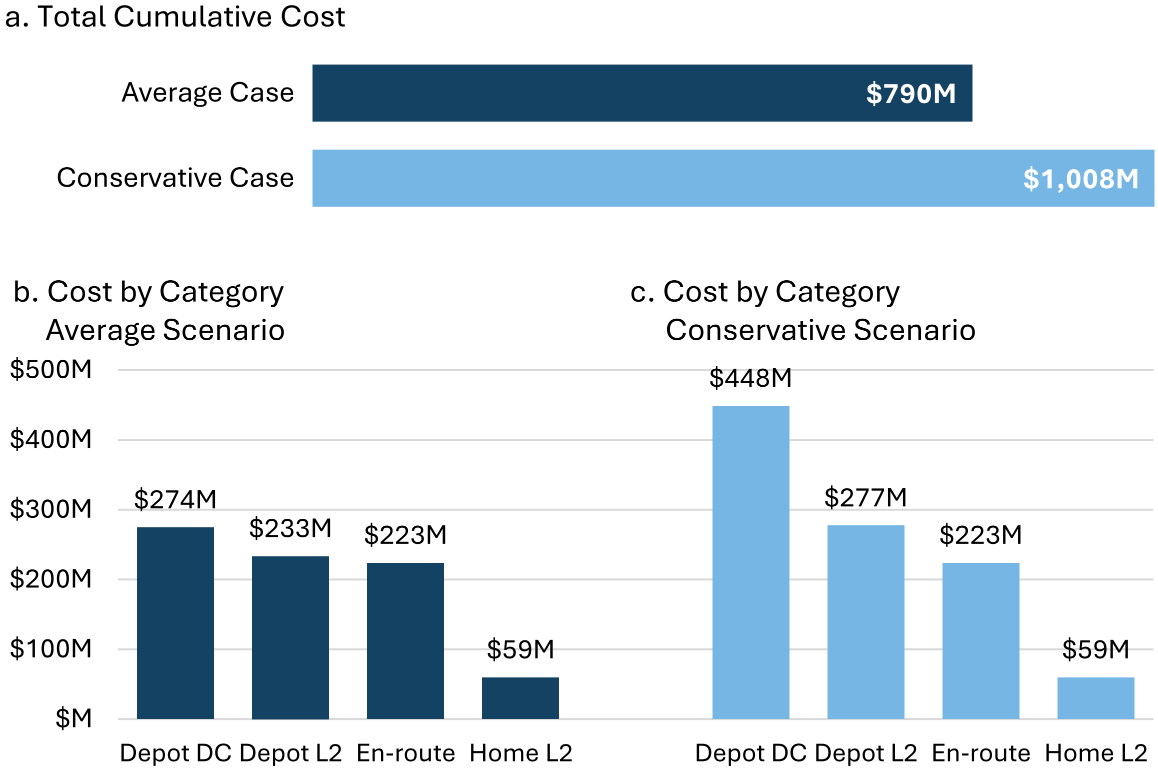
We find that Colorado will require between $790 million and $1 billion in cumulative investment in charging equipment deployment by 2030 to support the local and regional operations[10] of electric M/HD vehicles in the state. These figures include both the average and conservative case investments needed to construct the 30,000 individual ports required in 2030 and committed funding to deploy an additional 12,500 depot and en-route chargers by 2032 and 2033.

Breaking categories down further, the largest cost category is DC depot charging with $274 and $448 million in cumulative costs for the average and conservative case, respectively. En-route charging sits in the middle, costing $233 million in either scenario. The least costly category is home L2 chargers, at $59 million in either scenario.

[10] This figure does not include the costs to electrify freight corridors for long-haul truck traffic. For an accounting of those costs see Electrifying Freight Corridors

For a detailed breakdown of anticipated costs and ports by charger location and power level, see the digital appendix to this report: Quantitative Results Summary.xlsx

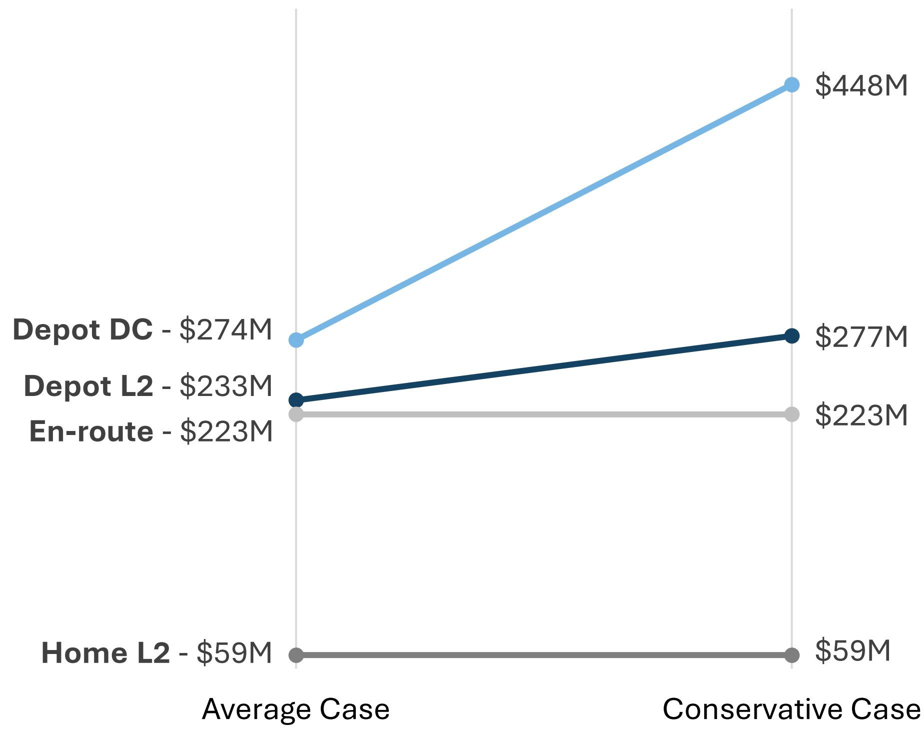
Figure 4. Summary INSITE Cumulative Cost Estimates 2030



shows cumulative investment needed compared across the two cases. As mentioned previously, en-route and home L2 charging do not change between the average and conservative scenarios. Depot charging costs increase to reflect the effect that more conservative planning has on number and power level of required chargers.

Figure 5 shows cumulative investment needed compared across the two cases. As mentioned previously, en-route and home L2 charging do not change between the average and conservative scenarios. Depot charging costs increase to reflect the effect that more conservative planning has on number and power level of required chargers.

Figure 5. Comparison of Cumulative Costs Between Scenarios in 2030



L2 depot charging costs see less increase between scenarios than depot DC charging. Larger energy recovery needs push many vehicles from cheaper, lower-powered (48 A) L2 chargers to higher-power (but more expensive) 80 A L2 chargers. However, the cost difference between the two charger types is not very large. Additionally, some vehicle categories that could charge using L2 charging in the average case move to the DC depot category in the conservative case, somewhat moderating the cost increase.

A similar pattern in DC depot charging pushes chargers from 50 kW to 150 kW in the conservative case. However, in the case of DC chargers, the absolute difference in costs between the two power levels is high, leading to a steeper increase in costs. Moreover, vehicles that change from L2 to DC charging also see a substantial increase in costs, further increasing depot DC costs in the conservative case.

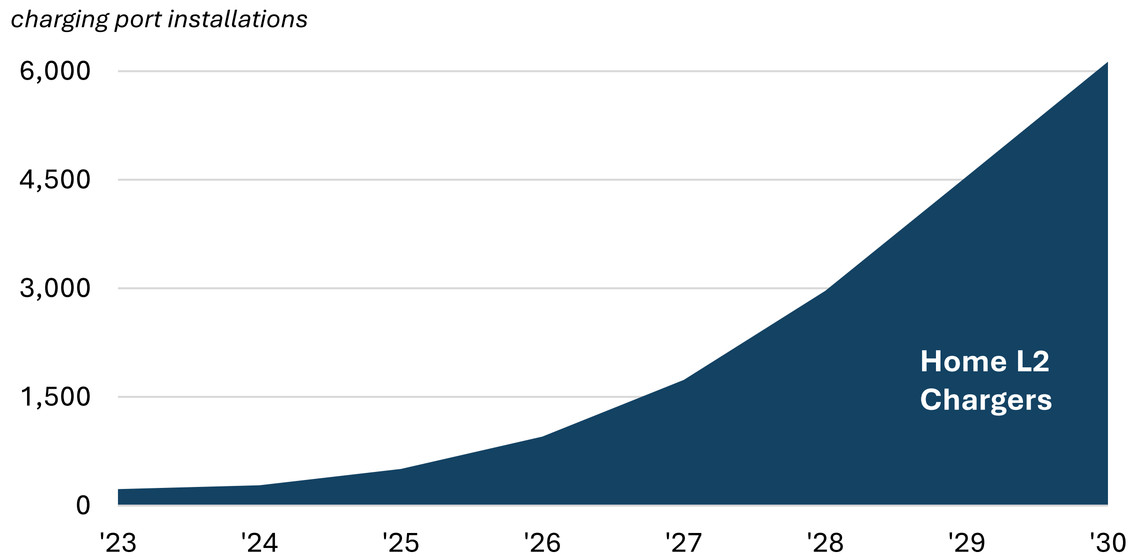
Home L2 Charging

Home L2 charging need is estimated from the number of Class 2b and 3 vehicles (primarily heavy-duty pickup trucks) registered for personal use. [11] The INSITE tool assumes that the vehicles in this category that electrify are parked at residences and obtain most of their required energy there. Because Class 2b and 3 vehicles (particularly pickup trucks)

[11] Identified by registration to an individual rather than a corporation or other organization

registered for personal use are by far the largest category of M/HD vehicles in Colorado, home L2 charging has the highest charging port requirements, growing to more than 6,000 per year by 2030 (Figure 6). However, because the average per port cost of installing home L2 charging is relatively low compared to other charging installations, home L2 charging is also the least costly category of M/HD charging investment need. Cumulatively, Colorado will need about 17,400 home L2 chargers by 2030.

Figure 6 Annual Home L2 Charging Deployments (2023 – 2030)



Depot L2 Charging

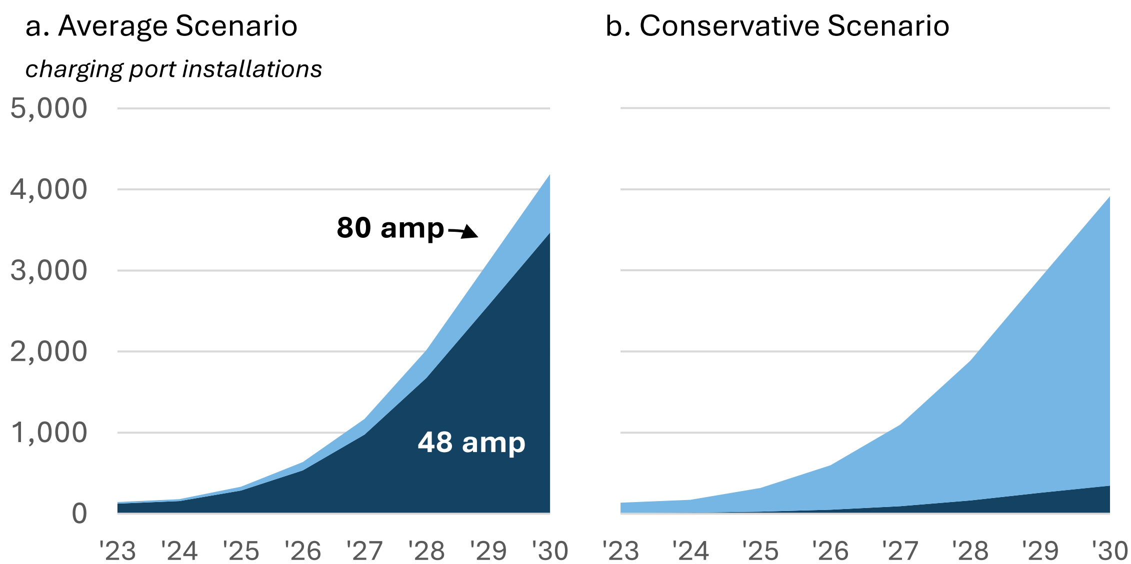
Depot L2 charging supports vehicles with light daily energy needs, either because they do not travel far between charging opportunities, they are smaller and therefore require less energy overall, or both. Vehicle categories that can be supported by L2 charging at a depot are mostly lighter Class 2b and 3 fleet vehicles, but also include heavier Class 4-8 vehicle categories that have less intense operating duties. Examples of vehicles that fall into this category include cargo vans, step vans, and school buses.

Overall, depot L2 charging is the second-largest charging category by cumulative port count in both scenarios. Figure 6 shows that the script is flipped in the conservative case, indicating that most L2 charging vehicle categories are close to the threshold of needing additional power. In addition to swapping L2 power levels, a few categories—certain classes of step van, refuse trucks, and school buses— move from only requiring L2 charging to needing 50 kW charging in the conservative case. However, the difference in total number of L2 chargers between scenarios is small, amounting to a fewer than 250 ports-per-year difference by 2030.

Figure 7 shows that annual need for depot L2 chargers will grow from just a few chargers in 2023 to between 3,900 and 4,200 in 2030. Though fewer chargers are needed for depot L2 than home L2, the higher average cost of depot installations makes them cost substantially more than home L2 chargers. Cumulatively, Colorado needs between 11,000 and 11,800 depot L2 chargers by 2030.

