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Colorado charging infrastructure needs to reach electric vehicle goals

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Introduction

The global shift to zero-emission vehicles (ZEVs) is underway, and governments are setting goals to accelerate electric vehicle market growth and planning accordingly with supporting infrastructure and policy. In the United States, twelve states have adopted ZEV standards which require that automakers sell greater shares of ZEVs over time,[1] and several have announced their vision to shift entirely to 100% ZEVs over the 2035 to 2050 timeframe.[2]

Colorado is one such state that has set long-term goals to eliminate vehicle emissions to mitigate the health, climate, and economic consequences of transportation pollution. In its 2020 Electric Vehicle (EV) Plan, Colorado announced its long-term goal of having 100% electric light-duty vehicles and its additional goal to increase the number of EVs to nearly 1 million by 2030.[3] Recognizing that EVs and charging infrastructure should grow in unison, Colorado's 2020 EV Plan identifies the need for a charging infrastructure gap analysis to identify the number, type, and distribution of chargers needed across the state to meet its EV goals.

1 "Zero emission vehicles," Vermont Department of Environmental Conservation, accessed October 2020, https://dec.vermont.gov/air-quality/mobile-sources/zev.

2 See for example: California Executive Order N-79-20, Governor of the State of California, September 23, 2020, https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-text.pdf and "Members", International Zero-Emission Vehicle Alliance, accessed December 2020, http://www.zevalliance.org/members/.

3 Colorado Energy Office, "Colorado EV Plan 2020," (2020), https://energyoffice.colorado.gov/zero-emission-vehicles/colorado-ev-plan-2020.

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While most charging typically occurs at home, widespread adoption necessitates increased charging options for EV drivers. Drivers without home charging, including multi-family housing dwellers or those without off-street parking, will rely on convenient and reliable infrastructure options elsewhere. Greater infrastructure deployment at and near EV driver residences, workplaces, and public locations is needed to support market growth. Government agencies can proactively plan for infrastructure deployment to match their electrification goals, and such plans need to be tailored to the unique circumstances and landscapes within the jurisdiction. Data on vehicle ownership, EV adoption, charging behavior, housing, commuting patterns, and driver behavior are critical to inform infrastructure planning.

This working paper analyzes the number, type, and distribution of EV chargers needed to meet Colorado's EV goals. It quantifies charging needs at the county level across the state by 2030, focused on the public, workplace, and home charger needs for passenger vehicles. The analysis also estimates the costs required to meet these infrastructure needs. Charging infrastructure needs for medium- and heavy-duty vehicle electrification are also assessed with less granularity. This report also includes a discussion of the changing role of policy support for charging infrastructure investments through 2030.

Analysis

This analysis assesses the home, workplace, and public charger needs across Colorado based on its statewide EV sales goal, adapting an approach applied in a previous study.[4] Primary inputs include EV stocks informed by the EV uptake rate and vehicle stock-turnover model, charging behaviors from the best available study of real EV drivers' charging behaviors,[5] and county demographic factors from the American Community Survey.[6] Infrastructure costs are calculated as the product of the total number of chargers needed for the given charger type and per-charger infrastructure cost estimates identified in a previous analysis.[7] The approach for medium- and heavy-duty EVs is adapted from the ICCT's zero-emission truck infrastructure needs report.[8] The following sections summarize the key methodological steps taken to estimate infrastructure needs and costs for passenger EVs, followed by medium- and heavy-duty EVs.

Composition of Colorado passenger EV sales and stock

Figure 1 shows the analysis of EV sales share (green) and EV stock (blue) in Colorado for 2020 through 2030. The solid lines represent a "high growth scenario" and are based on Colorado's goal for 70% EV sales by 2030 and 940,000 EV stock by 2030.[9] The hashed lines represent a "low growth scenario" such that the 2030 EV sale share is about 42.5%

4 Michael Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-gap-US.

5 Gil Tal, Jae Hyun Lee, and Michael Nicholas, *Observed charging rates in California*, (Institute of Transportation Studies: Davis, CA, 2018), https://escholarship.org/uc/item/2038613r.

6 2018 5-Year American Community Survey (accessed October 2020), https://www2.census.gov/programs-surveys/acs/summary_file/2018/.

7 Michael Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-cost-US.

8 Dale Hall and Nic Lutsey, *Estimating the infrastructure needs and costs for the launch of zero-emission trucks*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/zero-emission-truck-infrastructure.

9 Colorado Department of Agriculture, Colorado Department of Natural Resources, Colorado Department of Public Health & Environment, Colorado Department of Transportation, and Colorado Energy Office, "Colorado Greenhouse Gas Pollution Reduction Roadmap" (September 30, 2020), https://energyoffice.colorado.gov/climate-energy/ghg-pollution-reduction-roadmap. We use a 0.94% annual light-duty vehicle sales growth to result in an EV stock, 940,000, similar to that projected in Colorado Energy Office, "Electric Vehicle Market Implementation Study", (2015) https://www.colorado.gov/pacific/sites/default/files/atoms/files/EV%20Market%20Study%202015_0.pdf.

and 2030 EV stock is about 580,000. The green EV sales share curves are constructed based on logistic growth which passes through two points of reference: the actual 2019 Colorado EV sales data and the 2030 state targets.[10] New EVs include both battery electric and plug-in hybrid electric vehicles, and the ratio of battery electric to plug-in hybrid electric vehicle sales remains constant at 20% and 80%, respectively, consistent with the published values by the state.[11] The EV stock is calculated based on new EV sales and the fleet stock turnover model.[12]

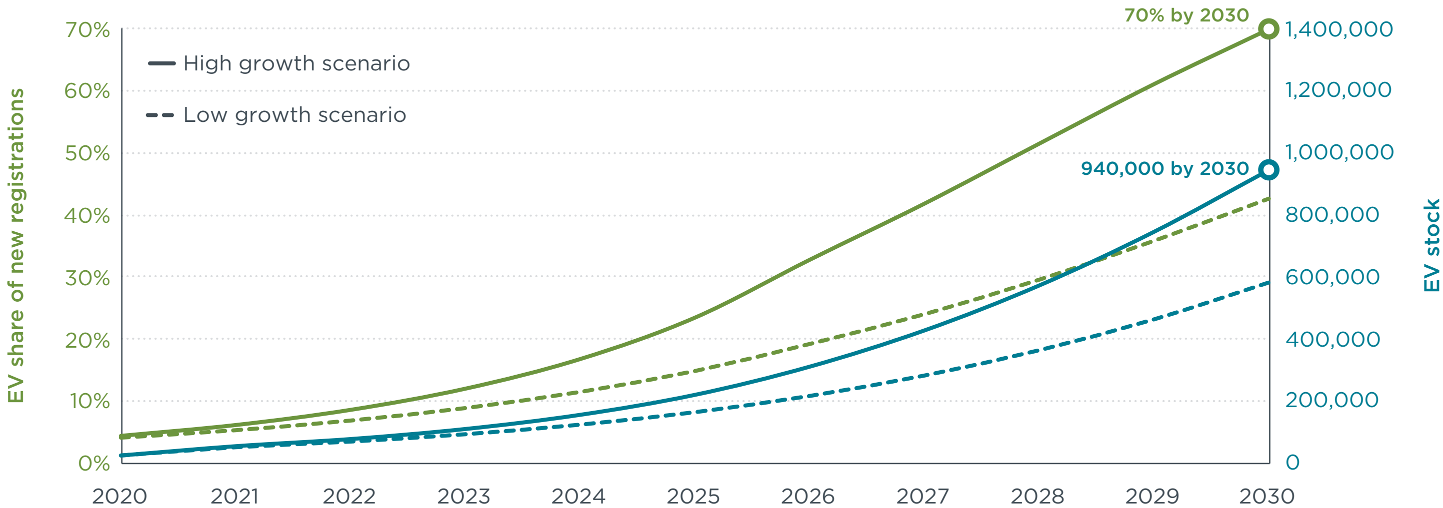

Figure 1. Assumed Colorado new vehicle EV share (green) and total EV stock (blue) from 2020 to 2030 for high (solid line) and low (hashed line) growth scenarios.

This analysis builds on the statewide EV growth in Figure 1 to assess county-level EV sales and stock. Each Colorado county has its specific EV sales projection based on the recorded 2019 county-level sales and the statewide annual growth rate. By using the same statewide growth rates for different counties starting with different 2019 EV sales percentages, we model a case where the leading EV-uptake counties in 2019 continue to lead in EV adoption and vice versa. We then allocate the projected statewide EV stock identified above proportionally to each county based on the cumulative sales among the counties. Relative differences in county-level vehicle ownership per capita remain identical to 2018 throughout the analysis, reflecting general density, housing, and vehicle ownership patterns across the state.

10 "State EV registration data," Atlas Public Policy (accessed October 2020), https://www.atlasevhub.com/materials/state-ev-registration-data/.

11 Battery electric vehicle (BEV) to plug-in hybrid electric vehicle (PHEV) ratios adapted from Navigant, "Electric Vehicle Growth Analysis Results." (2019) https://drive.google.com/file/d/1uIRw0Yfjz53nbvBjWQO14z_4jLsqzK4z/view. High-growth scenario: 0.96% PHEV annual sales growth rate resulting in 3.46 BEV:PHEV stock in 2030; low-growth scenario: -0.26% PHEV annual sales growth rate resulting in 4.74 BEV:PHEV stock in 2030.

12 See Appendix A for the detailed assumptions, method descriptions, and the results for the statewide EV sales and stock projections.

