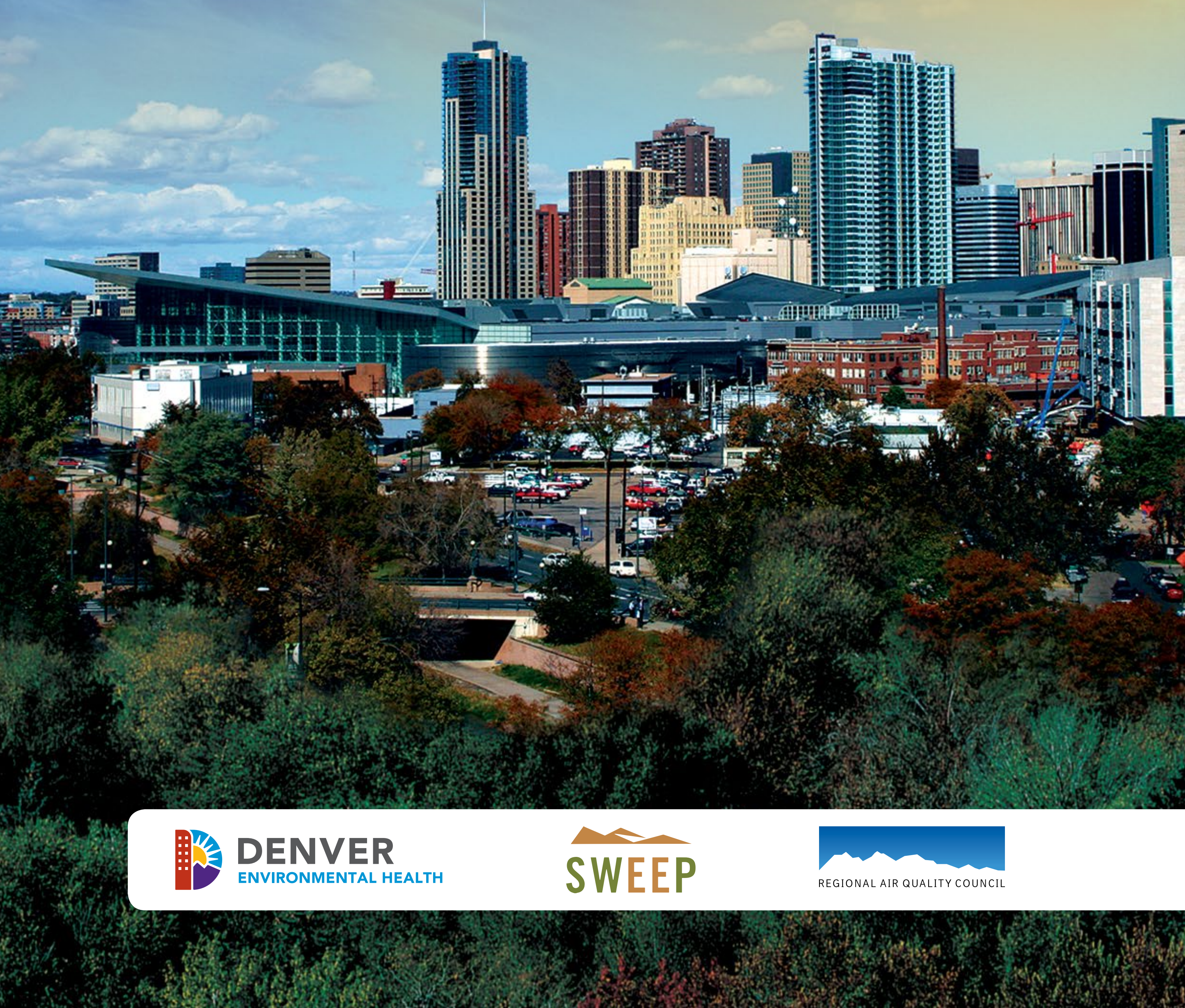
Opportunities for Vehicle Electrification in the Denver Metro area and Across Colorado

Overcoming Charging Challenges to Maximize Air Quality Benefits



DENVER ENVIRONMENTAL HEALTH

SWEEP

REGIONAL AIR QUALITY COUNCIL

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Contents

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List of Acronyms

ADA	Americans with Disability Act
BEV	Battery Electric Vehicle
BLAST-V	Battery Lifetime Analysis and Simulation Tool for Vehicle Applications
C2ES	Center for Energy and Climate Solutions
CAC	Charge Ahead Colorado
CARB	California Air Resources Board
CCS	Combo Charging System
CEC	California Energy Commission
CEO	Colorado Energy Office
CMAQ	Congestion Mitigation and Air Quality
CPUC	California Public Utilities Commission
DEN	Denver International Airport
DCFC	DC Fast Charging
DOE	U.S. Department of Energy
DRCOG	Denver Regional Council of Governments
EPA	U.S. Environmental Protection Agency
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
GM	General Manager
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Trans-portation
HOA	Home Owner's Association
ICCT	International Council on Clean Transportation
IOU	Investor-Owned Utility
kVa	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
LADWP	Los Angeles Department of Water and Power
LED	Light Emitting Diodes
MPGE	Miles per Gallon Equivalent
MW	Megawatt
NO_x	Nitrogen Oxides
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PEV	Plug-in Electric Vehicle
PG&E	Pacific Gas and Electric
PHEV	Plug-in Hybrid Electric Vehicle
PUC	Public Utilities Commission
PV	Photovoltaic
RAQC	Regional Air Quality Council
RMI	Rocky Mountain Institute
RTD	Regional Transportation District
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SWEEP	Southwest Energy Efficiency Project
TDM	Transportation Demand Management
TNC	Transportation Network Company
VOC	Volatile Organic Compound
WCEH	West Coast Electric Highway

Executive Summary

The City and County of Denver has set aggressive goals for reducing greenhouse gas emissions and energy consumption while improving air quality in both its 2015 Climate Action Plan and Sustainability 2020 Goals. The adoption of plug-in electric vehicles (PEVs) is expected to play an important part in meeting those goals, as transportation emissions are the second largest contributor in Denver's greenhouse gas portfolio. In addition, the entire metropolitan region faces significant challenges in meeting federal ozone standards and increased adoption of PEVs plays an important role in reducing ozone precursors. To maximize the health and environmental benefits of PEVs, Denver plans to double the PEV growth rate between now and 2020 by leveraging the findings in this analysis.