Within the depot L2 category, vehicles are subclassified into 48 Amp (10 – 11.5 kW) and 80 A (16.6 – 19.2 kW) charger power levels, depending on their assumed energy requirements. In the average case, a large majority of the vehicle categories in this charging Class can manage with lower-powered 48 Amp chargers. Figure 6 shows that the script is flipped in the conservative case, indicating that most L2 charging vehicle categories are close to the threshold of needing additional power.[12] In addition to swapping L2 power levels, a few categories—certain classes of step van, refuse trucks, and school buses— move from only requiring L2 charging to needing 50 kW charging in the conservative case. However, the difference in total number of L2 chargers between scenarios is small, amounting to a fewer than 250 ports-per-year difference by 2030.

Figure 7. Annual Depot L2 Port Deployments by Scenario and Power Level (2023 – 2030)



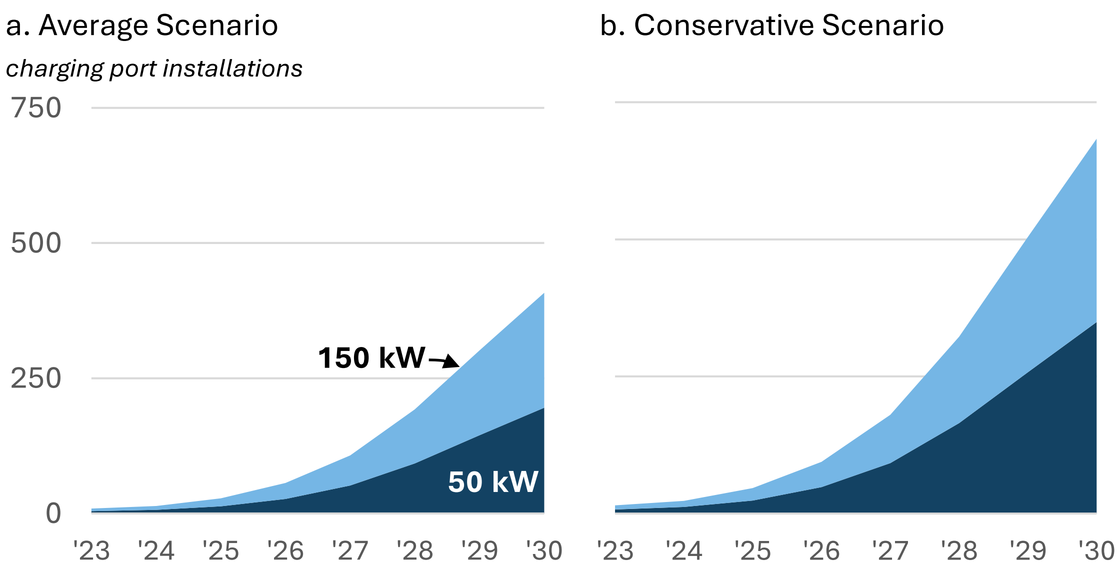
Depot DC Chargers

Depot DC chargers support depot-based vehicles with heavier energy needs than can be supported by L2 chargers. Larger vehicles and those that travel longer distances between charging fall within this category. Only Class 4 through 8 vehicles fall into this charging category, including larger shuttle buses and regional trucks.

Overall, annual need for DC charging at depots grows from near zero in 2023 to between 408 and 683 stations by 2030. Far fewer DC depot chargers are needed than L2 depot chargers. However, the high relative costs of DC depot chargers make the combined 50kW and 150kW DC depot charging the highest-cost category. Cumulatively, Colorado will need between 1,100 and 1,900 DC chargers by 2030.shows that between the two scenarios, the annual number of required DC chargers nearly doubles with the influx of vehicles that could be formerly charged with L2 chargers in the average scenario. The ratio of 50 kW to 150 kW stations remains similar across scenarios despite the influx of vehicles that were in L2 charging categories, indicating that a substantial fraction of vehicles that could have charged at 50 kW in the average case must charge at 150 kW in the conservative case.

Figure 8 shows that between the two scenarios, the annual number of required DC chargers nearly doubles with the influx of vehicles that could be formerly charged with L2 chargers in the average scenario. The ratio of 50 kW to 150 kW stations remains similar across scenarios despite the influx of vehicles that were in L2 charging categories, indicating that a substantial fraction of vehicles that could have charged at 50 kW in the average case must charge at 150 kW in the conservative case.

Figure 8. Annual Depot DC Port Deployments by Scenario and Power Level (2023 - 2030)



En-route Charging

The final category, en-route charging, is based on a fixed 10 percent of energy need that we assume will need to be satisfied outside of home base charging during the early electric M/HD market. This category is distinct from the corridor charging[13] because it supports travel within a region rather than interregional corridor traffic. En-route chargers are all 350kW DC charging ports necessary to quickly recharge M/HD vehicles.

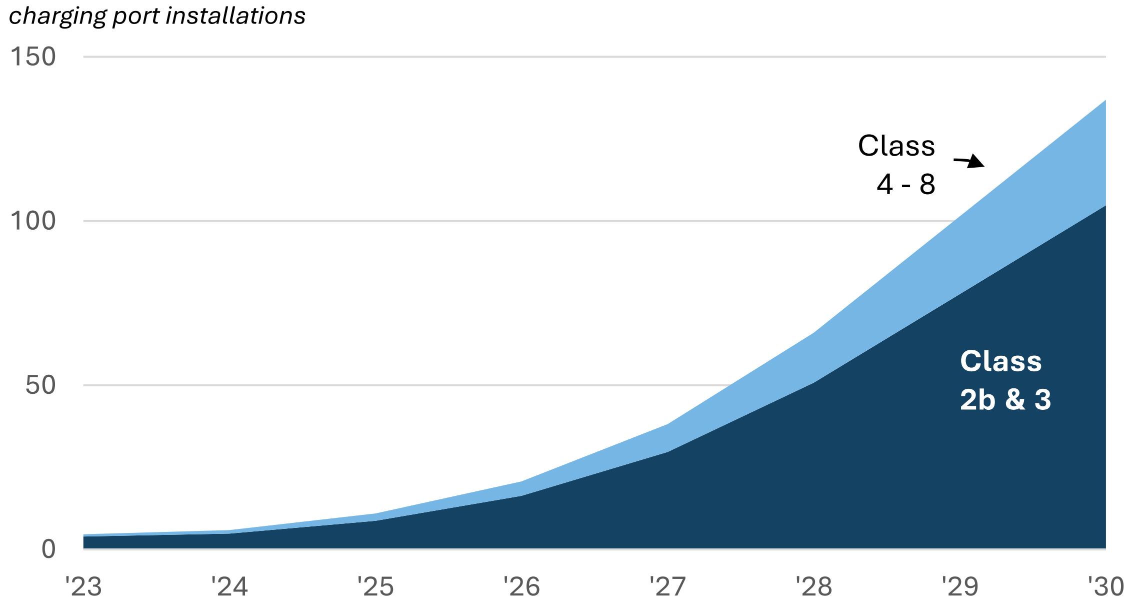
Because public, en-route charging is meant to refuel vehicles quickly at high power levels, many more vehicles can share the same charger. Therefore, the number of chargers needed to satisfy en-route energy demand is based on not only energy recovery need but also assumptions about charger utilization (see Appendix A for additional details)

Because Class 2b and 3 vehicle footprints are typically close to those of light-duty vehicles[14], the charging stations to cover energy need for Class 2b and 3 vehicles can be built incrementally alongside light-duty-focused charging. On the other hand, Class 4 through 8 vehicles typically have substantially larger footprints and will need charging sites that can accommodate that additional space. Figure 9 shows that annual need for new en-route charging grows from near zero in 2023 to 137 in 2030. Of those, 32 would serve Class 4 through 8 vehicles and 105 would serve Class 2b and 3 vehicles. Cumulatively, around 380 en-route chargers are needed by 2030.

[13] Corridor charging need is described later in this chapter.

[14] Note: because Class 2b and 3 vehicles are often used for towing, some pull through stations will be needed.

Figure 9. Enroute Charging Ports Needed by Vehicle Class (2023-2030)†



† Excludes Corridor Charging Sites

Costs by Geography

The costs of deploying charging infrastructure will not be evenly distributed across Colorado. Denser areas with more M/HD vehicle populations will require much more investment than the more sparsely populated parts of Colorado. While the INSITE tool provides estimates at the statewide fleet level, in this report we have downscaled those results to county and utility territory level using vehicle registrations as a spatial proxy for charging station need. For a full explanation of the downscaling method, see Appendix A.

At a county level, investment need is substantially concentrated in the counties of the Denver Metropolitan Statistical Area, along with Boulder, Fort Collins, and Colorado Springs. The top ten counties by investment need (shown in Table 6. Cumulative 2030 Investment Need for Top 10 Counties in Colorado) account for almost 75 percent of the total investment need across Colorado. While investment need skews to highs as much as $113 million in Denver-area counties, the median Colorado county will need somewhere between $33 and $46 million in M/HD charging investments by 2030.

Table 6. Cumulative 2030 Investment Need for Top 10 Counties in Colorado

County	Average Case	Conservative Case
1. Denver County	$90,430,000	$113,070,000
2. Weld County	$86,090,000	$109,740,000
3. Adams County	$77,130,000	$95,830,000
4. El Paso County	$71,640,000	$86,200,000
5. Arapahoe County	$65,410,000	$80,790,000
6. Jefferson County	$53,560,000	$64,010,000
7. Larimer County	$50,680,000	$63,450,000
8. Mesa County	$30,070,000	$37,710,000
9. Douglas County	$28,580,000	$36,100,000
10. Boulder County	$28,040,000	$35,840,000

When downscaled to utility territory, investment need becomes considerably more concentrated. The top 10 utilities by investment need (shown in Table 7. Cumulative 2030 Investment Need for Top 10 Utility Districts in Colorado) account for approximately 95 percent of total investment need, while the top utility, Xcel Energy, takes up about 58 percent by itself.

Table 7. Cumulative 2030 Investment Need for Top 10 Utility Districts in Colorado

Utility	Average Case	Conservative Case
1. Xcel Energy	$465,850,000	$587,050,000
2. United Power	$84,300,000	$108,680,000
3. Black Hills	$68,050,000	$84,570,000
4. City of Colorado Springs	$41,260,000	$51,060,000
5. Holy Cross Electric Assn	$32,300,000	$42,610,000
6. Intermountain Rural Elec Assn	$24,210,000	$30,250,000
7. Highline Electric Assn	$17,010,000	$23,440,000
8. Delta Montrose Electric	$10,490,000	$13,320,000
9. Empire Electric Assn	$10,060,000	$12,740,000
10. K C Electric Assn	$6,020,000	$8,710,000

Despite a substantial concentration of investment need in Colorado's investor-owned utility territories, a full one third of the $700 million to $1 billion in required investment will be needed in Colorado's many cooperative and municipal utilities. While the median cooperative or municipal utility will only require $2-3 million in investment, at least seven will require investment in excess of $10 million.

For a full breakdown of anticipated costs and charging ports by county and utility, see the digital appendix to this report: Quantitative Results Summary.xlsx

Electrifying Freight Corridors

As previously mentioned, we took a different approach to modeling charging needs for long-haul trucking. Because these vehicles do not return to base overnight, their uptake will be enabled by geographic buildout along key routes. For this analysis, we model the needed investment to provide minimum-coverage en-route charging for long haul-trucks along key freight corridors in Colorado. Our approach identifies the number and location of sites along those corridors based on the assumption that minimum coverage requires stations at approximately 100-mile intervals[15] along freight corridors and where corridors intersect at or near freight corridor junctions. For a full description of these methods see Appendix A.

For this study, we include three build phases between 2023 and 2035. Corridor selection and sequencing for this study were provided by CEO in consultation with the Colorado Department of Transportation.

Table 8. Colorado Electric Freight Corridor Charging Phases

Phase	Years	Location / Highway
One	2023-2027	Denver Metro
Two	2025-2030	I-70, I-25, I-270
Three	2030-2035[16]	I-76, US-287, US-385, US-85, US-50, US-40, US-160

The minimum charging locations we model in this analysis are relatively small 3.5 MW installations that, depending on need, could accommodate either exclusively 350 kW chargers sufficient for long duration, truck parking charging, or some combination of higher power (MW+) stations sufficient for the rapid recharging of long-haul truck batteries. We use costs from the West Coat Clean Transit Corridor Initiative (WCCTCI) report for a 3.5 MW charging site: approximately $3.8 million. As described in that report, as the electrified

[15] Minimum network requirements based on the WCCTCI Interstate 5 Corridor Final Report [39]

[16] Due to long lead times for high power charging sites, funds for many of the stations in this phase must be committed by 2030.

long-haul trucking market picks up, these vehicles will likely require larger sites beyond this minimum build to avoid congestion and enable charging both during drivers' mandated ten-hour break and during shorter stops. The right mix of site sizes and charging station power levels for these vehicles remains an open question for industry and researchers as this nascent market develops.