Charging demand

Charging demand in each county is primarily based on each county's unique EV stock for a given year, the housing characteristics of EV drivers,[13] and the assumed EV drivers' travel and commute patterns.[14] Housing characteristics are used to inform the likelihood of home charger access. The overall housing characteristics of EV drivers shift throughout the analytical timeframe as the market moves beyond early adopters who primarily live in detached homes to widespread adoption reflecting broader housing patterns. Together, the data on housing as well as travel and commute patterns are used with data from the California charging behavior survey to determine charging demand (in events per day) for each charger type.[15] The total daily energy demand for each charger type is then calculated as the product of EV stock, the daily charging events per EV, and the energy transferred per charging event (in kWh).[16] The energy per charging event increases slightly across the years as more light-duty electric trucks and SUVs enter the EV fleet, reflecting the shift to larger and inherently less energy-efficient EVs.[17]

Charging infrastructure needs: Home, workplace, and public chargers

Level 1 and Level 2 home charging needs for detached and attached homes are quantified based on the number of EV owners that have home charging access and the average number of vehicles in a vehicle-owning household, accounting for the shared use of home chargers within a household. The analysis assumes that approximately 25% of all EV-owning households have two home chargers. For multi-family housing, each residential charger is assumed to support two EVs.[18] For workplace charging, we assume that one-third of commuters who drive EVs have access to workplace chargers in 2020, increasing by 1% per year until 2030. Workplace chargers needed are quantified by dividing the total commuter workplace charging events per day by the energy transferred per event and the assumption that each workplace charger supports two charging events a day on average. The additional commuter charging demand unfulfilled by the workplace chargers is supplied by additional public chargers and the existing home chargers, based on observed EV driver charging behaviors.[19]

Public Level 2 and DC fast charging needs are quantified by dividing the daily energy demand by the average daily energy a charger can provide based on its utilization (hours per day) and power (kW). This charging infrastructure analysis projects the number of *chargers* needed, as opposed to the number of connectors or plugs. The technical term for chargers as used in this analysis is "Electric Vehicle Supply Equipment" (EVSE), which is the equipment "that controls the power supply to a single EV in a single session. An EVSE may provide multiple connectors but only one of these

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13 Colorado statewide EV driver housing characteristics in 2018 are assumed to resemble those found in Tal, Lee, and Nicholas, *Observed charging rates in California*. We then approximate the county-level EV driver housing characteristics based on the portion of the given housing type stock in the specific county compared to the state. For example, this means that counties with more of the state's multi-family housing units will see higher percentages of the county's EV drivers in multi-family housing. Each county's EV driver housing characteristics then gradually approach the countywide housing characteristics as of 2018—the American Community Survey data year (see footnote 6), so that by 2040 the housing characteristics of the EV drivers in each county are identical to all county residents.

14 We assume initially in 2020 that 80% of EV owners commute with their EVs. After 2020, the percentage of EV owners that commute approaches the percentage of all light-duty vehicles used for commuting in the given county in 2018 according to the American Community Survey. The shift in the share of EV owners that commute is applied at a pace similar to the statewide shift to greater EV stock.

15 Tal, Lee, and Nicholas, *Observed charging rates in California.*

16 See Appendix B for the charger events per day based on the driver topology and energy per charging event.

17 See Appendix C for the detailed method on fleetwide EV efficiency changes.

18 Multi-family housing is characterized by five or more units in a building or connected by shared walls.

19 Tal, Lee, and Nicholas, *Observed charging rates in California.*

can be active at the same time."[20] For DC fast chargers, this means that each dual-head DC fast charger, which typically does not allow for the charging of two vehicles simultaneously, is considered one charger. For Level 2 chargers, which do allow for the charging of multiple vehicles simultaneously, each connector is considered one charger.

The findings of 2030 public charging needs are compared against the deployment of public charging in Colorado through October 2020, based on data from PlugShare.[21] Initial 2019 charger utilization and power inputs for public Level 2 and DC fast chargers are based on real-world charging session data provided by the Colorado Energy Office for chargers funded through the Charge Ahead Colorado program. Charger utilization is assumed to increase as a function of EV adoption by county.[22] Statewide, from 2020 to 2030, charger utilization increases on average from 4.0 hours per day to 7.5 hours per day for public Level 2 chargers, and 1.2 hours per day to 2.7 hours per day for DC fast chargers. Charger power is assumed to increase logarithmically from 4.6 kW in 2019 to 8 kW in 2035 for public Level 2 chargers and from 26.4 kW to 130 kW for DC Fast chargers. These trends reflect greater deployment of higher-powered DC fast chargers and continued improvements in onboard charging technology.

The portion of the projected public DC fast chargers that will primarily serve the corridor travel demand is determined by Colorado state highway traffic data and the projected share of EV stock.[23] Corridor fast chargers are quantified based on the number of highway light-duty vehicle miles traveled and the associated energy demand. The associated energy demand is based on the average percentage of EVs in the Colorado vehicle stock, average DC fast charger power and utilization, and charging behavior data.[24] Deeper analysis into the broader transportation patterns across the state linking origins and destinations by county would help further reveal corridors across the state where relatively greater or fewer chargers are needed in the future.

Infrastructure cost

The infrastructure cost analysis quantifies the capital costs of infrastructure deployment through 2030, based on the infrastructure projection and average costs for each type of charger. Capital costs include installation (labor, materials, permitting, taxes) and hardware and are based on a 2019 ICCT study of infrastructure costs in the United States.[25] Table 1 summarizes the average per-charger installation and hardware costs for each type of charger used in this analysis in 2020. Although the table shows simplified averages, home charging costs can vary by housing type, grid upgrade requirements and, in the case of public charging, the number of chargers per site.

20 Defined by Open Charge Point Interface, "OCPI 2.2," (December 2020), https://evroaming.org/app/uploads/2020/06/OCPI-2.2-d2.pdf and adapted by the U.S. Department of Energy as discussed in Abby Brown, Stephen Lommele, Alexis Schayowitz, Emily Klotz, "Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: First Quarter 2020," (National Renewable Energy Laboratory, 2020), https://www.nrel.gov/docs/fy20osti/77508.pdf.

21 Charging infrastructure data (accessed October 2020), https://www.plugshare.com.

22 See Appendix D for the detailed assumptions and methods for the charger utilization growth.

23 Highway Traffic Counts in Colorado, (accessed October 2020), https://data.colorado.gov/Transportation/Road-Traffic-Counts-in-Colorado-2018/bk6n-e4g7.

24 See Appendix E for a detailed method for estimating the corridor DC fast charger need.

25 Michael Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*.

Table 1. Capital costs in 2020 for each charger type used in this analysis.

Charger type	Per-charger capital cost
Home Level 1	$520
Home Level 2	$2,312
Workplace	$3,535
Public Level 2	$4,959
DC fast (50 kW)	$54,968
DC fast (150 kW)	$98,198
DC fast (350 kW)	$168,708

Several points help provide context to the infrastructure cost analysis. We apply a 3% per year reduction in hardware costs for all chargers from 2020 through 2025. The analysis assumes that approximately 80% of public Level 2 chargers are networked; because networked chargers are about three times more expensive than non-networked chargers, if all public Level 2 chargers were networked the average costs would increase by about 15%. For DC fast chargers, the analysis incorporates a phase-in of higher-powered chargers, such that in 2030 about 45% of new DC fast chargers are 50 kW, 45% of new chargers are 150 kW, and the rest are 350 kW. From 2026, we apply a 4% annual increase in capital costs for all chargers to reflect the trend of new charging deployment increasingly shifting away from the most affordable locations.

Medium- and heavy-duty electric vehicles

We investigate the medium- and heavy-duty electric truck charging infrastructure based on the state 40% sales goal in 2030. We assess annual truck sales based on 2019 truck stock data from the Colorado Department of Public Health and Environment and the truck-specific stock turnover model. Annual truck sales data were not available. Electric truck sales are analyzed using the same adoption pattern as described in Appendix A and reach 40% in 2030 for both medium- and heavy-duty trucks. We then estimate the infrastructure need and costs based on findings in ICCT's electric truck infrastructure study that assesses the charging need of representative electric trucks, routes, and duty cycles.[26] Table 2 shows the report's findings on truck to charger ratio, the cost per ultra-fast charger (> 350 kW), and the cost per depot charger (50 kW) at different deployment stages.

Table 2. Electric truck to charger ratio and capital cost per charger at different stages of deployment.

	Electric truck to charger ratio		Cost per ultra-fast charger		Cost per depot charger	
	Heavy-duty	**Medium-duty**	**Heavy-duty**	**Medium-duty**	**Heavy-duty**	**Medium-duty**
Initial deployment (under 1,000 trucks)	2.9	7.1	$283,318	$181,000	$47,342	$38,862
Mid-term deployment (1,000 to 10,000 trucks)	4.1	23.8	$247,442	$158,207	$36,185	$34,819

26 Hall and Lutsey, *Estimating the infrastructure needs and costs for the launch of zero-emission trucks.*

Results

The analytical findings of the passenger vehicle charging infrastructure needs analysis are first presented on a statewide level to illustrate the scale of increasing infrastructure needs. Statewide results are followed by county-level results with deeper insight into variation in infrastructure needs across counties. The findings from the cost analysis for passenger EVs follow the analysis of charging needs. The infrastructure needs and cost results for electric medium- and heavy-duty vehicles are presented after those for passenger EVs.

Electric vehicle charging infrastructure needs

Reaching Colorado's EV goals requires significant infrastructure deployment. Figure 2 shows the statewide EV stock and the associated number of public chargers needed. Results for the high-growth scenario, where EV sales reach 70% by 2030, are shown by the solid line and bars and results for the low-growth scenario, where EV sales reach 42.5% by 2030, are shown by the dashed line and hashed bars. As shown, this growth in EV sales would lead to approximately 940,000 EVs (high growth) to 580,000 EVs (low growth) on Colorado roads in 2030. About 80% of the projected 2030 EV stock is battery-electric compared to 20% plug-in hybrid electric.[27] For the high-growth scenario, the figure shows the number of public chargers would need to increase from about 2,100 in 2020 to about 7,500 in 2025 and 24,000 in 2030. By 2030, approximately 11 times as many chargers will need to be installed compared to chargers installed in the state prior to November 2020. This is equivalent to a 30% annual growth rate from 2020 to 2025 and a 26% growth rate from 2026 to 2030. About 80% of the public chargers needed are Level 2 and 20% are DC fast. For the low-growth scenario, the number of public chargers needed in 2030 is about 33% lower than the high-growth scenario.