PEV adoption rates in Colorado have been growing rapidly, with 43 percent growth in 2016 PEV sales compared to 2015, and a 48 percent increase in sales in the first quarter of 2017 compared to the same period in 2016. In order to achieve the medium growth scenario (where five percent of vehicles on the road in 2030 are PEVs) identified by the Colorado Energy Office's Electric Vehicle Market Implementation Study, Colorado will need to maintain an annual growth rate of over 40 percent.

The following report examines some of the major barriers to higher PEV adoption rates in Denver such as a lack of DC fast charging (DCFC) stations statewide and the difficulty of providing access to charging for residents of multi-family housing. Steps to address these barriers are also identified. The report also analyzes the emissions benefits of PEVs charging on Colorado's Xcel Energy's grid compared to gasoline vehicles.

DC Fast Charging

Current DCFC stations allow PEV owners to recharge their vehicles relatively quickly, adding about 50 miles of range in about 20 minutes. Higher power DCFC stations, which are beginning to enter the market, will provide even faster recharging.

A well-planned network of DCFC stations will provide PEV owners the ability to make longer trips and reduce range anxiety. A survey conducted for this report indicates that over 80 percent of PEV owners in Colorado feel limited in their PEV use due to lack of public charging.

> *Colorado PEV drivers feel limited due to lack of public charging*

PEV owners want fast charging along interstates and in the mountains.

Making longer PEV trips more convenient should also increase sales of PEVs in Colorado as higher levels of DCFC correlates with higher levels of PEV adoption. The top locations identified by PEV owners for fast charging stations were along the interstate corridors and at recreational destinations in the mountains.

In concert with this report, the National Renewable Energy Laboratory (NREL) has done research using their Battery Lifetime Analysis and Simulation Tool for Vehicles (BLAST-V) model to identify locations for DCFC stations, across the state and the potential utilization of these stations.

Due to the high costs to install and operate these stations and their utilization rates at current levels of PEV adoption (which lead to insufficient revenue generation), it is difficult for a DCFC station host to cover the costs of acquiring, installing and operating a station. Figure ES-1 shows that at current utilization rates, DCFC stations in urban areas and along highways struggle to recover their operating costs without even including the capital and installation expenses. Significant expansion of the DCFC network in Colorado likely requires that, at a minimum, much of the capital cost of stations be covered by public sources. This report finds that the full costs for future-proofed stations with two fast chargers and

Significant expansion of the DCFC network likely requires greater public funding

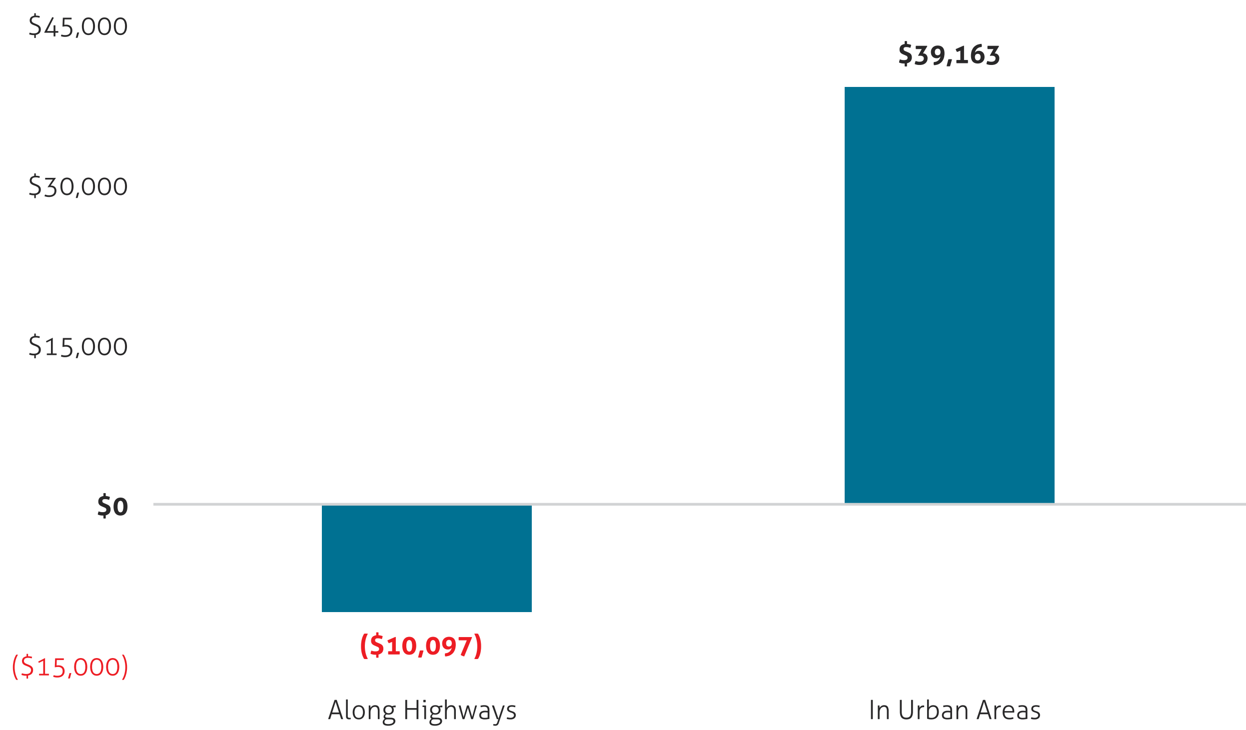

Figure ES-1. Total Revenue Minus Total Operating Costs After Ten Years of Operation from a DCFC Station

a co-located Level 2 station range from approximately $170,000 in urban areas to $200,000 along highway corridors.