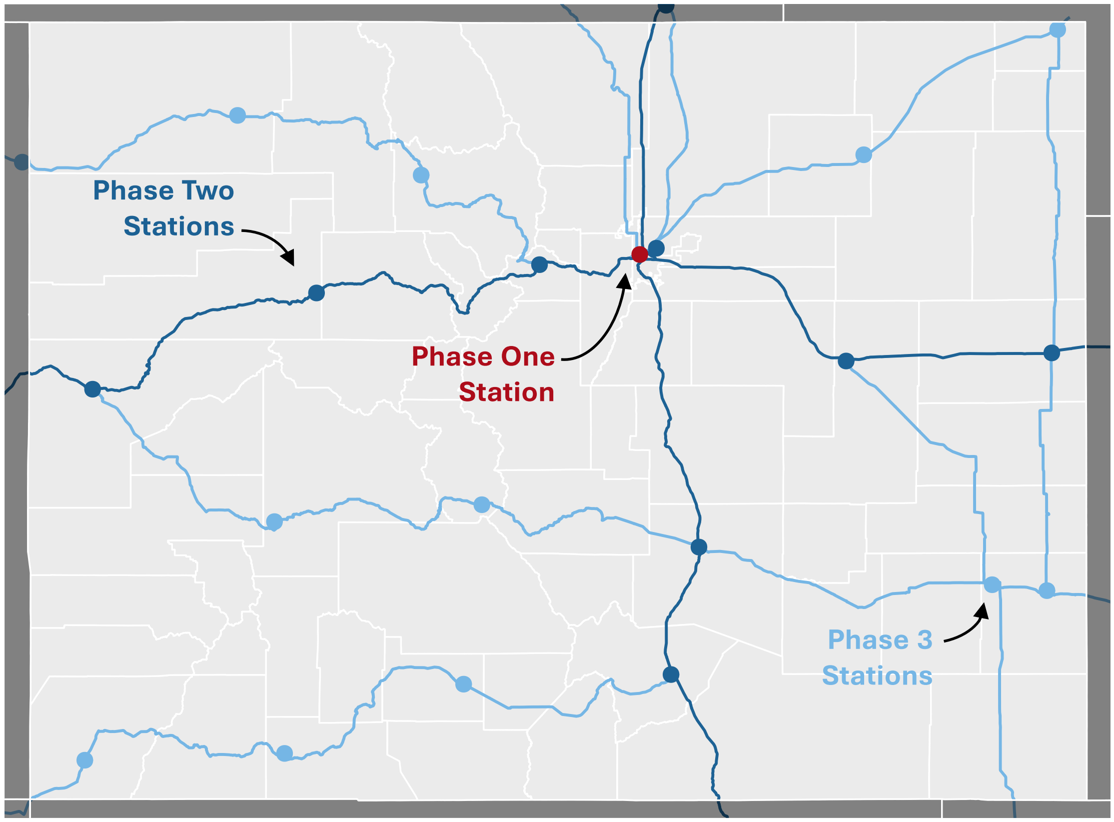
Phase one consists of a single pilot location in Denver. Phase two consists of eight charging sites along the I-70 and 1-25 corridors and an additional Denver location. Phase three fills out the remaining routes with 11 additional sites.

Figure 10. Installation costs by phase

The projected locations of these corridor stations are dependent on corridor segments that extend outside of Colorado to connect with out-of-state freight origins and destinations.

Most Colorado Utilities could expect one or none of these corridor chargers in their territory. However, as many as eight of these stations may be located in Xcel Energy territory. Highline Electric Association might see as many as three stations located in its territory in phase three and Morgan County might see two stations in the same phase.

Figure 11. Modeled Locations of Corridor Charging for Long-Haul Trucking



Current Funding Opportunities for M/HD Charging in Colorado

There are currently no funding sources dedicated exclusively to M/HD charging infrastructure development in Colorado, a funding gap that CEO is poised to fill with its new program.

Xcel Energy's 2021-2023 Transportation Electrification Plan has a remaining $48 million in funding; however, it is uncertain how much of that funding will be used for M/HD applications. The reauthorized section 30C federal tax credit for alternative fueling infrastructure can fund up to 30 percent of charger installation cost ($100,000 cap per charger) but has limited geographic scope, meaning that it will ultimately cover less than 30 percent of the $700 million to $1 billion in investment needed by 2030.

Funding sources such as the VW settlement funds, Diesel Emission Reduction Act (DERA), and the Clean School Bus Program may also contribute funding to MHD infrastructure for projects paired with vehicle deployment though often those funds are limited to charging equipment only. Additional federal funds may be available through programs created or reauthorized by the recent Infrastructure Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IIJA) such as the Congestion Mitigation and Air Quality Improvement program (CMAQ), Carbon Reduction Program, or the National Highway Freight Program. Though it is impossible to know how much of Colorado's needed infrastructure investments might be covered by funding from those programs. Some remaining funding may be available from the National Electric Vehicle Infrastructure (NEVI) Formula Program funding after Colorado has fulfilled its corridor deployment obligations.

Conclusion

Our projections demonstrate that Colorado needs between $790 million and $1 billion in cumulative committed investment by 2030 to meet the energy needs of vehicle adoption consistent with state goals. An additional $34-$76 million in committed funding is required to build out a minimum network of long-haul focused corridor charging along Colorado's priority freight routes. Notably, most of the costs required in the next seven years will accrue from depot-based charging installations where we expect most early-adopting fleets to charge their vehicles. The $210 million difference between the average and conservative case illustrates how costs may increase if depot-based fleets choose to build with a large operating margin. While a substantial fraction of the needed investment for M/HD charging. should come from private sources, the M/HD charging market in Colorado still requires policy support to close the gap on project profitability, unlock funding from the private sector, and encourage the long-term development of Colorado's electric M/HD vehicle market.

4. Strategies for M/HD Charging Incentive Program Design

To achieve statewide climate goals and facilitate rapid adoption of zero-emission medium- and heavy-duty (M/HD) vehicles in Colorado, incentive programs must be well designed, effectively bridge market and funding gaps, and successfully remove hurdles to fleet electrification. In developing an M/HD vehicle infrastructure program, the Colorado Energy Office (CEO) should pay close attention to a number of critical factors, such as project, applicant, and expense eligibility, funding amounts, as well as project and applicant requirements. In building on the foundation laid by California incentive and utility programs, Colorado has an opportunity to develop an effective incentive structure that applies best practices and lessons learned, while avoiding any issues encountered by first movers. As one of the first states to move into this space, Colorado too, will be setting precedent for others to follow as they design M/HD infrastructure incentive programs.

Methods and Data

The analysis and conclusions presented in this chapter are informed by both findings from the prior two chapters on the state of the market and Colorado's charging infrastructure need, and original qualitative analysis. Primary data collected for this chapter includes both responses from a set of semi-structured interviews of funders and administrators of existing M/HD charging and vehicle incentive programs and information sourced from M/HD charging program documentation.

Using these data, we discuss alternative program designs and features and identify best practices where they are clear. In addition, we employ criteria-alternative analysis that qualitatively examines the tradeoffs between competing program design features to provide CEO with a decision support tool that can inform their program design decisions.

Landscape of M/HD Charging Infrastructure Programs

Utility and government incentive programs are vital to scaling the adoption of electric M/HD vehicles and reducing charging infrastructure barriers. At the moment, only a few electric M/HD infrastructure incentive programs exist, nearly all of them managed by utilities and funded by ratepayers. California was the first government in the United States to stand up a program specifically designed to subsidize M/HD charging infrastructure, and in developing its own program, Colorado would join the small but growing list of leading states. The majority of government funding for M/HD electrification has been allocated to vehicle vouchers through programs such as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP) and the Clean Off-Road Incentive Project in California (CORE), programs, the New York Truck Voucher Incentive Program, the New Jersey Zero Emission Incentive Program, among others across the country. However, several investor-owned utilities (IOUs) noted in the table below support M/HD or fleet charging infrastructure deployment through targeted incentive programs, which complement existing public funding or fill gaps where government support does not exist.

The California Energy Commission's EnergIIZE program is the only statewide program currently financing M/HD vehicle infrastructure. EnergIIZE is the most analogous program to that which CEO intends to establish and is the most pertinent in terms of direct lessons learned. Like CEO's prospective infrastructure program, EnergIIZE is funded through a state energy office and will complement vehicle subsidies administered through an adjacent state agency (California Air Resource Board HVIP program). As a taxpayer-funded program, EnergIIZE must meet obligations laid out in legal statute and faces public funding constraints, akin to those likely to impact any CEO program. Similar to Colorado, the California government has robust clean energy, transportation, and environmental justice goals, and established EnergIIZE as a central means of achieving them. While the EnergIIZE program is very new, and not yet fully tested, it has already produced valuable lessons for CEO on how to structure a M/HD-focused infrastructure incentive program.

While California is the only state currently funding M/HD vehicle infrastructure in a standalone program, a number of utilities across the country currently manage similar initiatives. Most importantly for CEO, Xcel Energy currently manages a fleet electric vehicle infrastructure and advisory services program across its service territory. In designing its own program, CEO would need to directly engage with Xcel (or any CO utility that designed a similar program) to avoid duplication and best complement existing incentives. Likewise, all major investor-owned utilities in California (Southern California Edison, Pacific Gas & Electric, and San Diego Gas & Electric) currently administer M/HD charging infrastructure programs, in addition to a number of other utilities across the country such as Portland General Electric (OR) and Consumers Energy (MI). Many of these utilities manage more established programs that predate EnergIIZE, which offer important lessons learned in terms of program design. Unlike state agencies, investor-owned utilities stand to earn a return from their investments in these programs. Beyond the motivation of profit seeking, state laws and regulatory bodies may compel utilities to establish specific EV charging programs, including for M/HD vehicles [37]. In Colorado, for example, Xcel's programs are guided by the company's overarching Transportation Electrification Plan, which was reviewed and approved by the state public utilities commission.

See below for a comprehensive table highlighting the most relevant M/HD infrastructure programs currently active across the country as of November 2022. Program name, funder, year established , and a short description are provided. As depicted below, nearly all existing programs are managed through investor-owned utilities and were established in the past three years.

Table 9. M/HD Infrastructure Program Landscape (As of November 2022)

Name	Description	Jurisdiction	Year
EnergIIZE	Supports both private and public installations of DCFC and L2 chargers to support Class 2-8 vehicles. Broad participant eligibility.	California (California Energy Commission)	2021
Electric Vehicle Supply Infrastructure (EVSI) Program	Turnkey fleet charging make-ready infrastructure (utility-owned); utility- or customer-owned electric vehicle supply equipment (EVSE) options. Minimum 4 charging ports or 50kW of service. Paid technical advisory services as part of parallel Fleet Electrification Advisory Program.	Xcel Energy (Colorado) service territory	2020
Charge Ready Transport Program	No-cost utility-side make-ready infrastructure, specific to M/HD fleet operators. Must acquire at least 2 electric M/HD vehicles. Rebate option for customer-side make-ready. EVSE rebates for transit/school bus & sites disadvantaged communities	Southern California Edison (Southern CA, save San Diego) service territory.	2020
EV Fleet Program	Specific to M/HD fleet operators. (Must acquire 2 electric fleet vehicles). No-cost utility-supported infrastructure from line to meter. Customer responsible for panel and charger. EVSE rebates for schools/transit agencies and disadvantaged communities.	Pacific Gas & Electric (Northern CA) service territory	2019
Power Your Drive for Fleets	Specific to M/HD fleet operators (Class 2-8). Must procure at least 2 electric fleet vehicles. No-cost, turnkey installation of utility- & customer- side make-ready up to	San Diego Gas & Electric (San Diego, CA) service territory area	2020

	charger. Customer make-ready ownership option with rebate (80 percent). EVSE rebate up to 50 percent of cost for select applicant classes in disadvantaged communities (L2: $3K and DCFC: $75K).		
Commercial EV Program	Subsidies for Class 1-8 vehicles. Commercial EVSE rebates for L2 ($4500), public DCFC ($30K), and school bus DCFC ($15K). Incentives to support panel ($1K) and transformer upgrades ($5K).	Sacramento Municipal Utility District	2020
Fleet Partners Program	No-cost fleet advisory services. Turnkey charging infrastructure design/construction & $750K custom make-ready incentive. EVSE rebates for L2 ($1K) and DCFC ($25K). Must take 70kW of new load.	Portland General Electric (greater Portland, OR) service territory	2021
Commercial EV Charging Station Incentives	Fleet vehicle EVSE rebates for L2 ($5K) or DCFC ($40K). Not specific to M/HD vehicles. Must install 2 L2 or 1 DCFC.	NV Energy (majority of Nevada) service territory	2020
Charging Forward eFleets	No-cost fleet advisory service. Fleet vehicle EVSE rebate program (Class 1-8) for L2 ($2500) and DCFC ($70K). Customer will own EVSE.	DTE service territory (Detroit & Eastern Michigan)	2021
PowerMI Fleet	M/HD fleet operators eligible. Fleet electrification assessment. No-cost, utility-owned make-ready upgrades to the meter. L2 ($5K) and DCFC EVSE rebates ($35K).	Consumers Energy territory (Most of Michigan outside of East and Detroit)	2021

Program Design Considerations

In developing an M/HD infrastructure incentive program, CEO will need to carefully weigh several program design considerations, such as eligibility, program requirements, vehicle purchase requirements, interagency engagement, existing incentive coordination, among others. Existing programs, such as EnergIIZE and utility incentive structures, provide a valuable foundation on which to design a new program in a Colorado-specific context on a more limited budget. This section evaluates the numerous design factors CEO must consider when developing its M/HD program. This analysis will paint the landscape of possibilities, extract lessons learned from existing incentives, and provide a suggested course of action.

Eligibility

Eligibility is a basic component of any incentive program, providing filters to allocate program funding in a targeted fashion. For the design of Colorado's M/HD infrastructure program, eligibility breaks down along three important dimensions: project eligibility, applicant eligibility, and expense eligibility, which define the who and what of potential funding recipients. Limiting eligibility allows the incentive administrator to channel finite funding towards applications that best suit program goals. However, if targeted too narrowly, eligibility criteria may inadvertently disqualify otherwise beneficial uses or active applicant classes.