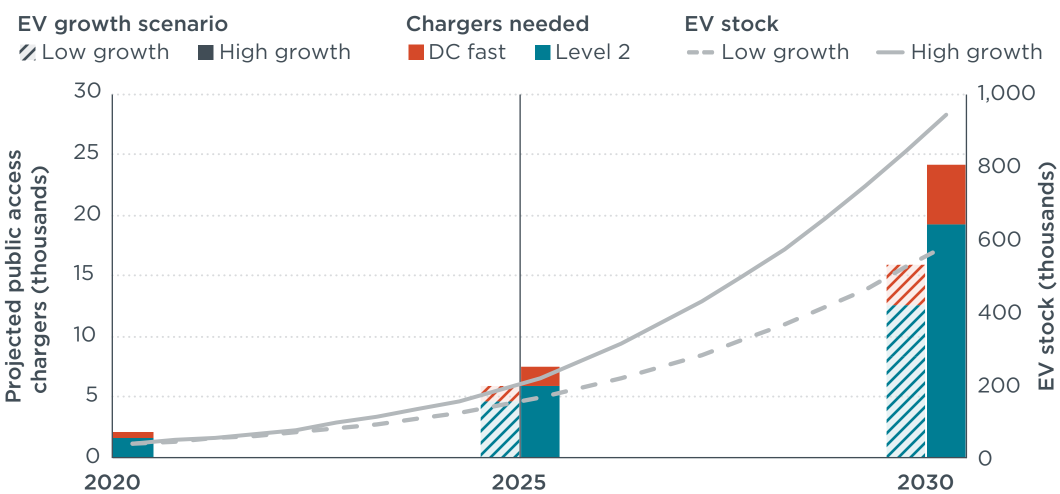

Figure 2. Colorado statewide public charging infrastructure needed under high-growth (70% EV sales by 2030) and low-growth (42.5% EV sales by 2030) scenarios.

The Colorado 2025 and 2030 infrastructure projections for home, workplace, and public chargers are shown in Table 3 for the high- and low-growth scenarios. In both scenarios, home chargers represent about 85% of all chargers in Colorado by 2030. This is based

27 Battery electric vehicle (BEV) to plug-in hybrid electric vehicle (PHEV) ratios adapted from Navigant, "Electric Vehicle Growth Analysis Results." (2019) https://drive.google.com/file/d/1ulRw0Yfjz53nbvBjWQO14z_4jLsqzK4z/view. See Appendix A for the detailed assumptions, method descriptions, and the results for the statewide EV sales and stock projections.

on the analysis that approximately 80% of all EV owners have access to residential charging at their homes or multi-family housing units. As shown, based on the high-growth scenario, about 105,000 home chargers are needed by 2025, and 437,000 are needed by 2030. Similar for both scenarios, of the home chargers needed by 2030, about 85% are for detached homes, 10% are for attached homes, and 6% are for multi-family housing. Workplace chargers and public chargers represent about 9% and 6% of the total chargers, respectively.

Table 3. Projected charging infrastructure needed in Colorado in 2025 and 2030.

EV growth scenario	Year	Detached home	Attached home	Multi-family housing	Workplace	Public Level 2	DC fast (non-corridor)	DC fast corridor
High growth	2025	90,495	9,415	4,976	10,772	5,882	1,287	412
	2030	369,021	42,325	25,626	46,686	19,291	3,771	1,070
Low growth	2025	67,960	7,017	3,663	7,995	4,620	1,030	345
	2030	228,632	26,076	15,591	28,776	12,597	2,621	760

Several points provide context to the projections of home chargers needed, which are informed by EV owners' housing characteristics. In 2021, EV uptake largely resembles the housing characteristics of early EV adopters, meaning most reside in single-family homes. By 2040, as EVs are more widely adopted, the percentage of new EV owners by housing type resembles the percentage of the residents by housing type in each county.[28] Modeling a faster shift to universal EV adoption by housing type would increase the number of multi-family chargers needed. This analysis finds that in 2030, about 75% of Colorado EV owners live in detached homes, 10% live in attached homes, and 15% live in multi-family housing units. The relative breakdowns vary across each county: in Denver for example, about 60% of EV owners in 2030 live in detached homes, 12% live in attached homes, and 28% live in multi-family housing units. This analysis also assumes that each residential multi-family housing home charger can support two EVs; relatively more multi-family home chargers would be needed without the shared use.

Charging infrastructure demand varies across the state, as counties with more EVs tend to need more chargers. Because the analysis of EV sales and stock applies each county's 2019 EV sales share to the statewide annual growth rate, the counties with the most EV sales through 2019 continue to lead the state in EV adoption through 2030. For example, the 2030 EV sales shares in counties such as Denver, Jefferson, Douglas, Boulder, and Broomfield is about 80% to 99%, whereas 2030 EV sales shares in El Paso, Weld, Pueblo, Mesa, and Garfield counties is about 13% to 44%. In terms of 2030 EV stock, for Denver—the most populous county—29% of the passenger vehicle stock is electric, compared to 11% for the rest of Colorado.

The public charging infrastructure projections follow a similar trend as the EV stock projection. Figure 3 shows the numbers of public chargers needed (blue for public Level 2 and red for DC fast), the DC fast corridor charger density (thickness of the highway), and the percent of EVs in the light-duty vehicle stock (green shading) in each county in 2030. The findings are based on the high growth scenario; county-level infrastructure results for the low growth scenario are shown in the appendix. Figure 3 shows how Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, and Larimer counties need 1,400 to 3,400 public Level 2 and 300 to 850 DC fast chargers in 2030. Counties including

28 Colorado statewide EV driver housing characteristics in 2018 are assumed to resemble those found in the California EV driver survey by Tal et al., 2018 (see footnote 5). See footnote 14 for the method of shifts in EV owner housing characteristics.

Broomfield, Eagle, Elbert, Garfield, La Plata, Mesa, Pueblo, and Weld need about 100 to 800 public Level 2 and 25 to 185 DC fast chargers. In general, the counties with relatively greater population and EV stock tend to require relatively more public chargers in 2030.

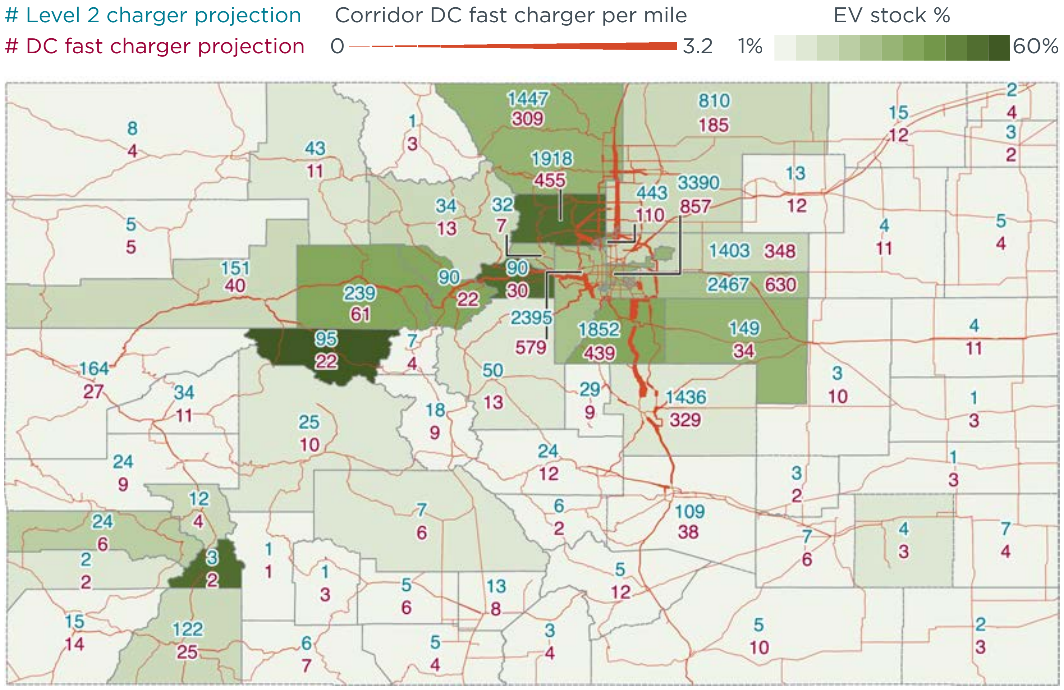

Figure 3. 2030 county-level public Level 2 (blue numbers) and DC fast (red numbers) chargers needed and share of EV stock, based on the high-growth scenario.

Additional points provide context to the Figure 3 findings. As shown by the dark green areas on the lower left and left side of the map, San Juan and Pitkin counties stand out with relatively high shares of EV stock in 2030. These counties had some of the highest EV sales shares in Colorado in 2019. Because this analysis of EV sales and stock assumes that the counties with the greatest EV market success through 2019 continue to lead, these areas are modeled to have some of the highest EV sales shares and stock in 2030. Yet despite the relatively high EV adoption in San Juan county, relatively few chargers are needed due to its small population.

The analysis of corridor DC fast charging needs indicates how more chargers tend to be needed along the routes that have the most daily vehicle miles traveled, such as Interstate 25, Interstate 76, and Interstate 70 in and around the Denver-Aurora-Lakewood and Boulder metropolitan areas. About two to three DC fast chargers per mile are needed along the corridor segments with the greatest charging needs, as shown by portions of highway with the thickest red line. On average across the Denver-Aurora-Lakewood and Boulder metropolitan areas, about one corridor DC fast charger is needed for every three miles of highway. The average corridor DC fast charging needs for the rest of the state excluding these metropolitan areas is about one corridor DC fast charger for every 10 miles of highway. As the EV market grows, deployment of public charging has trended toward more chargers per location to reduce the overall installation costs.[29] As a hypothetical example, if there are eight DC fast chargers per location, then on average approximately one DC fast charging location is needed every

29 Peter Slowik and Nic Lutsey, *The surge of electric vehicles in United States cities,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/surge-EVs-US-cities-2019.

80 miles, which is less than half of the range of most 2020 EV models, along corridors outside the two metropolitan areas mentioned above.

The analysis of corridor charging needs excludes highway segments that pass through urban areas, as detailed in Appendix E. Level 2 chargers are not included in the analysis of corridor infrastructure needs due to the relatively longer dwell times associated with Level 2 charging. As a result, Figure 3 shows how there is a greater need for DC fast chargers relative to Level 2 chargers in several counties that have lower EV adoption and population. Deeper analysis into the broader transportation patterns across the state regarding origins and destinations by county and the specific transportation and charging behavior patterns of EV drivers could help additional local and regional planning efforts identify and fill potential charging gaps.