A significant cost associated with operating a DCFC station are demand charges which may make up approximately 80 percent of the electrical bill incurred by these stations. Variances in demand charges at utilities across the state can lead to identical DCFC stations having differences of tens of thousands of dollars in their annual electrical bills. Working with utilities to find creative ways to reduce or eliminate demand charges while still allowing them to recover costs will be critical to improving the business model for DCFC stations. A number of utilities in other states have adopted new tariffs that charge higher time of use energy charges and reduce or eliminate demand charges for DCFC stations.

> *Reducing or eliminating demand charges will be critical to improving the business model for DCFC stations*

Multi-Family

Most PEV charging takes place at home, so the availability of home charging is critical to PEV adoption. Fourty-four percent of Denver residents live in multi-family housing and without access to charging at their homes these residents will be unlikely to purchase a PEV. Charging simulations done by NREL show the provision of charging at multi-family residences increases electric vehicle travel more than a robust set of urban DCFC stations which shows the critical importance of home-based charging. Providing people who live in multi-family buildings access to charging stations at their residences has proven to be a significant challenge. Owners of condominiums may struggle to convince Home Owner Association (HOA) boards and members to pay for electrical infrastructure upgrades to support charging stations in common parking areas. Due to the temporary nature of residency, apartment dwellers and building owners may be reluctant to invest in charging stations that may not be used in the future. The barriers faced by residents of lower income apartments are even greater as these buildings tend to lack extra amenities. Compared to a single-family home, the cost of retrofitting a multi-family property may be much more challenging and expensive due to panel upgrades, trenching and new wiring on top of the cost to purchase and install the charging station itself.

> *44 percent of Denver residents live in multi-family housing*

To address the inclusion of charging stations in new multi-family buildings (and other commercial properties), municipalities can adopt PEV Ready building codes that, at a minimum, require the provision of conduit or wiring between the electrical panel and the parking area and sufficient additional panel capacity for future charging stations. This significantly reduces the cost of installing stations in the future. It is recommended Denver adopt a policy to help move this part of the market in the right direction.

> *PEV Ready building codes will help get charging into new multi-family buildings*

Currently, the Charge Ahead Colorado (CAC) program provides grant funding that covers up to 80 percent (up to $6,260) of the cost of a Level 2 multi-port charging station. Due to the additional barriers existing multi-family buildings may face compared to public or workplace charging installations and the importance of access to charging at one's residence, it may make sense to increase the maximum funding for multi-family properties, especially apartment buildings.

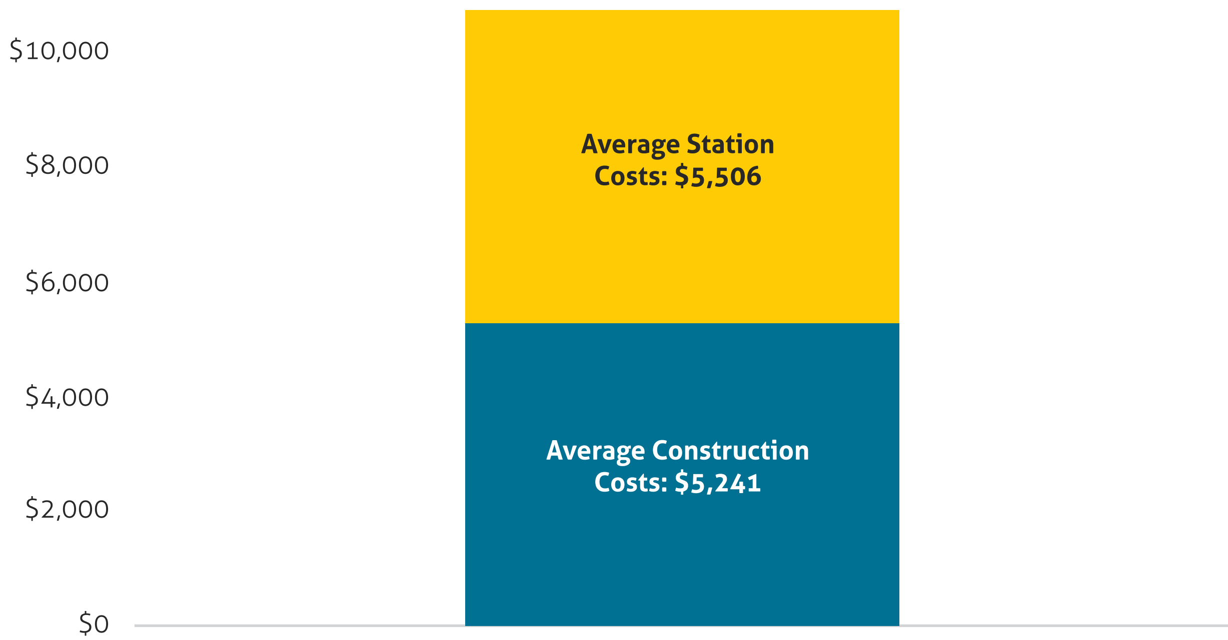

Figure ES-2. Average Costs for Multi-Family Projects Funded by Charge Ahead Colorado

Utilities can play an important role in addressing the need for more charging stations

Figure ES-2 breaks down the average retrofit costs compared to station costs for multi-family buildings which have received funding from the Regional Air Quality Council (RAQC) for charging station installations. The figure shows that the cost of the station makes up about half the cost of the total installation.

There is currently a lack of research on the financial benefits to building owners of adding charging stations to a multi-family property. Without data showing that the costs of installing charging stations can be recovered through higher rents, improved tenant retention or higher sales prices for properties, many building owners may be reluctant to make this type of investment.

In both the multi-family and DCFC areas, the engagement of electric utilities can be important to addressing the infrastructure demands of additional charging.