At the most basic level, eligibility requirements can strictly exclude one or more project, applicant, or expense type from receiving program funding. However, more complex program designs subdivide funding into buckets, lanes, or carveouts which match to specific or set-aside budgets.

A funding lane or bucket creates subprograms for different project, applicant, or expense categories (or combinations thereof) within the parent program. This allows the program administrator to support a diversity of project types while reducing risk of a single project or applicant type dominating program subscription. Of course, this practice requires program administrators to determine their funding priorities (and consider likely demand) and allocate funding to each lane or bucket accordingly.

Carveouts or set asides differ from funding lanes or buckets in that they *reserve* part of a program budget for a particular project, applicant, or expense type, rather than creating a separate funding amount. This means that a carveout specifies a minimum funding amount for prioritized eligibility categories, and an effective maximum for those categories outside the set-aside funding. This practice allows the funder to ensure a minimum amount of funding goes to a prioritized applicant, project, or expense type without imposing a cap.

Carveouts are most often used to ensure a project type or applicant class receives a share of the program funding that they might not otherwise be able to secure in open competition for grant funding. Typical examples include equity-based carveouts for applicants or projects that meet specific equity qualifications. For example, M/HD infrastructure incentive programs managed across all three California investor-owned utilities require a minimum percentage of funds to be spent in designated *disadvantaged communities*.

Project Eligibility

Project eligibility defines the types of M/HD charging projects that qualify for funding and ultimately shapes how the program performs with respect to its goals.

There are two fundamental types of M/HD charging projects:

1) Private charging equipment and infrastructure that is reserved for single fleet or operator use
2) Public or semi-public charging that is shared across multiple fleets or operators

Private charging projects are the most common type of M/HD charging project to date. They typically involve installing chargers in areas where a single operator has access, such as at a truck depot or freight facility. These projects are usually associated with a specific vehicle or fleet of vehicles. Public or semi-public charging projects, on the other hand, include several subtypes such as third-party charging depots, truck parking, en-route charging, as well as corridor-focused, high-power charging locations. These types of projects are not necessarily tied to the deployment of a specific vehicle or fleet and are typically led by a charging service provider rather than a fleet operator. Project eligibility for the M/HD program may be permissive and allow all project types. It also can restrict funding to a single type, or selectively exclude other projects. Alternatively, projects of different types might form the basis for funding buckets or set asides.

The current M/HD charging market is primarily focused on deploying private charging projects. These projects match the return-to-base operations most conducive to early market adoption and are therefore likely to be the majority of viable projects in the next several years. However, development of public and semi-public, high-power charging networks suitable to quickly recharge large vehicles en-route is advancing on the U.S. West Coast and in Europe. Early market entrants in this space indicate that available incentive funding is a major factor in their market expansion decisions.

Notably, lack of access to public charging serves as a primary market barrier for truck electrification. This is particularly true for those vehicles without return-to-base operations or more difficult site ownership issues, but that otherwise have operations compatible with early market electric M/HD vehicles. Additionally, access to offsite charging may be an enabling factor for some fleets that have charging access at depots, if the offsite charging can support occasional operations that exceed vehicle ranges. The development of public or semi-public charging should therefore be perceived as a potential enabler for electric M/HD adoption.

In California, EnergIIZE provides funding opportunities for both private fleet charging (Class 2b and above), as well as public M/HD charging installations, across several different funding lanes.[17] California has committed to electrifying all M/HD vehicles by 2045 and adopted the Advanced Clean Trucks Rule. To meet these goals, the state sought to support both private and public fleet charging projects to best shore up gaps where the private sector will be slow to act.

In contrast, utility funding programs have mainly focused on private charging models for dedicated customers. For example, Xcel's EVSI incentive program pairs advisory services with turnkey infrastructure support for private fleet customers; the company has been approved to install and own just 12 public DCFC stations to date, though they are not specific to M/HD vehicles. . Utility interviewees explain that they are hesitant to invest in public charging without certainty of usage and that they require assurance that investments in public infrastructure will generate additional revenue and increase electricity sales. Exceptions to this trend include San Diego Gas & Electric and Portland General Electric, both of which are investing in public charging infrastructure for M/HD vehicles.

Applicant Eligibility

Applicant eligibility defines the applicant classes who can secure funding. Like project eligibility, the choice of which entities or organizations can participate is consequential to program outcomes and warrants specific attention. Important considerations for the M/HD charging program include:

a) Whether the applicant operates M/HD vehicles or is a third-party charging supplier
b) Size of fleet
c) Financial capacity of the organization
d) Whether applicant organization is an underrepresented/small business
e) Whether the applicant is a privately or publicly owned organization

Whether or not third parties are allowed to engage in the program will have a substantial impact on program outcomes. Disallowing third parties in effect disallows any public or semi-public charging projects, and it also limits opportunities for private charger installations funded by charging as a service providers or logistics facility owners.

Larger companies with high revenue and easy access to capital are most likely to be the first movers in private sector electrification and will therefore represent a large fraction of early M/HD charging market participants. However, those organizations are also those least likely to be in a position where incentives are critical for M/HD electrification. Limiting

[17] The EnergIIze funding lanes are as follows: 1) EV Fast Track provides funding to those who have already purchased an electric M/HD vehicle or can furnish a purchase order, 2) Jump Start Track supports fleets operating in disadvantaged communities, or those who identity as a small business/fleet owner or an underrepresented demographic, 3) Public charging funding lane, and 4) Hydrogen fuel infrastructure track.

funding for private sector eligibility through a maximum annual revenue limit can improve the efficiency of the program. In doing so, program designers can target funding at firms where additional financial support is more likely to be the deciding factor in whether they adopt electric M/HD vehicles and associated infrastructure. Southern California Edison's (SCE) Charge Ready Transport program incorporates this feature in its EVSE rebate structure, where only companies not on the Fortune® 1000 list are eligible for the EVSE rebate.

Public fleets make up a substantial fraction of Colorado's large M/HD fleets. However, as a result of public commitments, government fleets are more likely to electrify; providing them access to funding may crowd out private fleet participation to the detriment of program outcomes.

California's EnergIIZE program supports a number of specified applicant categories, with a distinct focus on equity, project readiness, school buses, and public charging deployment. Any specific carveout or decision made surrounding applicant prioritization is made to best achieve goals or binding commitments enacted by state government. For private fleet charging (Fast Track Lane), this program specifically targets commercial fleet operators and independent owner operators who already own electric M/HD EVs or who have purchase orders. In doing so, the state intends to best align vehicle procurement and infrastructure deployment timelines, as well as move those most ready for electrification through the process as fast as possible. In prioritizing those with acquired or ordered vehicles, the state will mitigate scenarios in which fleet operators are forced to sit vehicles in lots without access to onsite charging.

EnergIIZE also puts a significant emphasis on deployment in disadvantaged communities and supporting minority-owned fleet operators, dedicating an entire funding stream (EV Jump Start Lane) just to these applicants. As part of the state's 2021-2022 Clean Transportation Investment Plan, the California Energy Commission committed to investing 50 percent of all clean transportation funds to support disadvantaged communities. In line with this objective, CEC has allocated 60 percent of EnergIIZE funds to equity-focused applicants or projects benefiting disadvantaged communities, as defined by the CalEnviroScreen Tool (geography-based). And for public charging, EnergIIZE remains relatively flexible, but is intended to support public charging developers, including offsite "as-a-service providers," that can demonstrate project demand. According to interviewees, CEC is focused on ensuring these projects will see sufficient levels of usage. In investing in public charging, CEC seeks to de-risk these projects for private companies and to develop a nascent market.

Industry and stakeholder interviewees frequently mentioned the importance of specifically targeting funding to rural communities, low-income communities, and small fleet operators, especially those in territories served by rural electric cooperatives or municipal utilities. Equity in charger placement across the state, and therefore choice of applicants, was of critical importance to many interview participants. Moreover, interviewees called for expanding applicant eligibility beyond just entities with direct vehicle ownership, and to provide funding opportunities to the organization best positioned to manage and install site infrastructure (to include “as-a-service” providers). This point was of particular importance when discussing public infrastructure funding.

Expense Eligibility

Weighing what is eligible for cost coverage or reimbursement is a critical component of program design. This is a broad category of considerations that covers both the parameters for equipment eligibility such as EVSE type, power rating, certification, and warranties, in addition to the broad array of expenses that may be incurred by a M/HD charging project. These may include:

- Electrical and construction costs necessary to install chargers
- Soft costs such as site design, permitting, labor, and installation
- Other construction costs such as supporting structures, site reconfiguration costs
- Distributed energy resources
- Energy management software and equipment
- Electrical capacity upgrades
- Warranties
- Future proofing costs

Expanding the scope of covered costs can make more projects financially viable, but it will also raise the average cost per installed charger. Some associated expenses such as the installation cost of the supporting electrical infrastructure and soft costs should be expected for any charging program. However, those costs may vary widely depending on site-specific attributes and utility program offerings. Other expenses, such as construction costs to reconfigure space or accommodate chargers, or costs to augment electrical capacity will not be necessary for all projects. While some utility-side capacity expansion will be required for most M/HD charging projects, investor-owned utility customers may have some or all these costs covered, while customers of municipal or cooperative utilities will not.

Unlike other cost categories that will impact immediate charger deployment, future proofing means sizing infrastructure to accommodate expected future need rather than current need. While the installation will be oversized and more costly than what is needed to match current needs, consolidating construction enables economy of scale, spreads fixed costs across more chargers, and reduces site disruption, all of which will minimize costs and project timelines in the long run. Applying funding budgets to future proofing costs requires care to ensure that money spent by the program eventually yields additional charger deployment.

The EnergIIZE program will support expenses related to demand mitigation software, make-ready infrastructure (switchgear, panel upgrades, wiring, meters) and EVSE hardware (L2 and DCFC) for private fleet charging. In providing DCFC funding for behind the fence charging, CEC can support needs-based charging to cover a diverse range of use cases, such as fire trucks or quick turn-around delivery. To further ease the burden of electrification, equity-focused applicants are entitled to additional incentive funds (adders) to cover soft costs such as planning fees and labor/installation. For public charging, CEC intends specifically to support opportunity charging with future proofing in mind, requiring the installation of high-power 150kW DCFCs and encouraging developers to install at least one stub-out for a 350kW DCFC charger.

Utilities across the country support a diverse array of cost coverage options, each with their own ownership models and service offerings based on internal goals, program budget, or regulatory requirements. Programs usually cover both L2 and DCFC charger options. As is common, utilities may offer no-cost fleet advisory services to guide operators as they move through the process, assigning a singular point of contact to support projects with charging assessments, site designs, and vendor identification. Interviewees noted that these services are especially valuable to smaller fleets, rural communities, or those in disadvantaged areas who have fewer resources and require more support. Moreover, interview data reveals that fleets in rural Colorado should be primary targets of education and advisory programs, given that most will be unable to take advantage of Xcel's service offerings.

In certain cases, utilities like Xcel provide full turnkey M/HD charging infrastructure services, where the company covers the total cost of utility- and customer-side make-ready infrastructure and provides the option for Xcel to install/maintain the EVSE hardware for a monthly fee. Likewise, in these instances, the utility normally also provides the option for customers to purchase their own hardware and in some specific cases, such as low-income or high emission community customers in the case of Xcel, to receive a rebate. In other cases, utilities like Portland General Electric will cover make-ready infrastructure up to the charger, while also offering all program participants the option to apply for rebates for utility-qualified and networked L2 and DCFC chargers. On the other hand, utilities like PG&E cover utility-side infrastructure from the line to the meter, with customers on the hook for the customer-side cost of the panel/switchgear and EVSE. In cases where customer-side make-ready or EVSE are not covered costs, as is one option provided by SDG&E, the utility may offer rebates to offset those expenses (often for specific customer segments). And beyond make-ready support, certain utilities like NV Energy, Black Hills

Energy, and DTE may also strictly provide EVSE rebates (L2 and/or DCFC) in the absence of direct infrastructure support.

According to interview data, make-ready infrastructure (line to the panel) levies the greatest cost burden on fleet operators, and CEO should prioritize a program that offers low-cost installation or high-value incentives for infrastructure deployment. Interviewees demonstrated interest in expanding cost coverage to include expenses beyond EVSE and make-ready, to also include labor, installation, and other soft costs, in addition to any amenities associated with public charging. Interview participants frequently mentioned the importance of distributed energy resources in mitigating electricity costs and improving resilience, and would seek cost coverage (incentive adders) for deployment of onsite solar and storage.

Funding

Incentive design is an exercise in determining how to allocate funding in a way that best suits program goals. Eligibility considerations determine allocation on the macro scale. Equally important are micro-scale decisions about how funding is allocated to projects and applicants. Funding amount considerations include relative and absolute maximum funding amounts per funded charger, per project or site, and per applicant.

Program funding is finite, which means there is a tradeoff between program generosity and the number of projects a program can fund. Determining an optimal amount of funding to be allocated to projects is challenging. In theory, the goal is to only include enough funding to make a project economically viable, as any additional support does not lead to incremental project adoption and any fewer funds will not lead to any project investment at all. Complicating matters for private charging projects are that decisions to proceed with a charging project are dependent on the viability of not just the chargers, but also the entire cost of switching to electric vehicles. This means the funding for chargers will interact with any funding for vehicles that applicants may receive, including for example, the federal credit for Qualified Commercial Clean Vehicles (otherwise known as 45W credits), and funding from Colorado's forthcoming Clean Fleet Enterprise M/HD vehicle incentive program.