The areas with the greatest charging needs in 2030 are also where most of the public Level 2 and DC fast chargers have been deployed as of October 2020. This is illustrated by the concentration of blue (public Level 2 chargers, including Tesla Destination charges) and red (DC fast chargers, including Tesla Superchargers) data circles in and around the Denver area in Figure 4. The figure also shows the deployment of public charging infrastructure as a percentage of what will be needed by 2030, overlayed with the public chargers installed by October 2020 based on data from PlugShare.[30] Shades of blue indicate that more than 50% of the charging needed in 2030 had been installed, whereas shades of red indicate less than 50% had been installed. Overall, most of the counties are shown in dark red, indicating that less than 25% of the public charging needed by 2030 was in place as of October 2020.

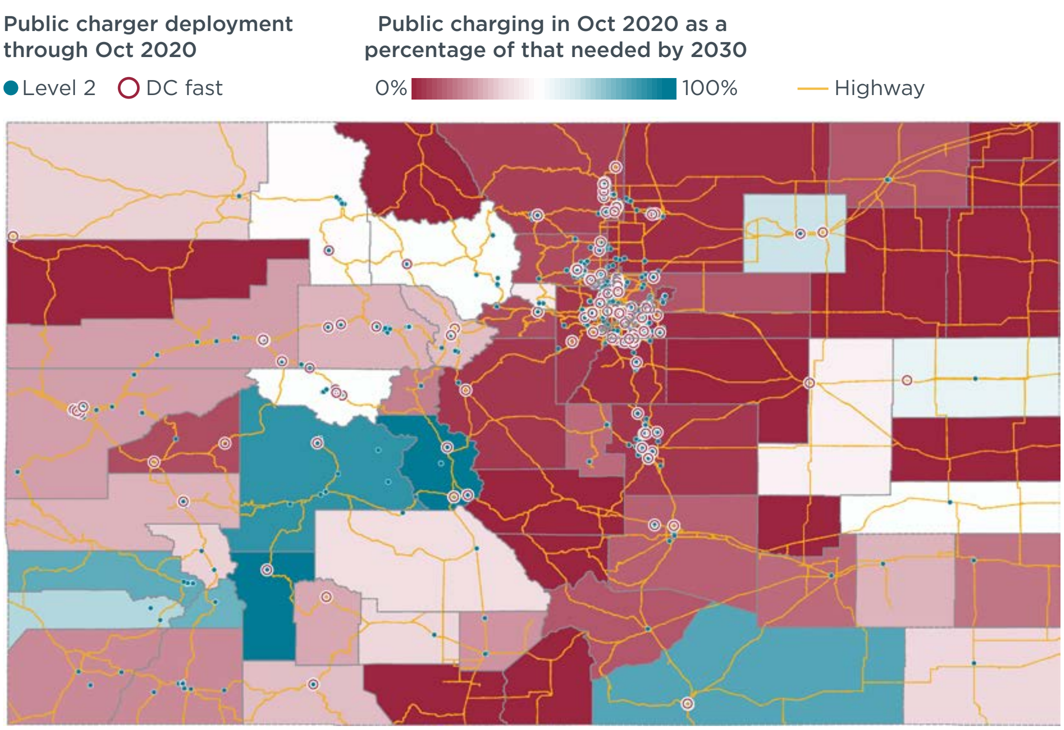

Figure 4. Colorado public Level 2 (blue data circles) and DC fast (red data circles) charger deployment as of October 2020, and county-level public charging in place as a percentage of infrastructure needed by 2030. Charging infrastructure data are from PlugShare.

30 Charging infrastructure data, (accessed October 2020), https://www.plugshare.com.

As shown by the cluster of blue and red data circles in and around the Denver area, Arapahoe, Boulder, Denver, and Jefferson counties combined are home to about 40% of all Colorado public chargers installed through October 2020. Yet, each of these counties had less than 10% of the public charging needed by 2030 in place, based on their expected growth. In contrast, areas including Chaffee, Gunnison, and Hinsdale had more than 90% of the public charging needed by 2030 in place. Although a handful of counties in the Southwest region have deployed 50% or more of the public chargers needed by 2030, many are located at major destinations including ski resorts. These chargers may be insufficient to serve the daily charging needs of the local residents, and more local and regional planning efforts are needed to identify and address such challenges.

Several additional points provide context to the underlying data shown in Figure 4. The counties with relatively high EV adoption through 2019 tend to be the same counties that require the greatest infrastructure growth through 2030, largely due to continued growth in EV stock in these areas as forecasted in this analysis. PlugShare data through October 2020 reflect how infrastructure deployment has been geographically dispersed, providing EV drivers with charging options in key areas across the state and within and outside of population centers.[31] Public Level 2 chargers are typically installed at destinations where EVs tend to be parked for several hours. Based on the Colorado PlugShare data, the top locations with the most public Level 2 chargers installed include hotel or lodging (24%), parking garage or lot (17%), and store or shopping center (9%), with Tesla Destination chargers more frequently identified at hotels and lodging. DC fast chargers, in addition to 40% being deployed at key locations within urban areas such as shopping centers, have also been installed along highway corridors to provide convenience and enable longer distance EV trips. Figure 4 shows how, as of October 2020, some DC fast chargers have been deployed along key Colorado routes including Interstate 25, Interstate 76, Interstate 70, Route 50, and State Highway 82.

The daily energy needed to power light-duty EVs statewide in 2030 is a relatively small portion of the statewide energy consumption. In 2018, Colorado consumed approximately 176 GWh of electricity daily.[32] Based on the high-growth scenario, this analysis finds that 2.3 GWh and 9.9 GWh of electricity is needed daily for EV charging in 2025 and 2030, respectively, which is approximately 1% and 6% of the statewide energy consumption. Figure 5 shows the statewide energy demand required to support the EV fleet, with each segment of the bar representing a charger type. As shown, home chargers provide more than half of all EV charging energy demand due to the longer dwelling time and greater convenience of home charging. On average through 2030, home charging provides more than 60% of the daily total EV charging energy demand, followed by DC fast and workplace charging (both at 15%), and public Level 2 charging (8%). For context, the daily energy demand of EV charging under the low-growth scenario is about 75% that of the high-growth scenario in 2025 and 63% in 2030.

31 Charging infrastructure data, (accessed October 2020), https://www.plugshare.com.

32 Colorado End-use energy consumption 2018, estimates, (accessed Nov 2020), https://www.eia.gov/beta/states/states/co/overview.

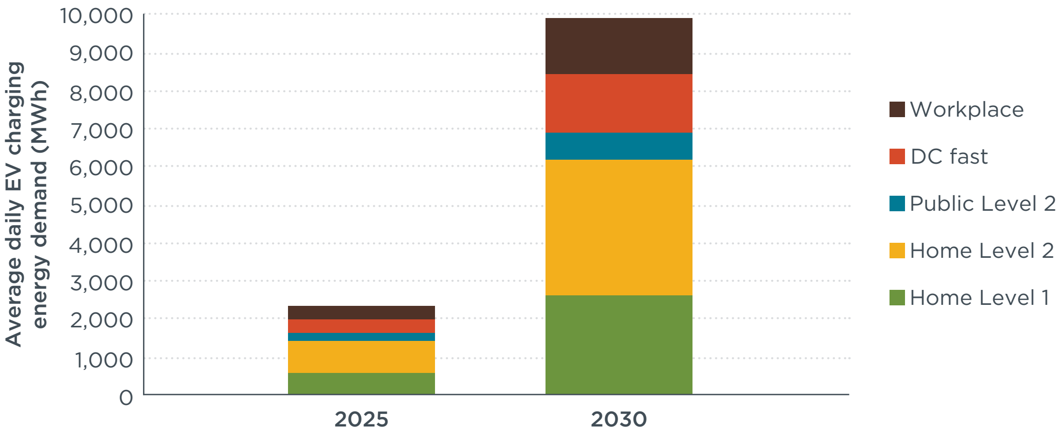

Figure 5. Colorado statewide EV charging energy demand projections by charger type in 2025 and 2030.

Charging infrastructure cost

As of 2020, Colorado, together with its public utilities, has invested at least $25 million in EV charging infrastructure through programs such as Charge Ahead Colorado, CEO's fast-charging corridors program, and Xcel's EV Supply Infrastructure program.[33] Additional investments are being planned to support EV growth. For example, in December 2020 the Colorado Public Utilities Commission approved Xcel's Transportation Electrification Plan which proposed providing $24 million, $34 million, and $45 million for 2021, 2022, and 2023, respectively, in charging infrastructure investment.[34] The majority of the investment will provide capital costs for EV make-ready supply infrastructure, owning and operating a small number of public DC fast chargers, and charging as a service across residential and commercial portfolios.

Figure 6 shows the total hardware and installation cost of home, workplace, public Level 2, and DC fast charging infrastructure in Colorado from 2021 through 2030. Annual charging infrastructure costs increase through 2030 as EV sales and stock increase, from about $13 million per year in 2021 to about $200 million per year in 2030. Overall, the cumulative infrastructure cost from 2021 through 2030 is about $860 million. The total DC fast charging costs are the greatest at about 39% of the cumulative costs through 2030, followed by home (33%), workplace (18%), and public Level 2 (10%). Compared to the total costs, the average infrastructure costs on a per-charger basis are smallest for home chargers, followed by workplace, public Level 2, and DC fast chargers. The costs shown in Figure 6 are based on deploying about 437,000 new home chargers, 47,000 workplace chargers, 19,000 public Level 2 chargers, and 4,000 DC fast chargers over the 2021-2030 timeframe. A detailed summary of the annual infrastructure costs by charging type is shown in Appendix G.

33 Colorado Energy Office, "Colorado Electric Vehicle Plan 2020" (April 2020), https://energyoffice.colorado.gov/sites/energyoffice/files/2020-07/colorado_ev_plan_2020_-_final.pdf.

34 Details of Decision C21-0017, Colorado Public Utilities Commission, C21-0017, Jan 11, 2021, https://www.dora.state.co.us/pls/efi/EFI_Search_UI.Show_Decision?p_session_id=&p_dec=28011; Xcel Energy, "2021-2023 Transportation Electrification Plan" (2020), https://www.xcelenergy.com/company/rates_and_regulations/filings/transportation_electrification_plan.