Air Quality Benefits

Based on an analysis by the study authors, PEVs provide significant environmental benefits when driven in the Denver metropolitan area. In 2016, a battery electric vehicle (BEV) reduced emissions of Nitrogen Oxides (NOx) by 38 percent, Volatile Organic Compounds (VOCs)

PEVs provide significant environmental benefits when driven in the Denver metropolitan area

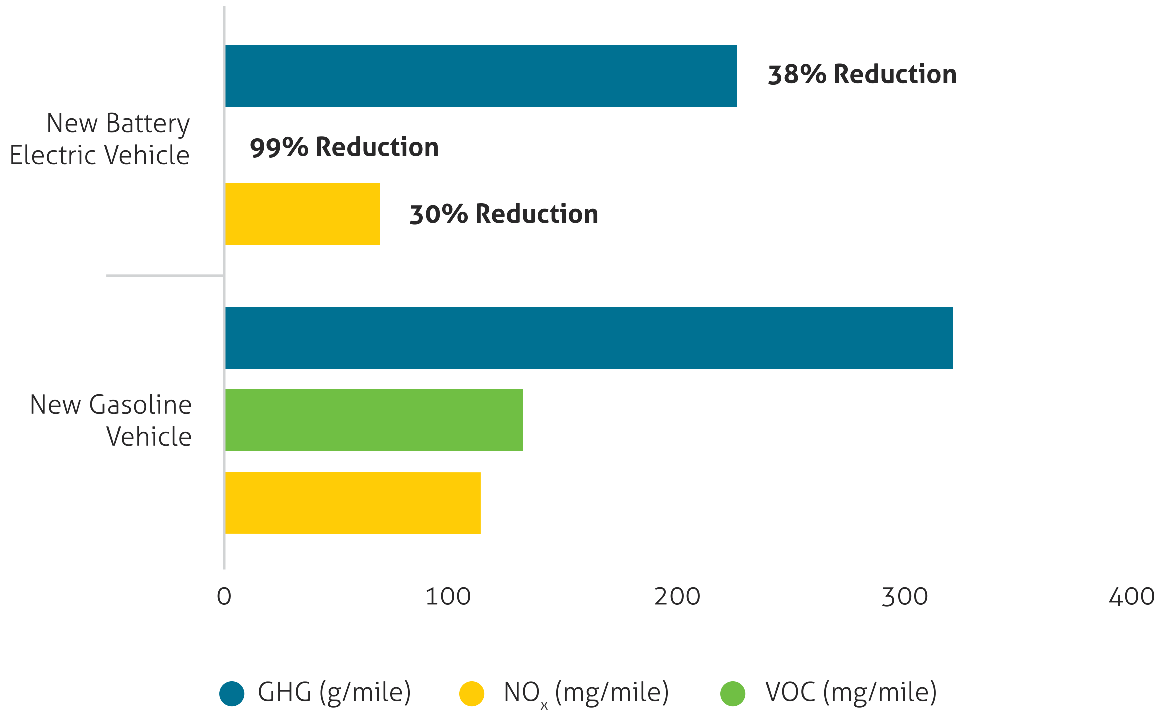

Figure ES-3. Emissions Comparison of New Vehicles in 2016

by 99 percent and greenhouse gas (GHG) emissions by 30 percent compared to a new gasoline vehicle.

Comparing a BEV to the average gasoline vehicle on the road gives even greater emissions benefits. NOx is reduced by 63 percent, VOCs by 99 percent and GHG by 43 percent.

Due to the replacement of electricity from coal by natural gas, solar and wind energy, the fuel source for existing and new PEVs will become even cleaner over time. While new gasoline vehicles will also reduce their emissions, the emissions benefits of PEVs will continue to improve over the next eight years. By 2025, a BEV will reduce NOx emissions by 84 percent, VOC emissions by 99 percent and GHG emissions by 49 percent compared to a new gasoline vehicle.

The GHG emissions from a BEV are the equivalent of a 47 MPG gasoline vehicle in 2016, and a 75 mpg vehicle with the 2025 electricity mix

The GHG emissions from a BEV are the equivalent of a 47 MPG gasoline vehicle in 2016, and a 75 mpg vehicle with the 2025 electricity mix.

The emissions of NOx and VOCs from Denver's light-duty vehicles play a significant role in the high levels of ground level ozone the region experiences. More PEVs on the road can play an important part in improving air quality and the health of the region's citizens.

The following table summarizes the potential action items identified as part of this research that could contribute to lowering barriers to PEV adoption. It also indicates which parties are most important to taking these actions.

Table ES-1. Potential Actions to Promote DCFC Stations

Potential Actions	Impact	Impact Timeline	Potential Participants
Provide increased capital cost funding for new DCFC stations	High	Short-Term	RAQC, Colorado Energy Office (CEO)
Develop new funding to support the operating costs of DCFC stations	High	Short-Term	RAQC, CEO
Work with utilities to develop tariffs that limit the impact of demand charges on DCFC stations	High	Medium-Term	Denver, CEO, RAQC, Investor-owned utilities (IOUs), Municipal utilities, Cooperative utilities, Public Utilities Commission (PUC)
Engage with utilities to encourage them to invest in DCFC stations	High	Medium-Term	Denver, RAQC, CEO, IOUs, Municipal utilities, Cooperative utilities, PUC
Prioritize future-proofed new DCFC sites to allow for higher capacity charging in the future	Medium	Long-Term	RAQC, CEO
Prioritize modular new DCFC stations to allow for adding more capacity without the need for replacing hardware	Medium	Long-Term	RAQC, CEO

Table ES-2. Potential Actions to Promote Multi-Family Stations

Potential Actions	Impact	Impact Timeline	Potential Participants
Engage with utilities to encourage them to invest in charging at multi-family buildings	High	Medium-Term	Denver, RAQC, CEO, IOUs, Municipal utilities, Cooperative utilities, PUC
Consider raising cap for grant funding for existing multi-family housing	High	Short-Term	RAQC, CEO
Adopt building codes to make new and remodeled multi-family housing (and other commercial buildings) PEV Ready	High	Long-Term	Denver
Focus new urban DCFC and Level 2 stations in areas with high percentages of multi-family buildings	Medium	Medium-Term	Denver, RAQC, CEO
Initiate research into the impacts of charging stations on multi-family property values and tenant retention	Low	Medium-Term	Denver, RAQC, CEO

DC Fast Charging

Capital, Installation and Operating Costs & Funding Options

Current DCFC stations allow PEV owners to recharge their vehicles relatively quickly, adding about 50 miles of range in about 20 minutes.[1] Higher power DCFC stations, which are beginning to enter the market, will provide even faster recharging, and will allow fast charging of longer range vehicles.