Project costs also vary widely depending on the use case. Lower-cost AC charging is suitable for many M/HD applications despite its lower power rating, so long as the vehicle is stationary long enough to recover its daily energy needs. The higher-power chargers necessary for higher-energy-need applications and public charging cost substantially more. Table 2 shows recent average cost ranges for installation of depot and public charging sites. Costs are estimated on a per-port basis and do not include utility-side costs.

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Table 10. Project Cost Ranges from INSITE Model

Project Type	Charger (EVSE) Cost	Installation Cost
48 – 80 Amp AC Depot Charging	$2,000 - $5,000	$4,000 - $20,000
50 – 150kW DC Depot Charging	$40,000 - $110,000	$32,000 - $54,000
150 – 350kW DC Public Charging	$110,000 - $210,000	$33,000 - $45,000
350kW – 2MW DC Truck Corridor Charging	$210,000 - $600,000	$85,000 - $130,000

The high charger costs for M/HD charging will easily strain project budgets if cost coverage for M/HD mirrors the 80 percent cost coverage maximums common among light-duty-focused incentive programs such as CEO's Charge Ahead Colorado program. Moreover, depot charging projects may include many more charging stations of much higher power than the typical light-duty charging project, further pushing up charging station costs.

California's EnergIIZE program covers a baseline 50 percent of eligible costs and caps project funding at $500,000. These project cost maximums are set against an annual $50 million program budget (2021) and were designed with the intent that the state will substantially increase funding for M/HD charging infrastructure over the next several years.

On the utility side, most funding programs cover substantially more project costs, often paying for make-ready in its entirety. For example, SoCal Edison's M/HD incentive program will cover all costs for utility-installed infrastructure and up to 80 percent of customer-installed electrical equipment. Interviewees relayed that these allowances almost always cover all non-EVSE costs. Utility programs, like those managed by NV Energy or DTE, also offer a range of funding amounts for EVSE rebates, spanning from $1,000 - $5,000 per port for L2 chargers, covering a maximum of 75 percent of hardware costs. For DCFC, programs offer between $25,000 and $75,000 per charger, generally covering up to 50 percent of hardware costs.

Investor-owned utilities generally earn a rate of return on every dollar they spend on charging programs, so they are not incentivized towards thrift, nor are their funding amounts meant to efficiently distribute limited funds in the same way a government program should. EnergIIZE supplies a better model for funding amounts and limits. However, the sheer size of California's program allows it more flexibility to fund high-dollar projects. With a much smaller annual budget, Colorado's program funding would be swamped if just a few projects hit EnergIIZE's $500,000 funding limit.

Interaction with Other Funding Sources

Applicants are likely to have access to other funding sources, such as section 30C Alternate Fuel Vehicle Refueling Property Credit and utility program funding. Because more than one funding source may be at play, it is important for CEO to consider a minimum applicant cost share for projects. It is equally important to carefully decide how the program might stack with those other funding sources.

Minimum cost share ensures that project applicants are contributing at least a bare minimum amount of their own capital to the project budget. By forcing the applicant to cover a minimum percentage of a project, minimum cost shares can enforce cost discipline and ensure that project applicants have a vested interest in the success of the deployment and usage of funded chargers.

Cost share minimums are reasonably common across other incentive funding program designs (such as NEVI). Notably, EnergIIZE does not enforce a cost share minimum and only stipulates that applicants cannot be reimbursed more funding than was spent on authorized expenditures. However, EnergIIZE does include a stipulation that it will not pay any make-ready costs for applicants in IOU territories that have make-ready programs unless applicants have participated in the IOU program, ensuring that EnergIIZE program funds are only spent on costs that the IOU programs do not cover.

Equity Adders

In addition to considerations for appropriate funding amounts, funding parameters also provide another lever with which to achieve specific desired outcomes. Favored project types or applicant categories can receive a funding adder or might face relaxed cost share requirements. These levers are most valuable to support equity goals by providing additional funding (or ability to stack funding) for applicants or projects that may face steeper capital constraints than the typical applicant.

EnergIIZE equity-focused private fleet applicants receive a cost adder, increasing funding to up to $750,000, and can cover 75 percent of total hardware, software, and other soft costs. In offering additional cost coverage and a higher incentive cap for equity lane applicants, the government seeks to further de-risk these projects for those least likely to electrify without external support and to make good on their political commitments to support disadvantaged communities.

Project Requirements

While funding and eligibility considerations are geared towards the targeted allocation of funding, project requirements are aimed at ensuring that funded projects will be successful and deliver benefits as expected once the money has been disbursed.

Many best practices from light-duty infrastructure programs can be adopted directly for M/HD programs, including equipment warranty and certification requirements, interoperability requirements, and other basic assurances that program funds will be spent on lasting investments. However, other requirements from light-duty programs may not translate as directly to M/HD projects.

For example, reliability requirements are becoming a common feature of light-duty charging infrastructure programs. However, trucking industry sources interviewed for this project were critical of reliability requirements for depot-based charging because the infrastructure users would also be responsible for ensuring reliability, and as a result, they are motivated to keep their chargers operating reliably. In this case, reporting on reliability metrics may incur costs on funding recipients without any meaningful improvements to charger reliability. Other requirements such as accessibility and signage requirements are also not germane to private charging installations. However, public M/HD charging is more like public light-duty projects and may still benefit from these requirements, though restricted access may be desirable for some public MHD charging to limit access by light duty vehicles.

In addition, data sharing /reporting requirements are also common in light-duty charging programs. Trucking and charging service providers interviewed for this project expressed concerns about sharing data due to the sensitive nature of truck movement and operations. They cautioned that data requirements could be a potential obstacle for some projects. However, administrators of existing M/HD funding programs were confident that the prospect of financial support outweighs concerns about competitive information when potential applicants consider incentive programs. Regardless, program administrators should be careful to only collect data that is necessary and useful and at an appropriate level of aggregation to limit reporting burdens and reduce privacy concerns.

Another common light-duty program best practice that may require some adapting to M/HD applications is operating length requirements. Some industry members interviewed for this project indicated concern that long operation length requirements as implemented by other programs (upwards of 10-year duration) do not work well with the typical 5–7-year commercial lease length.

Two program requirements that are not necessarily common in light-duty program applications but are good practice for M/HD programs are landowner authorization requirements and documented utility communication. Commercial fleet applicants are likely to lease their facilities, meaning that clearing potential landlord concerns early is an easy filter for project success. In addition, the high-power requirements of M/HD charging programs make utilities key players in charger deployment. Including requirements for potential applicants to speak to their utility first will prevent surprises later in the process. This will also ensure that funding is not tied up while dedicated to projects that are ultimately non-viable. California's EnergIIZE program includes these two requirements for its projects.

Vehicle Purchase Requirements

While not a feature of light-duty charging programs, vehicle purchase requirements are common among M/HD infrastructure funding programs. Tying funding directly to the purchase of a specific M/HD vehicle is a blunt mechanism to ensure usage of program-funded chargers. Additionally, requiring a purchase order up front gives reasonable assurance that an applicant will proceed to project completion. This mechanism is only pertinent to non-shared chargers, and if applied strictly, will exclude public and semi-public projects. Additionally, strict requirements may also exclude charging-as-a-service providers or other leasing arrangements. Provisions should be made to allow payment to third-party charging providers if they demonstrate that chargers will be used for a specific customer vehicle or vehicles. Several charging providers interviewed for this project indicated that utility programs were closed off to them due to vehicle purchase requirements.

Multiple program administrators and industry sources interviewed for this study indicated that problems arise with purchase requirements when timelines for vehicle purchases and infrastructure deployment do not align. This is most problematic when applicants take delivery of vehicles before infrastructure because that leaves vehicles stranded without an option to charge. Infrastructure builds and utility interconnection for private depots can take as long as two years to complete, meaning that if a signed purchase order is required at the beginning of the project, there is substantial risk that vehicle delivery will precede powered chargers onsite.

In the case of public chargers, other provisions are required to reasonably ensure use of funded chargers. It's practically difficult to project demand for public chargers that are not attached to a specific vehicle, particularly in the early market. While proximity to truck traffic is a basic requirement for charging demand, it does not necessarily lead to utilization. California's EnergIIZE program requires projects applying for public charging funding to demonstrate demand for charging power they propose to install, as well as documentation that the charging location serves corridor charging. In addition to EnergIIZE, Portland General Electric has committed funding for public charging programs, and is pursuing a corridor-based approach to electrify freight routes in its service territory. Likewise, San Diego Gas & Electric has committed funding to support charging projects at publicly accessible truck stops through its Power Your Drive for Fleets Program.

Selecting Projects

The project selection process offers another opportunity to filter and fine-tune funding awards by assigning higher weights to projects with desirable attributes. Of course, relative to a first-come-first-served approach, a competitive selection process can also impose more administrative burden on both the administrator and grant applicant depending on how involved the selection process is. However, A competitive selection process can also weigh the cost-competitiveness of individual projects, which can encourage greater cost discipline on the part of applicants.

The competitive lanes of the EnergIIZE program subject applicants to a scoring process that weights geographic equity indicators (disadvantaged community, low-income community, and Tribal community) up to 50 percent of the project's overall score. For projects requesting funding of more than $150,000, applicants must also submit project narratives describing community support and benefits for the community. These narratives are assessed qualitatively and contribute to nearly one third of the score. The remaining weight is assigned to having a complete program application.

A scored application process can replicate or enhance the effect of carve-outs or targeted funding for equity-focused investments by weighting projects or applicants higher (like how EnergIIZE is structured). The application process also provides opportunities for project level evaluation that would be too complicated or unwieldy to implement through the overall program design. A good example of this is project benefit estimation. While it would be challenging to incorporate a benefit requirement into the overall program design, the selection process can consider expected benefits (such as projected greenhouse gas emissions reductions) as a weighting factor in funding decisions. EnergIIZE adopts a loose benefit selection criterion but stops short of asking applicants to quantify emissions reductions.

Interagency Alignment and Other Best Practices

CEO's M/HD charging program will coincide with a vehicle funding program administered by the Colorado Department of Public Health and the Environment (CDPHE). Many participants will both purchase a vehicle and install charging infrastructure and will likely apply to both programs across the two agencies. This creates both an opportunity for efficiency and a coordination challenge. CEO's relationship to CDPHE mirrors closely the relationship in California between CEC's EnergIIZE program and CARB's HVIP. Staff from both agencies and the program implementer, CALSTART, noted that coordination was an administrative challenge. However, they also noted several best practices that emerged from their collaboration, including:

a) Frequent coordination meetings
b) Sharing data and information
c) Establishing or adopting common definitions for applicant categories, equity metrics, and other relevant categories

California's experience is born from integrating the new EnergIIZE program into the long standing HVIP program. Because Colorado's programs are starting at a similar time, there may be more opportunities for upfront collaboration, including the potential for joint applications which can reduce application costs and streamline the process for prospective recipients.

Program Recommendations

As demonstrated in sections above, there is both considerable nuance and variation in possible approaches to deploying a charging incentive program for electric M/HD vehicles in Colorado. While the main goal of this analysis is to provide CEO with an effective and nuanced decision-making guide, in this section we do identify what we expect to be the most consequential decisions points and provide high-level recommendations to CEO.

Evaluating Program Design Tradeoffs

There are substantial tradeoffs at play with many design choices. Where there are substantial tradeoffs, we evaluate them across four criteria that assess: efficacy, efficiency, equity, and administrative feasibility. This evaluation provides high-level qualitative assessments of each program design decision on criteria, measured on a "very high" to "very low" scale.

Box 1: Evaluative Criteria

Efficacy – Impact on program goals/performance metrics such as: number of chargers deployed, charging capacity deployed, number of electric vehicles supported, GHG/Air quality emissions reductions. Low efficacy indicates program design is unlikely to spur deployment of charging infrastructure, whereas high efficacy indicates the opposite.

Efficiency – Related to cost effectiveness, this criterion is concerned with expected economic efficiency of program designs. Higher efficiency indicates a program design that reduces free riding and thus wastes fewer resources on projects that would have occurred without funding, whereas low efficiency indicates the opposite.

Equity – Effect on distributional impact of the program across several dimensions: environmental burdens, urban vs rural funding distribution, fleet (and company) size distributions. High equity scores indicate a design feature is equity improving (either through addressing historical inequities or ensuring more equitable access to M/HD infrastructure funding opportunities for all Colorado M/HD operators). Low equity scores indicate higher likelihood of unequal access to funding and investment.

Administrative Impact – This criterion evaluates the administrative burdens and costs (both on CEO and applicants) that are caused by program design specifics. High administrative feasibility indicates lower administrative burdens, lower application costs, lower use of CEO staff capacity, and fewer barriers to participation.

Applicant Eligibility

We recommend a permissive stance on applicant eligibility to encourage innovation and allow for a broad range of potential applicants. Due to the considerable uncertainty around how the market for M/HD charging will develop in the near term, we cannot confidently evaluate tradeoffs between approaches. There appears to be substantial room for innovation across business models and approaches, which lends itself to broad applicability in the near term. However, CEO should monitor program outcomes and awardees and adjust as necessary if it becomes apparent that certain business models do not perform well or if a small number of applicant types dominate program uptake at the expense of supporting broad market adoption or advancing equity goals.

We also recommend that CEO limit program funding opportunities to commercial or fleet-oriented applicants. While technically medium duty, many Class 2b and 3 vehicles are personal vehicles and so have use cases much more like personal light-duty vehicles than their fleet-owned and commercial counterparts. While electrification of those vehicles is desirable, such efforts are best continued through existing light-duty focused programs.