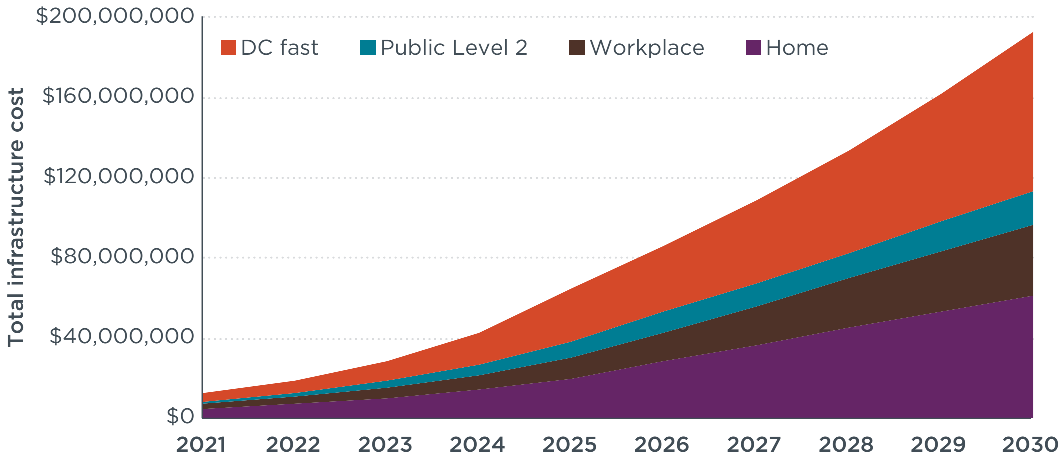

Figure 6. Colorado annual charging infrastructure costs for 2021 through 2030.

In addition to hardware and installation costs, soft costs can be a significant cost driver for EV charger deployment. The infrastructure cost estimates above do not include costs such as data agreements, product warranties, process costs, costs of delays in permitting, and costs of building extra capacity to help "future-proof" sites. From a public funding perspective, there will be more requirements in terms of project development, networked chargers, data agreements, service plans, and other factors that can increase soft costs for state-funded projects. Research shows that there are significant opportunities to reduce overall costs by lowering soft costs through actions like coordination with utilities, expedited permitting, shorter data agreement term lengths, and planning for future needs.[35] Although just one component of soft costs, project delays are estimated to increase DC fast charging costs by about 25%.[36] Broadly speaking, the specific share of EV infrastructure soft costs is generally unknown and highly variable: the best available research literature in this space draws upon lessons learned from the solar industry and reports that the soft costs in solar projects can represent up to about 60% of total costs in extreme cases.[37]

The counties that require the most charging infrastructure growth through 2030 typically require the greatest investment. Overall, the counties including Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, and Larimer that require 33,000 to 87,000 total chargers (home, workplace, public Level 2, and DC fast) require investments of $48 million to $124 million. On average in these counties, home chargers make up 30% of the needed investment while public Level 2 and DC fast chargers make up 9% and 40% of the needed investment, respectively. In contrast, counties with lower populations and lower EV stock need relatively less investment. In Kiowa and Cheyenne counties, home chargers represent about 7% of the needed investment while DC fast chargers represent about 90%, reflecting the greater importance of DC fast charging along major corridors in these areas.

35 Chris Nelder and Emily Rogers, "Reducing EV Charging Infrastructure Costs," (Rocky Mountain Institute, 2019), https://rmi.org/insight/reducing-ev-charging-infrastructure-costs/.

36 Estimated based on Jonathan Levy, Isabelle Riu, and Cathy Zoi, "The costs of EV fast charging infrastructure and economic benefits to rapid scale-up" (EVgo, 2020). https://www.evgo.com/wp-content/uploads/2020/05/2020.05.18_EVgo-Whitepaper_DCFC-cost-and-policy.pdf.

37 Nelder and Rogers, "Reducing EV charging infrastructure costs."

Medium-duty and heavy-duty electric trucks

Based on the Colorado Department of Public Health and Environment data, there were about 25% more class 7 and class 8 heavy-duty trucks on Colorado roads in 2019 than class 4 to class 6 medium-duty trucks. Meeting Colorado's goal of 40% electric medium- and heavy-duty truck sales by 2030 means that about 4,500 electric trucks, or around 4% of the stock, could be on the road that year. Table 4 summarizes the findings regarding the number of electric trucks, the number of ultra-fast chargers needed, and the infrastructure costs in 2025 and 2030. As shown, about $360 million of infrastructure spending is needed to support the electric medium- and heavy-duty truck fleet through 2030, including both depot chargers (50 kW) and on-route ultra-fast chargers (> 350 kW). Through 2030, about 20% of the cumulative infrastructure costs for medium-duty trucks are ultra-fast chargers and about 80% are for depot. For heavy-duty trucks, about 65% of the cumulative infrastructure costs through 2030 are for ultra-fast chargers and about 35% are for depot chargers. Similar to that of light-duty EV infrastructure, electric truck infrastructure costs rise rapidly in the second half of 2020 following the accelerating adoption rate.

Table 4. Number of electric medium- and heavy-duty trucks in 2025 and 2030 and the associated infrastructure needs and costs.

	Number of electric trucks		Number of ultra-fast chargers		Number of depot chargers		Average infrastructure cost per truck		Estimated cumulative infrastructure cost ($ million)	
Truck type	**2025**	**2030**	**2025**	**2030**	**2025**	**2030**	**2025**	**2030**	**2025**	**2030**
Medium-duty (class 4–6)	102	2,021	14	85	113	1,570	$82,000	$40,000	$8.3	$80.9
Heavy-duty (class 7 and 8)	113	2,480	38	598	132	2,350	$189,000	$114,000	$21.4	$282.7

Concluding reflections

The global transition to ZEVs is underway, yet key questions remain about the number, type, and distribution of charging infrastructure needed to support widespread adoption. This working paper explores the case for Colorado at the county level and is based on data inputs for EV growth, vehicle ownership patterns, commuting and housing patterns, and EV charging behavior, among others. The analysis leads to the following conclusions and policy recommendations:

Electric vehicle market growth requires similar growth in charging infrastructure. Achieving Colorado's 2030 goal of 70% EV sales means that 940,000 EVs could be on state roads that year. Substantial charging infrastructure deployment is needed to support these EVs. The 2,100 public chargers installed as of October 2020 will need to grow by about 28% per year to 7,600 by 2025 and 24,100 by 2030, which is an increase by a factor of about 11. Workplace and home charging will need to increase to approximately 47,000 chargers and 437,000 chargers, respectively, by 2030. Continued EV market growth in Colorado counties such as Denver, Boulder, Jefferson, and Arapahoe which have experienced relatively higher EV adoption through 2019, will require more home, workplace, and public charging more quickly.

Meeting Colorado's EV goals will require substantial investments in charging infrastructure. The needed statewide investments in public and workplace chargers are about $34 million for 2021–2022, about $150 million for 2023–2025, and about $730 million for 2026–2030. Of the total investment needed through 2030, DC fast chargers represent about 35%, followed by home (30%), workplace (25%), and public Level 2 (10%). In the near-term, counties such as those in the Denver and Boulder metropolitan areas that have relatively higher EV uptake and lower infrastructure deployed in 2020 as a percentage of what will be needed by 2030 would benefit from relatively greater infrastructure investments. Near-term investments can also be steered towards additional Tier 1 corridor locations beyond those that had initially been identified for EV charging under the ALT Fuels Colorado program.[38] This includes counties like Kiowa and Cheyenne where the local EV market may not be large enough to attract the necessary near-term public charging investment from the private sector. Public funding for corridor DC fast chargers in these counties can serve the crucial dual role of supplying both highway and local traffic charging demand.

Home chargers have a critical role in supporting EV adoption and operation. Widespread access to overnight residential charging is important for minimizing the need for more public chargers. This analysis finds that home chargers represent about 84% of the total chargers needed across Colorado and supply more than 60% of the EV energy demand in 2030. Home chargers usually have the lowest installation and energy cost and thus help to maximize EVs' economic benefits. Based on this analysis of Colorado's housing characteristics, early EV adopters' home charger access, and EV adoption trends, about 80% of EV owners in 2030 could have access to home chargers. Yet more inclusive and equitable alternative residential charging such as curbside or streetlight chargers in metropolitan areas with a significant population of multi-family housing dwellers would ideally be deployed to improve the affordability, accessibility, and practicality of EVs for all prospective drivers.

State policies will be key to achieving Colorado's EV goals and the associated infrastructure that is needed. Infrastructure growth across Colorado will need to increase by about 28% per year through 2030. Continued and stronger policies like tax incentives, grants, and rebates for chargers, utility ratepayer-funded infrastructure deployment, EV-ready building codes, and streamlined permitting are key to supporting the needed growth. Municipalities and local electric power utilities will need to plan for their unique charging needs based on their local landscapes.[39] Collaboration among state agencies, utilities, and charging providers will be key to identifying and filling charging gaps. Ongoing and increased public investment is needed to help deliver on the $900 million in cumulative costs for home, workplace, and public chargers needed through 2030. These programs could be funded by initiatives like a Low Carbon Fuels Standard that creates revenues for low-carbon fuel vehicle and infrastructure deployment.[40]

Table 5 summarizes how state-level EV infrastructure policy support could evolve over the 2021 to 2030 timeframe, consistent with the pace and scale of EV market growth analyzed above and the industry progression toward more durable business models. The table lists several EV infrastructure support actions, categorized by near-term (2021–2022), mid-term (2023–2025), and longer-term (2026–2030) policies.

38 Tiers as marked in Colorado Energy Office, "ALT Fuels Colorado Request for Applications," (2018), https://www.colorado.gov/pacific/sites/default/files/atoms/files/ALT%20Fuels%20Colorado%20EV%20DCFC%20Corridors%20Grant%20Program%20RFA%20FINAL.pdf.

39 Dale Hall and Nic Lutsey, *Electric vehicle charging guide for cities,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/city-EV-charging-guide.

40 Peter Slowik, Dale Hall, Nic Lutsey, Michael Nicholas, and Sandra Wappelhorst, *Funding the transition to all zero-emission vehicles*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/funding-ZEV-transition.

Table 5. State-level EV infrastructure policy support from 2021 to 2030.