A well-planned network of DCFC stations will provide BEV owners the ability to make longer trips and reduce concerns about running out of battery power. Making longer BEV trips more convenient should also increase sales of BEVs in Colorado.

DCFC stations located along highway corridors are especially important for long distance travel which currently may not be convenient or feasible. To date, nearly all the non-Tesla DCFC stations in Colorado are located in urban areas along the Front Range, making it difficult for BEV drivers to make any longer trips outside of the I-25 corridor between Fort Collins and Colorado Springs.

Key Findings

- DCFC stations have difficulty generating enough revenue to offset their operating costs, much less paying back their capital costs due to existing utilization rates and high demand charges.
- The capital cost for a new, future-proofed DCFC station in an urban area is approximately $170,000.
- The capital cost for a new, future-proofed DCFC station along an interstate highway is approximately $200,000.
- New DCFC stations may require increased public support to support their capital costs.
- A new funding source should be developed to offset the high operating costs of DCFC stations.
- New DCFC sites should be future-proofed to allow for higher capacity charging stations when these stations are available.
- New DCFC stations should be modular to allow for adding capacity without the need for replacing hardware.

[1] The DCFC section will generally only apply to battery electric vehicles and not plug-in hybrid electric vehicles. Due to their hybrid nature, PHEV owners do not experience the same range concerns as BEV owners and PHEVs are often not equipped to accept DCFC.

NREL has done an analysis of the locations for DCFC stations that maximize the electric range of BEV drivers along the Front Range. In addition, the limited number of DCFC in urban areas may not adequately address future needs, including as a potential approach to charging for residents of multi-family housing.

Due to the high costs of installing DCFC stations (especially if they are able to handle much higher levels of charging in the future) and the relatively low level of utilization these stations currently see (thus reducing revenue generating opportunities) some level of public funding will be necessary to support the installation of these stations. This section reviews the estimated costs of installing and operating future-proofed DCFC stations in Colorado in both urban areas and along major highway corridors and provides options for funding these stations.

Review of DC Fast Charging Station Capital and Installation Costs

A review of the most recent data and publications on the costs of installing a DCFC station showed a wide range of expenses for an average installation. Available data does suggest that the capital costs are higher for highway corridors (especially in rural areas), where the costs of obtaining the appropriate electrical service and upgrading equipment to the site may be significantly higher than in urban areas.

Capital and Installation Costs for Highway Corridor DCFC Stations

For the purposes of building out a highway (rather than urban) system of DCFC, the most relevant data came from work done on the West Coast Electric Highway and by the California Energy Commission. The West Coast Electric Highway (WCEH) provides the most comparable completed example of building out a network of highway based DCFC stations that would allow BEV owners to make long distance trips. In 2015, the Center for Energy and Climate Solutions (C2ES) put together an analysis of DCFC business models which included a summary of WCEH DCFC costs in Washington State from 2012.[2] The C2ES report did note that equipment costs have fallen since 2012 and for their own purposes assumed that a DCFC station would now be expected to cost around $35,000 per unit and for their analysis assumed these lower equipment costs.[3] Table 1-1 below breaks down the costs of major components from the WCEH and C2ES study.

Table 1-1. Capital and Installation Costs for DCFC Station Along Highways

Potential Actions	WCEH	C2ES
DCFC Station	$58,000	$35,000
Co-located Level 2 Station	$2,500	$2,500
Equipment Installation (Labor and Panel Upgrade)	$26,000	$26,000
Host Site Identification and Screening	$5,000	$5,000
Negotiation, Legal Review Execution of Lease	$6,000	$6,000
Utility Interconnection	$12,500-$25,000	$20,000
Total	**$109,500-$122,000**	**$94,500**

[2] Center for Climate and Energy Solutions. 2015. Business Models for Financially Sustainable EV Charging Networks. https://www.c2es.org/docUploads/business-models-ev-charging-infrastructure-03-15.pdf

[3] Center for Climate and Energy Solutions. 2015. Business Models for Financially Sustainable EV Charging Networks. https://www.c2es.org/docUploads/business-models-ev-charging-infrastructure-03-15.pdf

Table 1-2. CEC DCFC Stations Cost Estimates

Cost Component	Option 1	Option 2
Site Work (demo, concrete, mounting, signs)	$10,000	$15,000
Electric Work (wire, conduit)	$3,000	$5,000
New Transformer (300kVa/500kVa)	$32,500	$40,000
Extend Utility Service	$17,500	$17,500
Level 2 Charger (single port/dual port)	$7,500	$10,000
CHAdeMO DCFC single port (one/two)	$20,000	$40,000
Dual Protocol DCFC (one/two)	$35,000	$70,000
Subtotal	$125,550	$197,500
10% contingency	$12,550	$19,750
Total	**$138,050**	**$215,000**

The California Energy Commission (CEC) is currently providing financial support to entities that are installing DCFC stations along interstates and highways in California. The aim of the CEC's work is to fill in the current gaps in DCFC coverage along these highways, making long distance travel feasible for BEV drivers on these corridors.[4] The CEC proposed two potential site configurations (Option 1 and Option 2). Option 1's initial configuration allows for up to two fast chargers (along with a Level 2 station) to operate at the same time. The second option allows for four fast chargers to charge simultaneously. One important element of the CEC plan is that each location will be ready to add a 100 kW fast charger when these are commonly available. This site preparation consists of having enough additional transformer capacity to handle the load and running sufficiently sized conduit to an additional parking space. CEC plans to provide funding of $140,000 for sites following Option 1 and $215,000 for those following Option 2. For most areas, the CEC is planning to offer the full amount but in some of the more urban areas where there is likely to be higher utilization they expect the site host to provide a 25 percent match.