Public or Semi-public M/HD Charging Eligibility

It is apparent from the trajectory of the early market that CEO's M/HD charging program should include funding for private charger deployment. Dedicated charging is the most mature model for deploying electric M/HD vehicles. The value of providing funding for public charging, particularly the expensive high-power charging necessary to rapidly charge heavy-duty vehicles, is much less certain.

Because private or otherwise dedicated charging projects are attached to the deployment of a vehicle, there is a more direct line between the deployment of a private charger project and program objectives for electric M/HD vehicle deployment. In addition, as private vehicle charging deployments are typically less expensive on a per-charger basis, limited funds can cover more charging deployments. With public charging projects, their utilization and effect on M/HD vehicle deployment is neither as direct nor as certain, making them much riskier investments from a program efficacy standpoint. Moreover, early-market cost efficacy is also likely much lower for public shared charging. However, public charging will eventually be necessary to achieve the deep M/HD electrification envisioned by Colorado's policy goals, and early policy support for the sector may enable faster market development of that charging segment.

While limiting charging incentive funding to private, dedicated chargers is likely to mean the program will fund a greater number of charger deployments and electric vehicle deployments, it does not necessarily guarantee that funds will be spent more efficiently. Funding directed at private charging projects will certainly induce additional charger deployment, but because those types of projects are more likely to proceed regardless of funding, in doing so, there is a greater chance of funding projects that would occur without incentives (or with less funding). This would signify money is being spent without benefit. Because public charging is riskier, it is more dependent on public funding for viability, meaning that on average, funds spent on public charging will more likely be the deciding factor in determining project feasibility.

From an equity standpoint, public charging infrastructure has the advantage of enabling the electrification of fleets or independently owned commercial M/HD vehicles that do not have the resources or space to charge their vehicles where they are parked. Public (or semi-public offsite) charging may enable greater electrification for underrepresented small businesses and independently owned commercial vehicles in low-income communities. Conversely, limiting incentive funding to private, dedicated charging is likely to concentrate the benefits of the funding program in better-resourced fleets, particularly in early years and where equity specific designs are not in place.

Administratively, it is much simpler to manage a program that only supports private, dedicated charging, as it allows staff to focus on only a single charging project mode, avoids complicated evaluation of project viability, and reduces application complexity.

Table 11. Criteria Alternative Matrix for Public Charging Eligibility

	Efficacy	Efficiency	Equity	Admin Feasibility
Private Charging Projects Only	Very High	Moderate	Low	Very High
Public Charging Eligible	High	Very High	Moderate	Moderate

We suggest that CEO establish a limited funding pool for public and semi-public charging in Colorado to attract early investment. While the high-level scoring for a private charging project-only program has advantages, the average difference between programs is small. In the near term, ensuring that the majority of the funding granted through the program is targeted to private charging projects is advisable, given their high efficacy on near-term electric M/HD adoption. However, allocating a smaller pot of funding to public projects could return important benefits in market development outcomes and equity that might otherwise be missed or delayed if the entire program budget is initially dedicated to private projects. Moreover, the very early-market focus on depot charging will likely give way to a mid-market situation where the depot charging market has matured to the point where subsidies are less critical and where lack of public charging becomes the most significant barrier to continued electrification. At this point, the script will flip, and public charging incentives will have the largest impact on furthering electric M/HD vehicle adoption goals. In our charging needs assessment, we identify a need for $233 million in public charging investments by 2030, a figure not likely to be achieved without substantial seeding from public funds.

We suggest that CEO limit eligibility for incentives for public or semi-public charging projects to 350+ kW chargers. High power levels are required to quickly recharge M/HD vehicles. Where possible, CEO should encourage installation of chargers at a 1+ MW level.

Program Funding Amounts

Because Colorado's infrastructure incentive program is on the cutting edge of policymaking in this space, there is very direct little economic evidence on which to evaluate the effectiveness of any specific funding amount. Though public charging funding programs for light- duty vehicles have been in place for a decade, the differences between the use cases of personal light-duty vehicles and the commercial use of M/HD vehicles makes light-duty programs imperfect comparisons for determining funding for this program. Additionally, because funding amounts are open-ended rather than discrete, they do not fit well into a criteria-alternative analysis framework. Therefore, we avoid making specific recommendations of specific dollar amounts for charger installations and do not directly compare tradeoffs. However, we do suggest the following high-level guidelines for structuring initial incentive amounts.

We suggest that CEO follow California's lead in limiting incentives to no more than 50 percent of eligible project costs for private, behind-the-fence projects. While private projects will generate public climate, air quality, and market acceleration benefits, and so deserve subsidy, they will also provide assured benefits to the project applicant in the form of operational cost savings. This leads us to expect that private projects will require less subsidy to make feasible.

We recommend that CEO follow the precedent of past light-duty public charging programs and offer up to 80 percent of eligible cost for public or semi-public charging. Public or semi-public projects are much riskier to the project developer because there is no guaranteed utilization, especially in the near term. Therefore, those projects are likely to require more subsidy to encourage investment. Additionally, because it is shared, public or semi-public charging may support the adoption of multiple vehicles in the medium to long term, which increases a single charger's public benefit relative to a private installation.

We suggest that CEO limit per-port incentives to a maximum percentage of average port costs that coincides with cost coverage maximums. All else equal, this will generally limit public investment to projects that are at or below average cost, and thus conserve limited program budgets.

We suggest that CEO offer higher funding maximums for higher charger power levels. This is a common strategy for charging incentive programs and will allow for fleets with operations that require higher-cost charging to receive an appropriate subsidy. The program should encourage development of heavier usage fleets, as those are the fleets that are likely to deliver the most public benefits through electrification. Applicants should be required to demonstrate need for (and compatibility with) the power level of chargers for which they are applying for funding by submitting a brief electrification plan. However, we do suggest that CEO limit the number of funding maximum categories to avoid overspecification.

We suggest that CEO impose some level of self-match requirements on program participants. Given that applicants may have access to other forms of funding such as those from utility programs or section 30C tax credits, this approach will conserve program funds to be applied to a wider array of projects. This recommendation is particularly important if CEO elects to allow for cost coverage in excess of 50 percent from its program.

Relatedly, we recommend Colorado follow California's lead and disallow applicants that are customers of utilities that provide programs that cover costs of utility upgrades to use CEO funds for those expenses. Where possible, applicants should leverage funding from utilities. This will preserve program funding, particularly for those applicants who will not have access to utility funding.

We recommend generally limited total project budgets while allowing for a small number of larger project awards. Limiting overall project budgets to smaller total amounts will ensure that more projects can be funded which should also lead to a more diverse set of projects. However, because there are important lessons to be learned from the deployment of larger charger installations which require more power and more involved site work, CEO should consider offering a limited number of *large project awards* during each funding round.

Most importantly, we recommend that CEO approach funding amounts with the intention to iterate across program funding rounds. Information gleaned from program applications, project cost data, and overall program subscription rates should indicate whether program funding is either too generous or too limited. Moreover, as the market develops and the policy area attracts further research attention, CEO will gain access to more and better-quality evidence to base funding amounts on over time.

Equity-Focused Program Design

While emissions reductions, electric vehicle deployment, and M/HD charging market development are critical outcomes for the M/HD charging program, ensuring equitable distribution of both program funds and program benefits is a key goal for CEO. Due to historical inequities in both resource allocation and the incidence of environmental harms from M/HD vehicle operations, equity improving mechanisms require the proactive targeting of program funds to projects in underserved areas or for underrepresented funding recipients. However, equity measures can often come at a tradeoff to absolute efficacy, efficiency, and administrative feasibility compared to a program without equity considerations. In this section, we evaluate the high-level tradeoffs of equity-focused design options for: equity carveouts or funding buckets, equity funding adders and match reductions, and equity-focused application weights.

Relative to a program without equity-focused design, equity carveouts may limit program uptake, and therefore benefits. This will be true if too few eligible applicants apply for program funding set aside for equity-focused projects and non-earmarked funding is oversubscribed. The larger the set aside, the greater that risk. Equity funding adders increase the per-project average cost, limiting the number of chargers that can be funded by the overall program budget. Larger adder amounts contribute to higher per-project costs. Relaxed applicant self-match funding requirements do not increase costs over the maximum program cost share but can increase the overall amount of funding that a project will receive. However, they do moderately reduce the incentive for the individual applicant to carefully assess the value of their individual project while project costs are less than the program cap, leading to less effective projects overall. Equity-focused application weights do not set aside or take additional funding, so their impacts on efficacy will be limited to offsetting any efficacy-focused application criteria.

In general, equity-focused projects are more likely to also be projects where program funding is critical to project viability, meaning that equity-focused designs should also reduce free-ridership and improve program efficiency. However, offering additional funding to those projects does offset some of that effect.

However, impacts on equity are not equal. Both carveouts and application weighting serve to make eligible projects more competitive with other projects, though the firm requirement of a carveout is likely to have a stronger impact than an application weight. Funding adders have the strongest positive impact on equity because not only do they make eligible projects more competitive, they also increase the number of equity-focused projects that can be viable. Reduced self-match requirements has a similar effect, but its efficacy is blunted by the requirement that eligible projects find other sources of project funding.

All equity-focused designs increase administrative burdens because they require the program administrator to define and verify equity-based eligibility requirements.

Table 12. Criteria-Alternative Matrix for Equity Focused Designs

	Efficacy	Efficiency	Equity	Admin Feasibility
Carveout	Moderate	High	High	Moderate
Funding Adder	Low	Moderate	Very High	Moderate
Funding Match Reduction	High	High	Very High	Moderate
Application Weight	Very High	Moderate	Moderate	Moderate
No Equity Designs	Very High	Moderate	Low	High

Table 12 shows the strong tradeoff between equity measures and program efficacy. All else equal, a program without equity-based design is likely to deliver the largest absolute benefit in terms of overall emissions reductions, as well as vehicles and chargers deployed—though it will also likely have a higher free-ridership rate. However, that will occur at a substantial loss to equity, as projects from better-resourced applicants crowd out those who would meet equity criteria. The size of this tradeoff depends on the magnitude of the carveout, adder, match reduction, or application weight. Weaker equity components (such as a smaller funding adder) will have less downward impact on efficacy but also a lower positive impact on equity.

We suggest that CEO limit any equity adder to no more 10 percent additional funding limit or cost share. Given that CEO's likely allocated funding is relatively limited compared to investment needs to support Colorado's zero emissions truck targets, substantially increasing funding for equity-qualified projects is not advisable. However, a small adder may have appreciable equity improving impacts without straining project budgets if it proves sufficient to render some projects economic that would not otherwise have been.

We recommend that CEO relax self-match requirements for eligible projects. Decreasing self-match funding requirements (assuming strict self-match requirements are in place) for those projects so that they can gain additional funding by stacking program funding from different sources (such as the section 30C tax credit and utility programs) could substantially improve the economics of projects without substantially detracting from project funding.

We recommend that CEO include an equity-eligible project weight in their application scoring process. While this measure will not guarantee equity improvement, it is a low-risk strategy to improve the equitableness of CEOs funding programs.

5. Conclusion

With improving technology, expanding commercial offerings, and new policy goals, electric M/HD vehicle deployment is quickly transitioning from ambition and aspiration to a present priority. Among the key practical considerations of a rapid transition is the substantial amount of electric charging infrastructure necessary to support new electric M/HD vehicles. The market for M/HD charging is in its infancy but is already growing and showing signs of innovation. However, the infrastructure investment required to meet Colorado's adoption goals is substantial and other, non-monetary barriers threaten to impede deployment. With dedicated incentive funding, CEO is positioned to enable acceleration of M/HD charging infrastructure deployment with the development of a well-designed and thoughtfully administered incentive program.

M/HD Charging Market

While the technology used to charge M/HD vehicles is the same or very similar to that which serves light-duty vehicles, the needs of M/HD vehicle operators are often very different than those of light-duty vehicles. The supply side of the M/HD charging market is reacting to those differences with a number of emerging business models and products.

Much of the focus of these new models is on creating M/HD-focused turnkey solutions that relieve M/HD vehicle operators of managing the complex transition to electric fueling, either at the customers location or offsite. Additional experiments include alternative financing arrangements that provide customers with the ability to trade the capital-intensive process of charger deployment for an *as-a-service* or subscription model. These arrangements can provide charging equipment, shared or dedicated charging access, or even an electric vehicle with charging for a single ongoing fee. These emerging business models show substantial promise, especially to overcome electrification challenges for smaller fleets or M/HD operators with fewer resources. However, there is little in the way of evidence on the long-term effectiveness of these models, meaning that future research is warranted.

Regardless of charging business models, navigating split ownership issues between property owners and commercial fleet tenants will remain difficult. While outside the scope of CEO's planned program, legislation that expands Colorado's right to charge rules to include commercial tenants would alleviate some of the concerns fleets that do not own their depot properties may face.

Most initial investment will occur in local or regional vehicle applications where it is easiest to transition vehicles to electric fuel due to shorter operating distances and predictable charging opportunities. Longer-distance freight trucking where vehicles drive more than

500 miles a day and do not return to the same location each night will be much more difficult to electrify. Vehicle limitations present a substantial barrier to electrification of these trucking modes. However, as those barriers ease, Colorado will need a network of freight- focused corridor charging sites to support interregional trucking routes. Planning and early deployment of such stations is already underway on the West Coast.

Utilities and M/HD charging

Utilities are a key player in the M/HD charging market and can function as a primary enabler of electrification. However, M/HD charging deployment will require substantial upgrades to distribution grids, which will strain utility capacity that is already impacted by pandemic-related supply chain difficulties. Long timelines to power M/HD charging projects will be the norm for the foreseeable future, especially for high-power requirements. While much of this is outside of the power of CEO to change, it may still find a useful role in minimizing the impact of this barrier through careful planning, coordination, and utility advisement.