Timeframe	Policy actions
Near-term (2021–2022)	**Set plan and address barriers** • Develop strategy, identify partners, define roles • Continue and expand on Charge Ahead Colorado grant program • Support local government adoption of latest EV capable/ready building codes • Streamline infrastructure permitting processes • Inventory state-owned assets and deploy chargers at suitable locations • Work with utilities to design favorable tariff and time-varying pricing for EV charging
Mid-term (2023–2025)	**Sustain momentum** • Continue public assistance, prioritize areas less likely to receive private investment • Partner with the private sector to identify and fill charging gaps • Support local government adoption of latest EV capable/ready building codes
Longer-term (2026 – 2030)	**Ensure adequate infrastructure to support mass-market EV adoption** • Strengthen EV-ready building codes to increase residential, workplace, and public charging • Address specific charging needs of fleets and other commercial vehicles • Steer utility and private sector investments to areas with the greatest need

Broadly speaking, state policy can evolve from initial planning and addressing barriers, to sustaining momentum in the mid-term, and to supporting mass-market adoption over the longer-term by ensuring infrastructure access for all by 2030. Continuing and expanding on the state EV infrastructure programs underway will be key to near-term growth. Developing infrastructure plans and consulting with key public and private stakeholders will be important to identify infrastructure needs, barriers, gaps, and policy actions to address them. Continued and expanded infrastructure incentives and grant programs, supporting local jurisdictions' implementation of EV-ready building codes for new and existing buildings, and streamlining permitting processes help expedite deployment and lower costs.[41] These programs will be especially important in counties with a greater share of multi-family housing where EV charging is more expensive and difficult to install.

Sustaining momentum on infrastructure deployment over the 2023 through 2025 timeframe will be important for meeting 2030 goals. Infrastructure programs can evolve from early geographic coverage toward increasing deployment in the counties that require the most chargers by 2030, including Denver, Jefferson, Arapahoe, Boulder, and Douglas. At the same time, state-level programs can continue to prioritize areas that are receiving relatively less private sector and utility investment. Colorado and its utilities could help reduce the costs of DC fast charging by adapting a sliding-scale tariff for DC fast chargers based on utilization rate.[42] Such reduced energy and demand charges for chargers with lower utilization rates will improve the business case and accelerate near- and mid-term public and private sector investments.

Widespread charging infrastructure deployment is critical to support mass-market EV adoption. Building codes that require a significant share of parking spaces in residential, multi-family, and commercial buildings to be fully "turn-key ready" and 100% of parking

41 Research finds that EV-ready building codes in San Francisco can reduce the costs of EV charging by about 65% to 75%. See Ed Pike, Jeffery Steuben, Evan Kamei, "Plug-In Electric Vehicle Infrastructure Cost-Effectiveness Report for San Francisco," (Energy Solutions, Pacific Gas and Electric Company, 2017), https://evchargingpros.com/wp-content/uploads/2017/04/City-of-SF-PEV-Infrastructure-Cost-Effectiveness-Report-2016.pdf.

42 Garrett Fitzgerald and Chris Nelder, "DCFC Rate Design Study" (Rocky Mountain Institute, 2019), https://rmi.org/insight/dcfc-rate-design-study/.

spaces to be EV capable will support further growth. Continued collaboration with utilities, charging providers, and municipalities is needed to identify and fill charging gaps. If Colorado's EV infrastructure budget is limited, the state would ideally focus its financial support programs toward the locations and individuals that stand to benefit most, including low-income and pollution-burdened communities, communities that have not been prioritized by private sector and utility investments, and counties with the greatest charging gap as of 2020 (Figure 4). This analysis finds that Denver, Arapahoe, Jefferson, Boulder, and Douglas counties require the greatest infrastructure investment through 2030, from approximately $68 million to $124 million in cumulative costs.

The pace and scale of EV penetration vary across Colorado. While EVs and their infrastructure grow in unison, a critical first step in infrastructure planning is ensuring sufficient deployment that provides the necessary basic spatial geographic coverage. Therefore, less-dense regions may require faster build-out in the early stages of the transition, and somewhat slower growth once that need is met. This could be achieved by ensuring the early public investments prioritize basic spatial geographic coverage across all Colorado counties. With continued EV market growth, charging demand in urban areas and along major corridors will far surpass the capabilities of the initial stations. Planning for new public chargers will need to shift toward ensuring adequate charging capacity at the most popular locations. To do so, additional public funding could be directed toward supporting greater deployment of more chargers at more locations in urban areas and major corridors.

Continued data collection for key metrics including EV sales and stock, the number and type of public chargers deployed, and the availability of home charging can help guide state and local charging infrastructure strategies. Tracking infrastructure deployment and comparing progress with the number needed in each county by 2025 and 2030 (see Appendix Table F1) can reveal relative gaps and locations to prioritize increased public investment. More broadly, as the EV market and its infrastructure evolve, these metrics can be compared to those of similar states and cities that are at different stages of market growth to evaluate the relative need and type of additional infrastructure.[43]

This research points to several rich areas for future study. This analysis of EV sales and stock assumes that the counties with the greatest EV market success through 2019 continue to lead; analyzing an alternative scenario such that all counties reach the same statewide EV sales share has important implications for infrastructure distribution across Colorado and could help guide its deployment in a more geographically equitable manner. Additionally, deeper analysis into the broader transportation patterns across the state regarding origins and destinations by county and the specific transportation and charging behavior patterns of EV drivers could help additional local and regional planning efforts identify and fill potential charging gaps. Reexamining and updating Colorado's infrastructure planning based on the latest market trends is warranted as goals toward EV and infrastructure growth progress. Further analysis into regional EV power demand and grid capacity would support regional and utility planning. State-level infrastructure planning would ideally be aligned with regional and local efforts based on the latest data and market trends and identify the opportunity for state and local infrastructure policy support to complement one another. More thorough investigation and compilation of the broader infrastructure developments underway by Colorado utilities, private sector stakeholders, and municipalities could help reveal key gaps for the public sector to fill.

43 Dale Hall and Nic Lutsey, *Charging infrastructure in cities: Metrics for evaluating future needs,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/EV_charging_metrics_aug2020.

Appendix A. Analysis of EV sales shares, stock, and fleet stock turnover

We develop an EV sales curve using the logistic growth pattern with the 2020 to 2025 segment replaced with an exponential curve. The underlying logistic curve goes through two points: the EV sales percentage in 2019 and either a) 70% for the high-growth scenario, or b) 42.5% for the low-growth scenario by 2030. The logistic growth rate is determined such that EV sales shares reach 100% by 2040 and 70% in 2030 under the high-growth scenario. This same logistic growth rate is then used in the low-growth scenario. The 2020 to 2025 segment of the curve is replaced with an exponential curve, which is determined based on the recorded EV sales percentage in 2019 and the projected percentage in 2026 based on the logistic growth. This hybrid growth curve provides the annual EV sales as inputs to the vehicle stock turnover model which calculates the annual EV stocks based on the vehicle survival rate at different ages, as shown in Table A1. Table A2 and Table A3 show the EV sales and stock projections statewide from 2020 to 2030 in the high-growth (70% EV sales by 2030) and low-growth (42.5% EV sales by 2030) scenarios.

Table A1. Vehicle survival rate by vehicle age.

Age	Survival rate	Age	Survival rate	Age	Survival rate	Age	Survival rate
1	100%	**11**	82%	**21**	14%	**31**	6%
2	100%	**12**	73%	**22**	13%	**32**	5%
3	100%	**13**	64%	**23**	12%	**33**	4%
4	100%	**14**	55%	**24**	12%	**34**	4%
5	100%	**15**	47%	**25**	11%	**35**	3%
6	100%	**16**	40%	**26**	10%	**36**	3%
7	100%	**17**	34%	**27**	9%		
8	99%	**18**	29%	**28**	8%		
9	94%	**19**	24%	**29**	7%		
10	89%	**20**	16%	**30**	6%		

Table A2. Number of EV sales in Colorado used in this analysis.

Year	High-growth scenario			Low-growth scenario		
	BEV	PHEV	EV	BEV	PHEV	EV
2020	9,226	2,414	11,640	8,614	2,164	10,778
2021	12,988	3,440	16,428	11,319	2,764	14,083
2022	18,283	4,901	23,184	14,872	3,530	18,402
2023	25,735	6,984	32,719	19,537	4,508	24,045
2024	36,224	9,950	46,174	25,661	5,757	31,418
2025	50,987	14,177	65,164	33,700	7,353	41,053
2026	71,763	20,200	91,963	44,252	9,391	53,643
2027	92,212	26,276	118,488	56,114	11,583	67,697
2028	114,286	32,968	147,254	70,121	14,082	84,203
2029	136,475	39,857	176,332	86,171	16,838	103,009
2030	157,277	46,504	203,781	103,957	19,767	123,724

Table A3. Colorado EV stock projections used in this analysis.

Year	High-growth scenario			Low-growth scenario		
	BEV	PHEV	EV	BEV	PHEV	EV
2020	28,245	11,663	39,908	27,632	11,413	39,045
2021	41,160	15,021	56,181	38,879	14,095	52,974
2022	59,314	19,792	79,106	53,622	17,494	71,116
2023	84,833	26,578	111,412	72,943	21,805	94,748
2024	120,715	36,239	156,954	98,261	27,273	125,534
2025	171,156	50,019	221,174	131,416	34,228	165,644
2026	242,059	69,694	311,753	174,808	43,095	217,903
2027	332,979	95,311	428,290	229,638	54,023	283,661
2028	445,337	127,435	572,772	297,882	67,282	365,164
2029	578,973	166,209	745,181	381,371	83,099	464,470
2030	732,131	211,309	943,440	481,582	101,612	583,194

Appendix B. Assumptions on EV charging behavior

Table B1 shows the EV charging events per day based on EV technology (battery electric vehicle [BEV] and plug-in hybrid electric vehicle [PHEV]), commuting behavior, and home charger access. We assume the charging events per day at each type of charger holds constant across all analysis years. Table B2 shows the energy transferred per charging event at each type of charger based on the EV technology. The energy per event gradually changes each year at the inverse of the rate the fleetwide efficiency changes, as explained in Appendix C.

Table B1. EV charging events per day at home, workplace, public Level 2, and DC fast chargers based on EV driver topography.