Desired Highway DCFC Site Characteristics

Below are the desired station characteristics and amenities outlined by the CEC that each station should ideally include.[5]

Location

"The site should be within one mile from a highway interchange. It should have appropriate paved parking and reasonable ingress/egress points, as well as sufficient available area to support multiple charging-only spaces."

Sufficient Parking Spaces

"In addition to having enough parking spaces to serve installed stations, additional spaces should be available to allow the addition of future stations."

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[4] California Energy Commission. 2015. Considerations for Corridor Direct Current Charging Infrastructure for California. www.energy.ca.gov/2015publications/CEC-600-2015-015/CEC-600-2015-015

[5] California Energy Commission. 2015. Considerations for Corridor Direct Current Charging Infrastructure for California. www.energy.ca.gov/2015publications/CEC-600-2015-015/CEC-600-2015-015.pdf

Facilities

"The site should ideally have 24-hour access to a well-maintained and illuminated restroom. The restroom should be supplied with municipal water and have a clean and operable drinking fountain."

Safety

"The site should have dusk-to-dawn area lighting and have a reasonable level of activity. The site must also have shelter for inclement weather."

Public Amenities

"At a minimum the site should supply basic amenities such as vending, snacks, or fast food. Full-service amenities such as restaurants or retail shopping within a reasonable walking distance are preferred."

This will be especially important for more isolated stations along highways as during the winter BEV owners will need a comfortable place to wait indoors while their vehicle charges.

Electric Power

"Access to existing, nearby 480 V three-phase power is preferable. The local grid must have adequate capacity to serve the site and all the chargers."

Note that along some corridors (for example, Highway 50 in Colorado), there are many locations where three phase power is not available. Three phase power is preferable, because to date most DCFC stations have been designed to use it. Three phase power provides higher levels of power at more consistent levels and it is more reliable. In these areas, there will be additional costs to install a single phase to three phase converter. One option along rural highways in areas lacking three phase power would be to use DCFC stations that are capable of using only single phase power. Siemens produces a single phase DCFC station, though it only operates at 24 kW and will take nearly twice as long to charge. It is possible to purchase equipment that converts single phase power to three phase power. One model that operates at around 50 kW costs approximately $13,000.[6]

Reliability

"The stations should be expected to have very limited amounts of down time and vendors and applicants for funding should be able to demonstrate a record of reliability with the equipment they are proposing. In addition to reliable stations, redundancy (or having multiple charge ports) is also important to minimize waiting time for those who need to charge."

Universal Access

"Any PEV driver with a major credit card (or a smart phone) should be able to use (and pay for) the stations without needing a membership or a subscription."

ADA Compliance

"All installations should comply with relevant ADA guidelines."

Capital and Installation Costs for Urban Area DCFC Stations

Between 2011 and 2013, over 100 DCFC stations were installed across the country in urban areas as part of the EV Project, an initiative supported by the US Department of Energy (DOE) and the private sector to significantly expand PEV charging in the US. In 2015, the Idaho National Laboratory published a review of costs of these charging stations.[7]

For installation costs, the report found that in the EV Project, the average cost for a DCFC station was $23,662 with a range between $8,500 and $50,820.

[6] Grainger. 2017. 100HP Phase Converter, 460V, Rotary. https://www.grainger.com/product/PHASE-A-MATIC-100-HP-Phase-Converter-3EEA9

[7] US Department of Energy. 2015. Costs Associated with Non-Residential Electric Vehicle Supply Equipment. http://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf

For single port DCFC stations (available in the market in 2015) the DOE report found that the cost ranged from $10,000 to $40,000. At the higher end of the spectrum the DCFC station would have higher amperage (allowing for multiple vehicles to charge at the same time). It would also allow for advanced data collection, would be networked and allow customers to purchase charging on site without being a member of the charging network.

Table 1-3. Department of Energy DCFC Cost Range

	Low	High
Installation Costs	$8,500	$50,820
Equipment Costs	$10,000	$40,000
Total	$18,500	$90,820

In 2014, the Rocky Mountain Institute (RMI) published an analysis that attempted to break down the various cost components of DCFC stations.

Table 1-4. RMI DCFC Cost Elements[8]

Cost Component	Low	High
Hardware	$12,000	$35,000
Electrician Materials	$300	$600
Electrician Labor	$1,600	$3,000
Other Materials	$100	$400
Other Labor	$5,000	$15,000
Transformer	$10,000	$25,000
Mobilization	$600	$1,200
Permitting	$50	$200
Installation Subtotal	$17,650	$45,400
Total	$29,650	$80,400

So far, for the small number of urban fast charging stations funded by Charge Ahead Colorado (four to date), installation costs (not including charging equipment) have averaged approximately $10,000 per station which corresponds with the low end of the above estimates. Based on national and Colorado-specific data, the range of installation costs falls between $10,000 and $50,000. The major cost drivers are the extent of the electrical work needed at the site, especially the need for updated electrical service (such as new transformers) and how much the site needs to be retrofitted. At the low end, sites will not require any major electrical system upgrades while at the higher end new wiring, panels and transformers will be necessary.

Assuming higher end networked equipment allowing dual protocol charging and multiple ports, the equipment cost for a new DCFC station is expected to be between $35,000 and $40,000. This corresponds with the approximate cost of currently available fast charging stations with both a CHAdeMO and a SAE Connector. If two stations are co-located at one site, the total estimated equipment costs would be $70,000. This brings the total cost for equipment and installation for a new urban DCFC station to between $45,000 and $85,000. For two co-located stations the total cost would be between $80,000 and $115,000.