An additional concern with utilities is the high cost of utility upgrades that can accompany the already expensive charging equipment, installation, and vehicle acquisition. Colorado's investor-owned utilities can defray much of that upfront cost through their own investment and cost recovery through rates, but that avenue is largely closed for customers of municipal and cooperative utilities that generally do not provide such investments in utility upgrades. While CEO's incentive program may serve to offset some of that increased cost, it will remain a challenge for deployment of high-power charging in many of Colorado's utility service areas. This problem is not confined to Colorado and requires substantial ongoing research attention.

While outside the scope of its planned program, CEO should engage with, education and encourage utilities adopt processes and capacity that are complementary to infrastructure deployment. These include:

- Developing hosting capacity maps that easily and explicitly show the distribution capacity on three-phase feeder circuits[18] that can help charging infrastructure developers easily rule out project locations that are likely to run into grid constraints.
- Developing internal EV knowledge and capacity among utility staff to help support customer electrification projects. (This is particularly important for smaller

[18] See Dominion Energy EV Capacity Map Tool for example of accessible EV-focused capacity map: https://www.dominionenergy.com/projects-and-facilities/electric-projects/ev-capacity-map

municipal or cooperative utilities that will see substantial EV unfractured development in their service territories.

- Including forecasts of EV load growth in integrated planning (and other similar infrastructure and generation planning processes)

Infrastructure Need

By 2030, Colorado will need a combined $790 million to $1 billion dollars in committed investments to support electric vehicle adoption commensurate with its goals. In addition, building a minimum network of corridor-focused charging stations to support long-haul truck travel along Colorado's major freight routes will require as much as $76 million in committed funding by 2030.

In the *average scenario* where fleet managers adopt a leaner and more optimized infrastructure strategy based on their average energy needs, depot (private) charging accounts for about 54 percent of needed charging infrastructure. In the *conservative scenario,* where fleet operators size infrastructure to have a 30 percent capacity reserve, costs increase by about $210 million, increasing depot charging cost share to 75 percent of costs. This cost difference illustrates the substantial impact that oversizing infrastructure might have on needed investment.

Costs also include $59 million in home charging, primarily for personal use by Class 2b and 3 vehicles that are registered to individuals. This also includes $233 million in en-route (non-corridor) charging necessary to support incidental charging needs of vehicles that occasionally exceed the capacity of their depot-based or private charging capacity, as well as a limited number of M/HD vehicles that do not have access to home-base charging.

The median Colorado county will require between $33 and $46 million in investment by 2030, though investment need is highly concentrated in in the densely populated areas around the Denver Metro Area, Fort Collins, and Colorado Springs. About two thirds of needed investment occurs in Xcel Energy and Black Hills territory, Colorado's two investor-owned utilities, leaving about one third of investment required in municipal or cooperative utility territories that have more limited utility upgrade funding or capacity.

There is currently no funding dedicated to exclusive MHD vehicle charging infrastructure in Colorado. However, some of the $700 million to $1 billion will be covered through tax incentives, federal funds, and utility investments. CEO's incentive funding will help close the gap between available funding and expected need, but a substantial portion of investment must be made by private enterprise.

Program Design Strategy

There are limited examples of M/HD charging infrastructure funding programs, with the most direct predecessor being the California Energy Commission's EnergIIZE program, which launched in 2021. Other examples are confined to utility programs which provide programmatic lessons for CEO, but are imperfect models given the difference in structure, incentives, and governance of utility programs. Many examples of light-duty focused programs also exist, but the applicability learning from those programs is also limited due to the differences between private and commercial vehicle operator needs.

The variable nature of M/HD vehicles, their uses, and their charging needs makes incentive design for them more nuanced than past charging programs directed at light-duty charger deployment. Key design decisions include: a) whether to make funding available to depot based/private charging, public (or semi-public) charging, or both, and the extent to which funding should be allocated to either, b) how to best ensure equitable distribution of funds to historically underinvested areas and businesses, and c) how to structure funding and define funding limits and cost share.

The large early investment need for depot (private) charging necessitates substantial investment in that sector. However, the long-term development of the M/HD electric vehicle market will rely on a robust network of public or semi-public charging locations while depot (private) charging will require less incentive funding over time. Therefore, we recommend that CEO begin by allocating a small portion of program funding to public or semi-public charging in initial incentive rounds, with the expectation that they will need to adjust that share over time.

Creating an equitable program is an important objective for CEO. However, with limited program budgets, large equity adders could quickly strain resources. Therefore, we recommend either a small equity adder or relaxed self-match funding requirements for equity-qualified applicants. In addition, we recommend that equity-qualified applicants receive priority in the project selection process to ensure as many awards to viable projects by those applicants as possible.

Because Colorado is on the leading edge of M/HD infrastructure incentive program development, there is little in the way of evidence to strongly support any specific funding level as the most economically effective or efficient amount to maximize program cost-benefit ratios or cost effectiveness. However, CEO should consider awarding smaller amounts (on a per charger basis) to private charging projects as those will likely require less support to render economically viable, and higher funding amounts to public or semi-public charging projects because they lack the certainty of return on investment that private charging projects enjoy.

Most importantly, CEO should be prepared to continually evaluate program data, new research, and market trends to adjust funding amounts and cost share limits between rounds as more information becomes available. Furthermore, developing an understanding of the impact of incentives on uptake, the prevalence of free riding among programs, and the effectiveness of M/HD charging infrastructure incentives as compared to other policy interventions is a rich research area that deserves ongoing study, not only in Colorado but globally, as other jurisdictions inevitably seek to encourage the adoption of electric M/HD vehicles.

Appendix A: Modeling Infrastructure Need

As described in Chapter 3. Charging Needs Analysis," Atlas used our Investment Needs of State Infrastructure for Transportation Electrification (INSITE) tool to perform analyses of charging infrastructure need and associated investment need consistent with Colorado's M/HD zero-emission vehicle goals. This appendix provides additional modeling details for the use of that tool along with methods explanations for the corridor electrification analysis and ad hoc downscaling techniques.

Electric Vehicle Adoption

Atlas modeled an EV adoption curve provided by the Colorado Energy Office that is consistent with the state's Clean Truck Strategy. This adoption curve was provided by gross vehicle weight rating (GVWR) class: Class 2b – 3, Class 4 – 5, Class 6 – 7, and Class 8. (Table 13).

Table 13. Cumulative Electric Vehicle Stock Consistent with Colorado's Clean Truck Strategy

GVWR	2023	2024	2025	2026	2027	2028	2029	2030
Class 2b/3	390	868	1,738	3,365	6,337	11,410	19,182	29,661
Class 4/5	15	38	82	166	320	583	983	1,520
Class 6/7	23	56	119	244	482	899	1,555	2,461
Class 8	4	13	37	95	222	469	869	1,408
Total	431	974	1,976	3,870	7,360	13,361	22,590	35,050

Source: Colorado Energy Office

Energy Recovery

The INSITE tool calculates, for each vehicle use case and GVWR class (see Table 3), the daily energy recovery needed per vehicle. This calculation is the product of five factors:

1) **Vehicle efficiency:** We use forward-looking vehicle efficiencies from Argonne National Laboratory's Autonomie model [38]. See Figure 12 for a description of this process.
2) **Charging Window:** We use the California Air Resources Board's Advanced Clean Trucks rule documentation assumption of a 9-hour charging window. Refuse trucks

are assigned 13-hour charge windows due to documented longer average dwell time.

3) **Daily vehicle miles traveled (VMT):** We run two VMT cases:
    - An 'Average' Case. For this case, for most vehicle use cases and classes, we use national average daily miles traveled from the WCCTCI report [39]. See Figure 13. However, we use 141 miles per day for Class 7 and 8 Regional Haul trucks. This figure is based on the Colorado case in the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) Model and assumes 250 workdays per year (on advice from NACFE) [40].
    - A *Conservative* Case. This case is equal to 1.3 times the VMT used in the *Average* Case.
4) **Assumed slowdown in charge rate above 80 percent state of charge**: Based on advice we received from industry interviews, we assume that depot charging slows down beyond 80 percent state of charge such that it takes as long for vehicles to charge from zero to 80 percent as it does for them to charge from 80 to 100 percent state of charge. Given the economics of commercial driving, for en-route charging we assume that drivers do not stay and wait for this final 20 percent of charging to complete. Instead, they choose to oversize their battery relative to their daily energy need or stop multiple times to avoid the slow down when charging en-route.
5) **Assumed electricity losses in charging equipment**: These are assumed to increase energy recovery by 15 percent relative to the amount demanded by the vehicles themselves.

Figure 12. Process to estimate vehicle efficiency by INSITE vehicle type

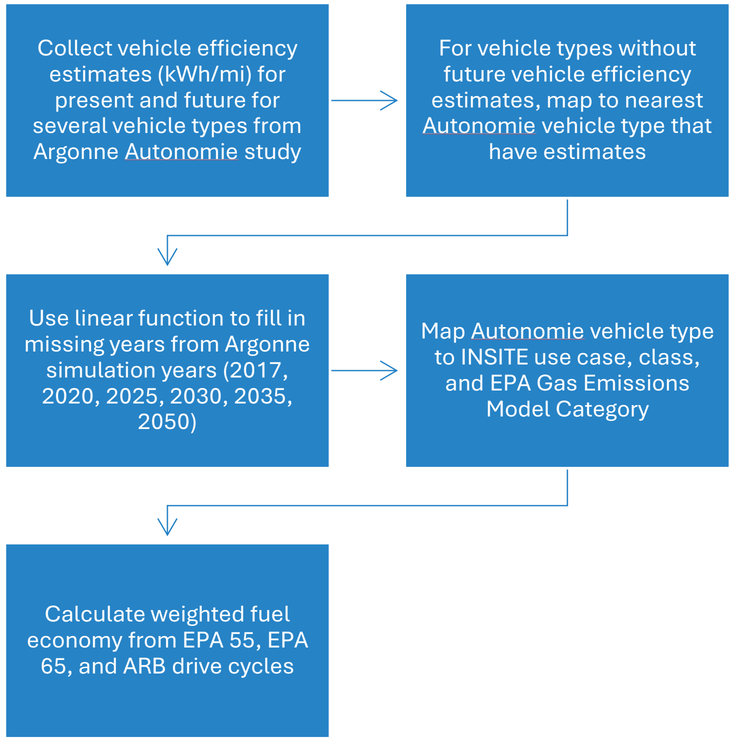

Figure 13. U.S. Daily Average Annual VMT Per Segment

Segment	Class					
	3	4	5	6	7	8
Construction Truck	48	34	48	38	38	38
Regional Truck	29	48	74	74	74	208
Motor Home	32	64	112	112	112	112
Pickup	77					
Long Haul Truck					545	545
Drayage					32	32
Bus		40	48	112	96	
Step Van	53	53	53	53		
Refuse				75	75	75
School Bus				48	48	48
VAN CARGO	87					
City Bus				112	112	112
Shuttle Bus	48	48	96	112		
Coach						112
Fire Truck						21
SUV	42					
Terminal Tractor						112
Emergency Truck			243	243		

Source: West Coast Clean Transit Corridor Initiative (WCCTCI) Report [39]

Charging Location

Since our analysis was focused on the next eight years, during which time electric M/HD markets are still expected to be in the growth stages, we modeled a home- and depot-focused charging ecosystem. Just like for light-duty vehicles, electric M/HD vehicles that can charge at home or at a depot face lower costs to electrification and are less reliant on the buildout of a full geographic network of en-route chargers making home and depot charging more viable in the short term.

We assume:

1) All school bus and shuttle bus charging are done at depots
2) Ninety percent of electric non-long-haul Class 2b – 8 truck charging is done at homes (trucks registered for personal use) or depots (trucks registered for commercial use). The remaining ten percent of energy for these trucks is from en-route charging.
3) Class 2b and 3 vehicles that are registered to an individual charge at home, but individually registered Class 4 and above vehicles charge at a depot or en-route
4) All long-haul truck charging is done en-route (at truck stops, truck parking, or gas stations)

Charger Power Level and Utilization

For every vehicle use case, weight class, and VMT case, we assign depot-charging vehicles to a power level that covers their daily energy recovery needs (including the slowdown above 80 percent state of charge) in a nine-hour overnight charge window. This overnight charge window is taken from the California Air Resources Board's Advanced Clean Truck Rule documentation [41].

We combine a) this charging power and location information with b) the EV adoption curve discussed previously and c) the share of each use case within each weight Class from 2019 S&P Global registration data[19] (the latest that Atlas had available). In doing so we allocated the electric vehicle stock provided by the CEO (Table 13) to charging location and power. The results are shown in Table 14 (Average Case) and Table 15 (Conservative Case). Note that we have used these adoption figures to implement the modeled split of energy recovery between homes/depots versus en-route charging (90 versus 10 percent of non-bus, non-long-haul charging, see prior section). In reality, it is possible that rather than 90 percent of vehicles charging solely at home/depot, and the remaining 10 percent charging solely en-route, individual vehicles could instead take 90 percent of their energy demand

[19] 2019 data was purchased from S&P Global Mobility, an automotive data provider.

from home/depot and ten percent from en-route chargers. This would lead to all the same outcomes in our modeling, i.e. the INSITE tool is agnostic to which specific vehicles are charging where and rather captures the total energy demanded at each location type.