EV driver topology	Home	Workplace	Public Level 2	DC fast
PHEV commuter, No home charger	0.00	0.59	0.10	0.00
BEV commuter, No home charger	0.00	0.38	0.03	0.13
PHEV commuter, Access to home Level 1	0.70	0.48	0.05	0.00
BEV commuter, Access to home Level 1	0.38	0.32	0.05	0.09
PHEV commuter, Access to home Level 2	0.76	0.44	0.06	0.00
BEV commuter, Access to home Level 2	0.50	0.27	0.04	0.04
PHEV non-commuter, No home charger	0.00	0.00	0.52	0.00
BEV non-commuter, No home charger	0.00	0.00	0.23	0.32
PHEV non-commuter, Access to home Level 1	0.70	0.00	0.26	0.00
BEV non-commuter, Access to home Level 1	0.48	0.00	0.10	0.06
PHEV non-commuter, Access to home Level 2	0.74	0.00	0.14	0.00
BEV non-commuter, Access to home Level 2	0.46	0.00	0.09	0.03

Table B2. EV charging energy per charging event (in kWh) in 2019.

Type	Home	Workplace	Public Level 2	DC fast
PHEV	6.5	7.5	5.3*	--
BEV	11.5	15.5	8.9*	11.7*

Note: Public Level 2 and DC fast data is based on charging session data provided by Colorado Energy Office

Appendix C. Fleetwide efficiency projections

We assume the 2020 light-duty EV energy efficiency is 3.4 miles per kWh for electric passenger cars and 2 miles per kWh for electric light-duty trucks and SUVs. Assuming the EV efficiency improves 0.6% a year, we calculate the fleetwide efficiency as the weighted average efficiency based on the electric personal car sales to electric light-duty truck and SUV sales ratio adapted from projections provided to the state by Navigant. Table C1 shows the projections of EV efficiencies and fleetwide efficiency.

Table C1. Electric vehicle energy efficiency projections.

Year	Passenger car efficiency (mi per kWh)	Passenger truck and SUV efficiency (mi per kWh)	Fleetwide efficiency (mi per kWh)	Ratio of electric passenger car sales to electric passenger truck and SUV sales
2020	3.40	2.00	3.21	6.48
2021	3.42	2.01	3.20	5.31
2022	3.44	2.02	3.17	4.28
2023	3.46	2.04	3.07	2.67
2024	3.48	2.05	2.93	1.59
2025	3.50	2.06	2.71	0.82
2026	3.52	2.07	2.63	0.62
2027	3.55	2.09	2.58	0.51
2028	3.57	2.10	2.60	0.51
2029	3.59	2.11	2.61	0.51
2030	3.61	2.12	2.63	0.51

Appendix D. EV charger utilization projections

We base the initial 2019 charger utilization in the analysis on real charging session data collected from the chargers funded through the Charge Ahead Colorado program. The dataset is provided by the Colorado Energy Office and recorded over 100 thousand charging sessions from July 2019 to the end of 2019. The dataset includes the charging session duration, the amount of energy transferred, and additional data points. Using the dataset, we estimate the average daily utilization rates of the public chargers in Colorado in 2019 was 3.95 hours per day for DC fast chargers and 1.2 hours per day for public Level 2.

From the estimates of 2019 charger utilization rates, we extrapolate future utilization for each county based on the growth in EV stock per million capita for each year. The function is based on the observed early market relationships between EVs per capita and the number of EVs per public charger. These relationships are assessed for both EVs per public charger and BEVs per DC fast charger and are based on an analysis of observed U.S. EV markets in 2017 with updates for 2019.[44] Charger utilization in each county increases based on the number of EVs per capita registered in each county from 2020 through 2030. Increases in charger utilization follow a logarithmic pattern as a function of EV penetration, normalized to the Colorado Energy Office 2019 base utilization data.

The average daily energy a charger can provide is projected by combining the utilization rate with the average charging power. Average charging power increases from the 2019 recorded values based on the same dataset mentioned above (i.e., 4.6 kW for Level 2 and 26.4 kW for DC fast) to assumed values in 2035 (i.e., 8 kW for Level 2 and 130 kW for DC fast) in a logarithmic manner. Table D1 below shows an example for the statewide average charger utilization rates and average energy per day in the high growth scenario of 70% EV sales by 2030 for illustrative purpose only; each county has its own utilization and average daily energy rates that are based on the relative EV stock in each county.

44 Michael Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-gap-US; Anh Bui, Peter Slowik, and Nic Lutsey, *Update on electric vehicle adoption across U.S. cities*, (ICCT: Washington, DC, 2020), https://theicct.org/publications/ev-update-us-cities-aug2020

Table D1. Average Colorado statewide EV charger utilization and energy rates.

Year	Utilization (hours/day)	Power (kW)	Energy (kWh/day)	Utilization (hours/day)	Power (kW)	Energy (kWh/day)
2019	4.0	4.6	18.1	1.2	26	32
2020	4.3	4.6	19.7	1.4	26	36
2021	4.7	5.4	25.3	1.5	52	80
2022	5.0	5.9	29.7	1.7	67	114
2023	5.4	6.3	33.7	1.8	78	144
2024	5.7	6.6	37.5	2.0	87	172
2025	6.1	6.8	41.1	2.1	93	199
2026	6.4	7.0	44.7	2.3	99	226
2027	6.7	7.1	48.1	2.4	104	251
2028	7.0	7.3	51.2	2.5	108	275
2029	7.3	7.4	54.1	2.6	112	297
2030	7.5	7.5	56.7	2.7	116	318
2031	7.7	7.6	59.1	2.8	119	337
2032	7.9	7.7	61.3	2.9	122	354
2033	8.1	7.8	63.3	3.0	125	371
2034	8.2	7.9	65.1	3.0	128	386
2035	8.3	8.0	66.7	3.1	130	399

Appendix E. Analysis of corridor charging needs

To estimate the corridor charging need, we use the Colorado Highway Traffic Counts data to calculate the light-duty vehicle miles for each highway segment as the product of the annual average daily traffic count and the highway length in miles. The light-duty vehicle miles are converted to energy in kWh based on the given year's fleetwide EV efficiency (see Appendix C). Since only BEVs charge from DC fast chargers, we include only BEV travels and the associated charging demand by multiplying the total energy by the projected percentage of BEV in the light-duty vehicle fleet. Finally, we find the corridor DC chargers as the product of the BEV charging demand (in kWh) and the percentage of the BEV charging energy at DC fast chargers in the given year (see Appendix B) divided by the statewide average daily energy supplied by a DC fast charger (see Appendix D). Finally, we exclude highway segments passing through urban areas (Figure E1), determined as those where the majority of the land within a quarter-mile of either side of the highway is classified as developed (classifications 21 to 24) in the National Land Cover Database. We exclude these segments because the charging demand at these locations can be fulfilled by the DC fast stations that do not primarily serve corridor travel—those are projected based on the method described in the "Charger need" section in the report.

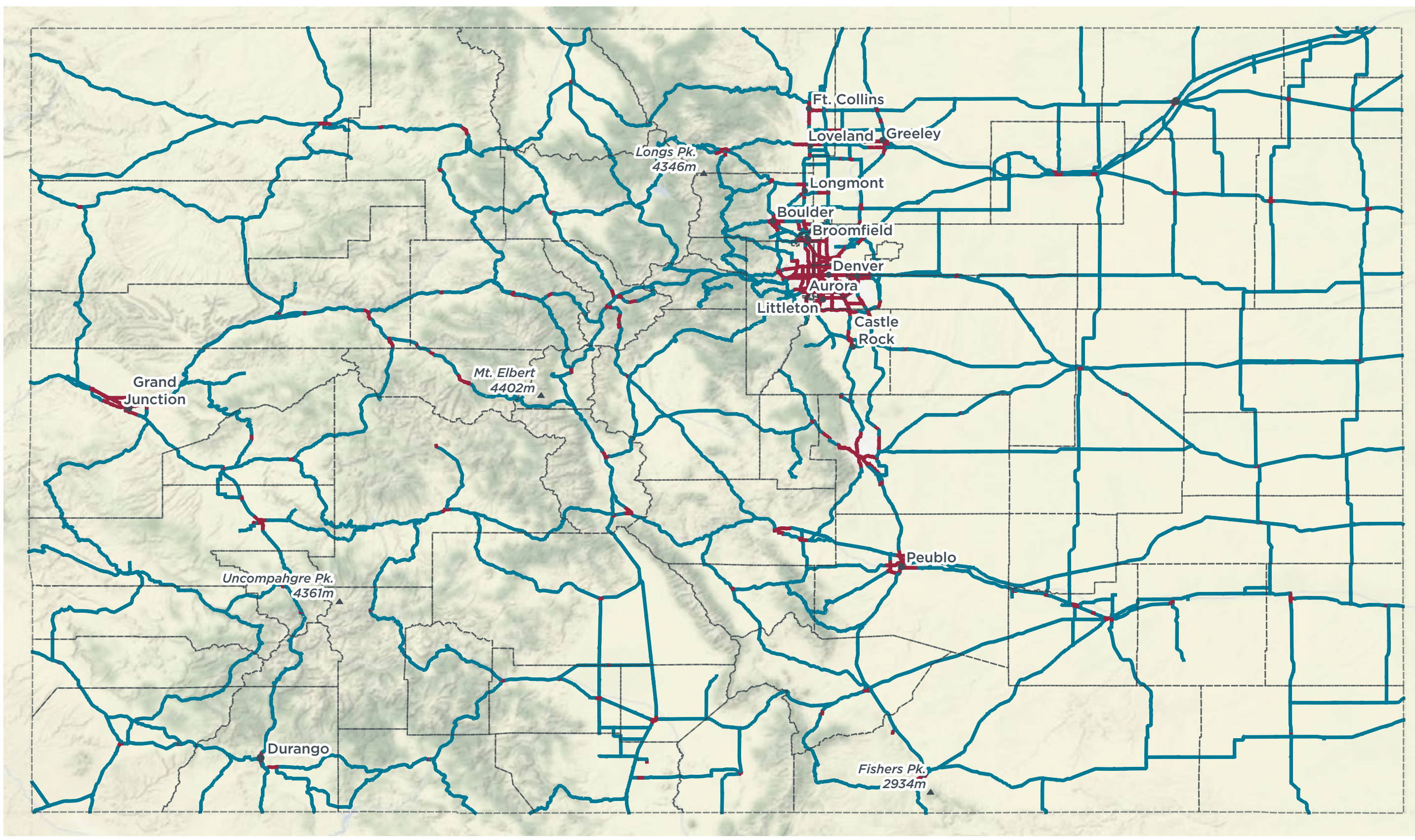

Figure E1. Highway segments and the surrounding area; developed or urban (red) and non-developed (blue). Data obtained from National Land Cover Database (accessed October 2020), https://www.mrlc.gov/data/nlcd-2016-land-cover-conus

Appendix F. Colorado county-level charger needs in 2030

Table F1 shows the high-growth scenario EV charger projections by county in 2025 and 2030. Table F2 shows the low-growth scenario EV charger projections by county in 2025 and 2030.