Future-Proofing Stations for the Next Generation of DCFC Stations

While almost all DCFC stations today provide up to 50 kW of power, several industry leaders are moving in the direction of much more powerful charging stations. Future stations are expected to be able to charge at 350-400 kW which could add approximately 200 miles of range in around 10 minutes.[9]

[8] Agenbroad and Holland. 2014. Pulling Back the Veil on EV Charging Station Costs. http://blog.rmi.org/blog_2014_04_29_pulling_back_the_veil_on_ev_charging_station_costs

[9] Electrek. 2016. The first electric vehicle DC fast-charging station capable of 350 kW output breaks ground in California. https://electrek.co/2016/12/15/electric-vehicle-dc-fast-charging-station-in-us-breaks-ground-in-california/

One concept to build towards this level of charging is to have modular and future-proofed stations which avoid stranded investments. Stations installed now would be able to power today's vehicles at 50 kW. However, the same stations would be able to provide higher levels of power (up to 400 kW) as vehicles become capable of accepting these higher levels of power. Infrastructure can be scaled up to meet both higher vehicle throughput (extra charging ports) and higher capacity (additional modules to convert larger amounts of power from AC to DC). This modular system avoids the expense of having to remove old stations and install new stations in the future.

While future-proofing a site will incur additional expense during construction and installation, it is less expensive to take these steps during the initial installation than having to retrofit the site at a later date. At a minimum, sites should ensure that the transformer serving the stations has enough capacity to handle additional charging stations in the future. The level of additional charging and how much this additional upfront capacity will cost are two important considerations.

In the CEC's proposal for highway DCFC stations, they require that each site allow for an additional 100 kW of capacity beyond what the installed charging stations need. If two DCFC were installed today that would mean that the site would need the capacity for 200 kW of power. This level of future-proofing would likely require the station to be supplied by a 300 kVa transformer. The incremental cost of purchasing a 300 kVa transformer instead of the next smaller size of 225 kVa is estimated to only be around $2,600.

Table 1-5 below estimates the incremental cost of different sizes of three phase transformers larger than 300 kVa during initial construction.[10]

There are also likely additional costs to future-proofing a site for larger capacity stations such as the need for larger conduit and additional land needs. Future-proofing a DCFC station by installing a higher capacity transformer would further increase the installation costs. To be able to serve multiple 350-400 kW stations (which are expected to more common in the next few years) the station would need to have electrical service of 1,500 kVa. The estimated cost of this size transformer is $60,000.

While utilities often bear the initial cost for new transformers to serve new electrical load and then recover this cost through their rates, this may not be the situation when future-proofing sites. Some future proofing may be allowed but the host site may bear the costs of the upgrade.

For urban areas, this significant electrical work would likely push the installation costs towards the higher end

Table 1-5. Incremental Transformer Costs and Capacity

Size of Transformer Upgrade from 300 kVa	Incremental Cost	Estimated kW Available	# of Potential 400 kW stations
To 500 kVa	$8,481	385	0
To 750 kVa	$17,592	577	1
To 1,000 kVa	$28,703	769	1
To 1,500 kVa	$35,705	1,154	2
To 2,000 kVa	$51,189	1,538	3

[10] The incremental costs were taken from a number of public bids on transformers that covered a wide range of transformer sizes and types.

of the cost estimates. The larger transformer would also add about $35,000 to the expected cost, increasing the expected cost to approximately $170,000. For highway stations, CEC's Option 2 had assumed the installation of a 500 kVa transformer at a cost of $40,000. Upgrading to the 1,500 kVa transformer would add $20,000 to the cost estimate making the total estimated cost close to $200,000. At this high level of power provision it is unlikely that any site would have enough existing service to meet the future demand. Therefore all sites that want to provide this level of future capacity would need to invest in new transformers.

Operating Costs and Revenue from DCFC Stations

A key question is how much revenue can a DCFC station generate over its lifetime, and does this revenue allow the station owner/operator to cover operating and maintenance costs or to recoup the initial capital and installation costs?

The study authors have collected data from DCFC stations across the state of Colorado to inform the analysis of what the utilization and energy consumption might be for future DCFC in the state. Data was available from the stations funded by Charge Ahead Colorado (CAC) as well as stations operated by EVgo. It is important to note that it is likely that a large majority of charging at EVgo's stations is currently free under the No Charge to Charge program and when this program ends it may affect station utilization levels. The individual station utilization rates from EVgo cannot be publicly shared under a non-disclosure agreement, but many of their stations do have higher utilization than the set of stations funded by CAC. There are stations in the state with utilization rates exceeding four sessions per day.

The average DCFC station is being used 1.4 times per day and the average electricity consumption for each charging event or use is 10.5 kWh. There is a wide range of utilization among the CAC stations, with some stations being not used at all (Ovid) or barely used (Loveland Tech) and other stations being used almost once a day (Denver Performing Arts Center and the Longmont Museum). In addition to the data from CAC, data from Tynan's Nissan in Fort Collins showed a very high utilization rate, with the two DCFC stations at the dealership being used over four times per day.

Table 1-6. Utilization Data for Colorado DCFC Stations Funded by Charge Ahead Colorado

	Average Sessions/ Day	Average kWh/ Session	Cost for User to Charge
DPAC Garage	0.84	12.4	Free
Denver Cultural Center Garage[11]	0.90	6.6	Free
Aspen	0.32	21.5	$1.50/hour
Pitkin County	0.31	7.3	Free
Marketplace at Centerra	0.21	8.3	$0.59 per kWh
Loveland Tech	0.10	10.4	$0.49 per kWh
Longmont Museum	0.99	11.1	$3 per session
Ovid	0.00	0.0	Free
Tynan's Ft Collins (2 stations)	4.5	7.3	Free

[11] The Cultural Center station has been out of service for most of 2016.

Due to a lower concentration of PEVs in the area, highway DCFC stations outside of urbanized areas are expected to have lower utilization rates than urban stations (where the existing usage data comes from). Data from the WCEH suggests that DCFC stations in urban areas experience about twice as much usage as those along more rural highways and this is supported by the modeling done by NREL on utilization of potential DCFC stations in Colorado.[12] Table 1-7 and Figure 1-1 look at annual revenue and operating cost for a ten year period under three different utilization scenarios. These scenarios assume significant annual growth in utilization over this period. For a detailed list of the assumptions underlying the data in Table 1-7 and Figure 1-1 refer to Appendix A.