Long-haul vehicles are assumed to electrify slower than other Class 8 vehicles, due to their greater range needs. We assume that none of the Class 8 EV stock is made up of long-haul until 2027, when we model five percent of Class 8 EVs as long haul. We increase this by one percentage point each year, i.e., in 2030, eight percent of Class 8 EVs are long haul. As mentioned in Chapter 3. Charging Needs Analysis," we model charging need for long-haul vehicles differently than the remaining vehicles. The long-haul EV stock shown here is therefore not used directly in the INSITE analysis because we assume that those vehicles' charging needs are met by minimum build corridor charging locations covered in the corridor charging analysis. However, we allocated and show those vehicles in table 14 to display the full set of EVs allocated from the EV stock figures provided by CEO (see section on EV Adoption).

Within the Level 2 depot charging vehicle categories, we assume:

In the 'Average' Case (where energy demand is lower):

- 97% are 48 A and 3% 80 A chargers for Class 2b – 3 vehicles.
- 35% are 48 A and 65% 80 A chargers for Class 4 – 8 vehicles

In the 'Conservative' Case (where energy demand is higher):

- 4% are 48 A and 96% 80 A chargers for Class 2b – 3 vehicles;
- 30% are 48 A and 70% percent 80 A chargers for Class 4 – 8 vehicles

These assumptions are based on the share of vehicles assigned to each power level using 2019 IHS registration data for Colorado.

Table 14. Allocation of Electric Vehicle Stock to INSITE Vehicle/Charging Types: Average Case

Location/Power/ Class	2023	2024	2025	2026	2027	2028	2029	2030
L2 (11kW) Home-charging Class 2b/3	228	508	1,017	1,969	3,707	6,675	11,221	17,352
L2 Depot-charging Class 2b/3	123	273	547	1,060	1,996	3,594	6,042	9,343
On-Road-Charging Class 2b/3	39	87	174	337	634	1,141	1,918	2,966

L2 Depot-Charging Class 4-8	19	49	110	233	467	886	1,542	2,431
50kW Depot-Charging Class 4-8	9	22	50	105	211	400	697	1,098
150kW Depot-Charging Class 7-8	10	25	55	117	234	444	773	1,219
En-route Charging Class 4-8 (non-long haul)	4	11	24	50	101	192	335	528
Long-haul vehicles	-	-	-	-	11	28	61	113
TOTAL	**431**	**974**	**1,976**	**3,870**	**7,360**	**13,361**	**22,590**	**35,050**

Table 15. Allocation of Electric Vehicle Stock to INSITE Vehicle/Charging Types: Conservative Case

Location/Power/ Class	2023	2024	2025	2026	2027	2028	2029	2030
L2 (11kW) Home-charging Class 2b/3	228	508	1,017	1,969	3,707	6,675	11,221	17,352
L2 Depot-charging Class 2b/3	123	273	547	1,060	1,996	3,594	6,042	9,343
On-Road-Charging Class 2b/3	39	87	174	337	634	1,141	1,918	2,966
L2 Depot-Charging Class 4-8	13	34	76	160	322	611	1,064	1,677
50kW Depot-Charging Class 4-8	13	32	72	153	306	582	1,012	1,596
150kW Depot-Charging Class 7-8	12	30	67	141	283	538	936	1,476
En-route Charging Class 4-8 (non-long-haul)	4	11	24	50	101	192	335	528

Long-haul vehicles	-	-	-	-	11	28	61	113
TOTAL	**431**	**974**	**1,976**	**3,870**	**7,360**	**13,361**	**22,590**	**35,050**

We assume each Level 2 charging port serves only one vehicle. We assume that depot fast charging ports are shared between vehicles up to 80 percent utilization of the charger during the nine-hour overnight charging window. Implementing this sharing feature results in a maximum of two vehicles sharing each depot DC fast charging port.

For en-route charging ports, we assume the following utilization:

- Ten (10) vehicles per day per 350kW en-route charging port for Class 2b – 3 vehicles. These vehicles are assumed to be able to charge at the same public charging stations as light-duty vehicles, and so this relatively high utilization assumption assumes that charging built for Class 2b - 3 vehicles is incremental to light-duty vehicle buildout at high-utilization locations where additional charging is needed to reduce congestion / support energy recovery for these additional vehicles.
- Six (6) vehicles per day per 350kW en-route charging port for Class 4 – 8 non-long-haul vehicles. In 2030, these vehicles are expected to take a weighted average of approximately 30 minutes to charge their daily energy need at this power level (assuming they avoid waiting to charge above 80 percent state of charge). This therefore assumes a 20 percent utilization rate during a 6am - 9pm window (or a 13 percent utilization rate across the entire 24-hour day). This assumes that the initial buildout of these vehicles over the next eight years is along select, higher-demand routes.

Cost Per Charging Port

Table 16 displays the cost assumptions used and their sources. From these EVSE costs, DC fast charger EVSE costs are reduced 3 percent per year through the end of the study period, in line with conversations with private sector electric vehicle service providers. All other costs are kept static.

Table 16. Modeled Costs Per Charging Port ($2022)

EVSE type	EVSE cost	Other costs	Total cost	Notes & Sources
Home L2 - Single-family detached	$759	$1,841	$2,600	ICCT home charging installation costs, inflated to 2022 dollars. Assume 100 percent need an outlet upgrade. Add $1,230 installation of

Home L2 - Single-family attached	$759	$3,641	$4,400	panel upgrade to 200 amps for 50 percent of homes [42]. EVSE cost is average of Juicenet model EVSE ($679) [43] and Clipper Creek ($899) [44] and ChargePoint ($699) [45].
Home L2 - Multi-home building	$759	$5,541	$6,300	
Depot 48a L2 - Class 2b/3	$2,255	$4,320	$6,600	EVSE cost is average 11kW EVSE cost from 2021 - 2022 CAC installs; other costs are labor costs for 2021 - 2022 9.6 - 11kW installs (due to smaller size of vehicles), ICCT 'outside CA' materials costs for workplace charging, assuming 6+ chargers per site, for site design/project management apply same cost percent as Class 4-8 trucks (from USPS installs)
Depot 80a L2 - Class 2b/3	$5,816	$4,320	$10,100	EVSE cost is average 19kW equipment cost from high-powered L2 CO-provided data for 2022; Other costs are labor costs for 2021 - 2022 9.6 - 11kW installs (due to smaller size of vehicles), ICCT 'outside CA' materials costs for workplace charging, assuming 6+ chargers per site, for site design/project management apply same cost percent as Class 4-8 trucks (from USPS installs)
Depot 48a L2 Class 4 - 8	$2,255	$19,225	$21,500	EVSE cost is average 11kW EVSE cost from 2021 - 2022 CAC installs; Other costs are labor cost from high-powered L2 data provided by CEO for four-port installs (due to larger vehicles) and site design/project management based on average per site costs from USPS sites
Depot 80a L2 Class 4 - 8	$5,816	$19,225	$25,000	EVSE cost is average 19kW equipment cost from high-powered L2 CO-provided data for 2022; Other costs are labor cost from high-powered L2 data provided by CEO for four-port installs (due to larger vehicles) and site design/project management based on average per site costs from UPS sites

Depot 50-62kW Class 4 - 8	$39,152	$47,721	$86,900	EVSE cost is average 2021 - 2022 CAC EVSE cost for 50 - 62kW. Labor, customer make-ready (scaled down from 150kW) and site design/project management costs are from GNA EDF report. Plus $144 per kW for front of the meter costs (average from data provided by LACI)
Depot 150kW Class 7 - 8	$108,500	$84,837	$193,300	EVSE, labor, customer make-ready, and site design/project management costs are from GNA EDF report. Plus $144 per kW for front-of-the-meter costs (average from data provided by LACI)
En-route 350kW Class 2b - 3	$210,000	$44,915	$254,900	EVSE cost is from WCCTCI, labor, and other site costs are from ICCT (inflated to 2022 dollars, assume 6+ ports per site)
En-route 350kW Class 4 - 6	$210,000	$126,000	$336,000	WCCTCI. Incl. permits, design, materials, construction costs for MD site. And utility upgrade costs for 3.5MW site
En-route 350kW Class 7 - 8	$210,000	$171,000	$381,000	WCCTCI. Incl. permits, design, materials, construction costs for HD site. And utility upgrade costs for 3.5MW site

Sources:

GNA Report: "California Heavy-Duty Fleet Electrification Summary Report" [46]

ICCT Report: "Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas" [47]

"West Coast Clean Transit Corridor Initiative Summary Report 2020" [39]

Energetics Incorporated Report: "California Investor-Owned Utility Transportation Electrification Priority Review Projects" [48]

Total Costs

Total costs are calculated by multiplying infrastructure need in each year (number of chargers per charging type) with infrastructure cost (by charging type) in each year. Charging costs for Home and L2 Depot modes are combined based on underlying percentages of home type and charging type. All costs reported are in undiscounted 2022 dollars. In order to calculate forward-looking budgets in nominal dollars for a given future year, users should inflate these results to the dollar year of interest. We suggest using the Producer Price Index to do so.

Costs by Geography

Due to inherent uncertainty around the geographic distribution of electric vehicle adoption, the INSITE model is designed to produce aggregate results for large geographies. However, for planning purposes, results at the county and utility territory level are desirable. For this analysis, we employed an ad hoc downscaling analysis that takes aggregate results at the state level and allocates them to utility and county level using vehicle registrations as a spatial surrogate.

A spatial surrogate is a geographic indicator that can be used as a proxy to predict how aggregate results would split up at a more granular spatial resolution. In this case, we use historical vehicle registration data, a measure of where M/HD vehicles are currently located, as a pattern for the likely deployment of future electric M/HD vehicles. Statewide INSITE results are allocated to county and utility territories based on the proportion of M/HD vehicles that are in that county relative to the statewide total. Equation 1 shows the mathematical operation we use to allocate results for port counts.

Equation 1. Port downscaling equation

$$PortsGEO_{i,x} = PortsINSITE_x \times \frac{RegGEO_{i,v}}{\sum_{i,v}^{n} RegGEO}$$

Where:

$PortsGEO$ is the needed ports in a geography (utility or county)
$PortsINSITE$ is the estimated statewide needed ports
$RegGEO$ is the number of vehicles registered in each geography (utility or county)
i is a specific geography (out of n Colorado geographies)
x is a specific charger type
v is the vehicle category or categories that correspond to charger type x

To illustrate how the downscaling method functions, we offer the following hypothetical example: If INSITE estimates that Colorado needs one hundred 150 kW depot chargers (X), and if there are 10,000 vehicles (V) across all Colorado Counties ($RegGEO_{i\text{-}n}$), where 1,000 of those vehicles are in Denver County ($RegGEO_i$), then the expected number of needed 150 kW depot chargers in Denver County ($PortsGEO_{i,x}$) can be expressed as shown in Equation 2.

Equation 2. Downscaling example equation

$$PortsGEO_{Denver,150\ kW\ Depot} = 100 \times \frac{1{,}000}{10{,}000} = 10$$

Because this allocation method can result in irrational estimates of fractional ports within a geography, we implement a de minimis of at least one port per geography for home and depot-based ports, and at least four ports for 350 kW en-route charging. Any remaining ports (or fractions of ports) left after this operation are aggregated and reallocated to the k geographies that had above-de minimis ports in the first allocation round.

The downscaling method for estimated costs (or $CostsGEO_{i,x}$) follows the same method as ports, but replaces $PortsINSITE_x$ with $CostsINSITE_x$ as the value that is allocated to geographies.

Electrifying Freight Corridors

The INSITE model is not equipped to estimate charging needs for long-haul trucks within a confined geography because long-haul freight traffic on in-geography corridors originates or terminates (or both) in locations outside of the modeled geographic bounds. Because INSITE modeling is predicated on estimating energy use of vehicles expected to be deployed in-geography, it cannot adequately model long-haul trucks for a limited region.

To address planning for long-haul trucks in Colorado, we took a minimum build approach, where we estimate the minimum needed infrastructure to electrify important freight corridors in Colorado. Corridors were selected by CEO in consultation with the Colorado Department of Transportation. CEO assigned corridors into three distinct phases based on target completion dates. Phases are identified in Table 17. Corridor Charging Phases .

Table 17. Corridor Charging Phases Specified by CEO

Phase	Years	Location / Highway
One	2023-2027	Denver Metro
Two	2025-2030	I-70, I-25, I-270
Three	2030-2035	I-76, US-287, US-385, US-85, US-50, US-40, US-160

To establish our minimum build scenario, we borrow the *West Coast Clean Transit Corridor Initiative Summary Report* (2020) assumption that effective corridor electrification needs at least one station per 100 miles to support through traffic on that corridor [39] We employ a geospatial analysis methodology that produces an approximation of that corridor charging station density while also respecting the network structure of Colorado's freight corridors.

We developed a simple, graph-based model of the highway corridors selected by CEO using the U.S. Department of Transportation Fright Analysis Framework national network dataset [49]. In the model, we represent intersections of corridors as nodes and the roadway between intersections as edges. We define boundary nodes for corridors that extend beyond Colorado's borders as the nearest intersection with another major freight corridor.

Nodes represent highway interchanges that are already common locations for fueling locations because they can serve multiple directions of traffic. These are natural charging site locations, and so we assign a single site to each network node to form the backbone of the corridor charging network. To ensure that average distance between charging sites remains about 100 miles on average, we site stations along network edges at approximately 100-mile intervals. If an edge (highway segment) between nodes is less than 120 miles, it is not subdivided. This means that sites are no more than 120 miles apart and no less than 60 miles apart. Where multiple intersections (nodes) between corridors fall within five miles of each other, we combine them into a single site that will serve both intersections.

Lastly, we define an approximate expected area for each corridor station by creating spatial buffers one mile from the highway and within a five-mile radius from a node/intersection or 20-mile radius from an edge-based site.

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