Table F1. High-growth scenario Colorado county-level EV charger projections.

County	Home		Workplace		Public Level 2		DC fast non-corridor		DC fast corridor	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Adams	5,897	26,427	717	3,400	415	1,403	94	292	21	56
Alamosa	70	333	4	21	4	13	0	0	3	8
Arapahoe	11,674	50,376	1,308	5,981	735	2,467	200	604	10	26
Archuleta	32	126	2	9	2	6	0	0	3	7
Baca	15	68	1	4	1	2	0	0	1	3
Bent	20	93	2	7	1	4	0	0	1	3
Boulder	16,040	51,379	1,420	4,715	710	1,918	177	407	18	48
Broomfield	2,139	9,705	238	1,127	123	443	29	94	6	16
Chaffee	111	506	7	31	5	18	0	0	4	9
Cheyenne	7	31	0	2	0	1	0	0	1	3
Clear Creek	681	2,188	82	262	35	90	0	0	11	30
Conejos	25	106	2	9	2	5	0	0	2	4
Costilla	18	83	1	6	1	3	0	0	2	4
Crowley	14	61	1	6	1	3	0	0	1	2
Custer	28	111	3	12	2	6	0	0	1	2
Delta	167	737	17	72	11	34	0	0	4	11
Denver	16,871	72,278	1,723	7,855	989	3,390	282	857	0	0
Dolores	16	66	1	4	1	2	0	0	1	2
Douglas	10,029	43,812	1,111	5,004	546	1,852	121	367	27	72
Eagle	1,221	5,176	124	575	71	239	7	26	13	35
Elbert	530	2,511	95	464	42	149	7	23	4	11
El paso	7,580	33,172	672	2,941	429	1,436	83	249	30	80
Fremont	113	450	11	42	8	24	0	0	5	12
Garfield	573	2,591	77	354	45	151	0	0	15	40
Gilpin	141	577	24	98	10	32	1	3	2	4
Grand	183	768	17	73	11	34	0	0	5	13
Gunnison	179	714	11	43	8	25	0	0	4	10
Hinsdale	7	22	0	1	0	1	0	0	1	1
Huerfano	28	113	2	9	2	5	0	0	5	12
Jackson	6	27	1	3	0	1	0	0	1	3
Jefferson	12,353	52,752	1,377	6,100	723	2,395	173	512	25	67
Kiowa	6	26	0	1	0	1	0	0	1	3
Kit Carson	29	133	2	7	1	4	0	0	4	11
Lake	27	119	3	14	2	7	0	0	2	4
La Plata	707	3,253	59	271	35	122	1	5	8	20

County	Home		Workplace		Public Level 2		DC fast non-corridor		DC fast corridor	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Larimer	8,714	39,498	798	3,648	420	1447,	78	238	27	71
Las Animas	27	107	2	8	2	5	0	0	4	10
Lincoln	16	76	1	5	1	3	0	0	4	10
Logan	82	372	6	26	5	15	0	0	5	12
Mesa	957	4,239	73	328	50	164	1	0	10	27
Mineral	5	18	0	1	0	1	0	0	1	3
Moffat	30	140	3	15	2	8	0	0	2	4
Montezuma	76	329	6	28	5	15	0	0	5	14
Montrose	129	562	9	40	8	24	0	0	4	9
Morgan	59	265	5	22	4	13	0	0	5	12
Otero	38	165	3	12	2	7	0	0	3	6
Ouray	73	291	8	30	4	12	0	0	2	4
Park	199	870	31	138	15	50	0	0	5	13
Phillips	16	74	1	5	1	3	0	0	1	2
Pitkin	1,134	3,043	81	215	44	95	10	14	3	8
Prowers	47	215	3	12	2	7	0	0	2	4
Pueblo	561	2,373	48	203	36	109	0	0	14	38
Rio Blanco	29	118	2	9	2	5	0	0	2	5
Rio Grande	26	110	2	8	2	5	0	0	3	6
Routt	236	1,109	18	84	13	43	1	3	3	8
Saguache	50	183	4	13	2	7	0	0	2	6
San Juan	48	146	2	5	1	3	0	0	1	2
San Miguel	160	707	12	50	7	24	0	1	2	5
Sedgwick	9	42	1	3	1	2	0	0	2	4
Summit	612	2,809	45	217	29	90	0	0	8	22
Teller	126	509	15	60	10	29	0	0	4	9
Washington	20	92	2	9	1	4	0	0	4	11
Weld	3,842	17,489	422	1,954	239	810	22	76	40	109
Yuma	28	126	2	8	2	5	0	0	2	4

Table F2. Low-growth scenario Colorado county-level EV charger projections.

County	Home		Workplace		Public Level 2		DC fast non-corridor		DC fast corridor	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Adams	4,402	15,723	532	2005	327	901	76	196	17	40
Alamosa	48	178	3	11	3	7	0	0	3	6
Arapahoe	8,773	30,260	977	3580	579	1,585	161	407	8	19
Archuleta	24	70	2	5	2	4	0	0	3	5
Baca	10	38	1	2	1	1	0	0	1	2
Bent	14	49	1	4	1	2	0	0	1	2
Boulder	12,178	39,268	1072	3620	558	1,491	142	346	15	34
Broomfield	1,600	5,886	177	685	96	285	23	65	5	11
Chaffee	81	298	5	19	4	11	0	0	3	6
Cheyenne	5	17	0	1	0	1	0	0	1	2
Clear Creek	516	1,702	62	208	27	72	0	0	9	21
Conejos	18	58	2	5	1	3	0	0	2	3
Costilla	12	47	1	4	1	2	0	0	2	3
Crowley	10	35	1	3	1	2	0	0	1	1
Custer	21	64	2	7	2	4	0	0	1	2
Delta	121	406	12	41	8	20	0	0	4	8
Denver	12,647	43,222	1284	4700	774	2,153	226	579	0	0
Dolores	12	40	1	3	1	1	0	0	1	2
Douglas	7,485	26,713	824	3048	427	1,199	96	252	22	51
Eagle	914	3,149	92	344	56	155	6	18	11	24
Elbert	393	1,471	70	268	33	94	5	15	4	8
El Paso	5,693	19,782	504	1785	340	915	67	169	24	56
Fremont	84	250	8	24	7	15	0	0	4	8
Garfield	427	1,547	57	213	35	97	0	0	12	28
Gilpin	106	334	18	57	8	20	0	2	2	3
Grand	139	459	13	44	8	22	0	0	4	9
Gunnison	137	419	8	26	6	15	0	0	3	7
Hinsdale	6	14	0	1	0	0	0	0	1	1
Huerfano	20	62	2	5	1	3	0	0	4	9
Jackson	4	15	0	2	0	1	0	0	1	2
Jefferson	9,260	31,517	1027	3647	568	1,526	139	346	20	47
Kiowa	5	15	0	1	0	1	0	0	1	2
Kit Carson	21	75	1	4	1	3	0	0	4	8
Lake	19	64	2	8	2	4	0	0	2	3
La Plata	520	1,883	43	158	28	76	1	2	6	15
Larimer	6,452	23,089	588	2137	327	901	62	159	22	50
Las Animas	20	60	2	5	2	3	0	0	3	7
Lincoln	11	42	1	3	1	2	0	0	3	7
Logan	59	209	4	15	4	9	0	0	4	9
Mesa	700	2,363	53	183	39	99	1	0	8	19

County	Home		Workplace		Public Level 2		DC fast non-corridor		DC fast corridor	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Mineral	3	11	0	1	0	0	0	0	1	2
Moffat	20	72	2	8	2	4	0	0	2	3
Montezuma	54	173	5	15	4	9	0	0	5	10
Montrose	97	324	7	23	6	15	0	0	3	6
Morgan	41	132	3	11	3	7	0	0	4	9
Otero	26	85	2	6	2	4	0	0	2	4
Ouray	55	166	6	18	3	8	0	0	2	3
Park	145	489	23	78	12	31	0	0	4	9
Phillips	12	42	1	3	1	2	0	0	1	2
Pitkin	864	2,509	62	180	34	79	7	14	3	6
Prowers	34	121	2	7	2	4	0	0	2	3
Pueblo	418	1,362	36	117	29	69	0	0	12	27
Rio Blanco	22	67	2	5	1	3	0	0	2	3
Rio Grande	19	60	1	4	1	3	0	0	2	4
Routt	177	666	13	51	10	27	0	1	3	6
Saguache	39	109	3	8	2	4	0	0	2	4
San Juan	36	110	1	4	1	2	0	0	1	1
San Miguel	123	426	9	31	6	15	0	0	2	4
Sedgwick	6	24	0	2	0	1	0	0	1	3
Summit	454	1,660	33	125	22	58	0	0	7	16
Teller	98	316	12	39	8	20	0	0	3	7
Washington	14	52	1	5	1	3	0	0	4	8
Weld	2,896	10,365	316	1157	191	519	18	50	33	77
Yuma	19	66	1	4	1	3	0	0	2	3

Appendix G. Colorado charging infrastructure cost projections

Table G1 shows the annual infrastructure capital cost needed, including hardware, labor, materials, permitting, and taxes, for the projected charging infrastructure from 2021 to 2030 under the high EV growth scenario.

Table G1. Colorado charging infrastructure annual capital cost projection, in million $.

	Home	Workplace	Public Level 2	DC fast	Total
2021	$5.1	$2.6	$1.0	$3.8	**$12.5**
2022	$7.2	$3.7	$2.2	$6.1	**$19.2**
2023	$10.1	$5.2	$3.5	$9.9	**$28.8**
2024	$14.2	$7.4	$5.2	$16.2	**$42.9**
2025	$20.0	$10.3	$8.0	$26.3	**$64.7**
2026	$28.2	$14.9	$9.8	$32.8	**$85.8**
2027	$36.3	$19.6	$11.8	$40.9	**$108.6**
2028	$44.9	$24.8	$12.9	$51.0	**$133.6**
2029	$53.5	$30.2	$14.6	$63.6	**$162.0**
2030	$61.5	$35.2	$16.1	$79.4	**$192.2**