Table 1-7. Estimated Operating Costs and Revenue Under Different Utilization Scenarios

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Base Case										
Operating Costs	$9,111	$9,374	$9,721	$10,180	$10,790	$11,601	$12,682	$14,058	$15,536	$17,558
Revenue	$2,436	$3,195	$4,201	$5,535	$7,308	$9,670	$12,822	$16,850	$21,243	$27,253
Cumulative Net Revenue	($6,675)	($12,854)	($18,374)	($23,020)	($26,501)	($28,432)	($28,292)	($25,500)	($19,793)	($10,097)
Medium										
Operating Costs	$9,558	$9,985	$10,557	$11,324	$12,355	$13,743	$15,613	$18,069	$21,025	$28,447
Revenue	$3,763	$5,011	$6,686	$8,935	$11,961	$16,038	$21,535	$28,773	$37,558	$49,579
Cumulative Net Revenue	($5,795)	($10,769)	($14,640)	($17,029)	($17,423)	($15,128)	($9,207)	$1,498	$18,031	$39,163
High										
Operating Costs	$11,535	$12,690	$14,259	$16,390	$22,666	$26,608	$31,973	$38,283	$40,769	$43,503
Revenue	$9,640	$13,053	$17,690	$23,994	$32,568	$44,236	$60,122	$78,815	$86,204	$94,332
Cumulative Net Revenue	($1,895)	($1,532)	$1,899	$9,503	$19,405	$37,033	$65,181	$105,714	$151,149	$201,978

[12] Idaho National Laboratory. 2016. Direct Current Fast Charger Usage in the Pacific Northwest During 2014. https://avt.inl.gov/sites/default/files/pdf/evse/INL_WCEH_DCFC_Usage_2014.pdf

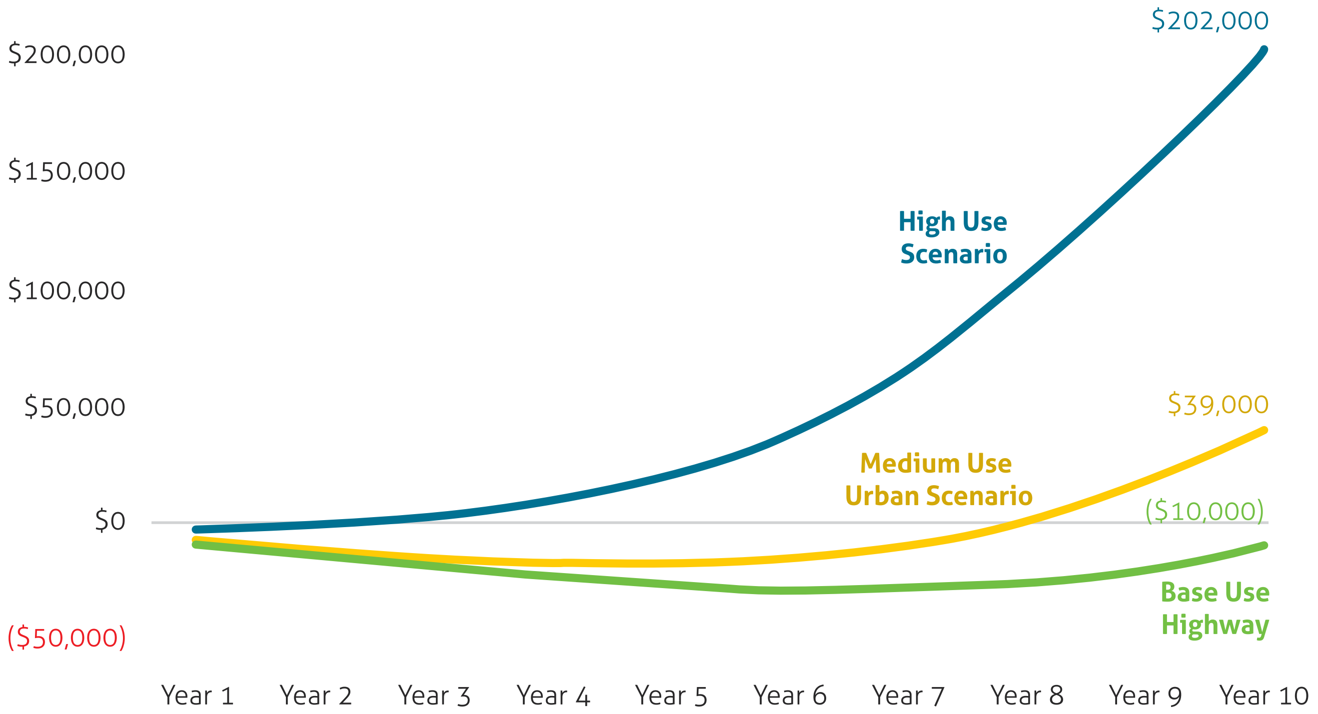

Figure 1-1. Cumulative Net Operating Revenue Over Ten Years for DCFC Station in Three Utilization Scenarios

At the relatively low utilization (less than one use per day per charger in year one) used in the Base Case scenario, it is difficult to cover operating costs much less to recoup the capital costs via sales of electricity or charging. In the Base Case scenario with two DCFC co-located with a Level 2 station, it would take seven years before annual revenue was greater than annual costs. At the end of ten years, the cumulative net revenue (revenue less operating costs) from the station would be below zero at $10,087. This Base Case utilization rate is meant to reflect what one might expect to see on highway DCFC stations based on the assumption that DCFC stations along highways will have approximately half the utilization of those in urban areas.[13] Changing the underlying assumptions will impact the revenue generating capabilities of these stations. Higher levels of utilization will be critical to making DCFC stations profitable.

A Medium use scenario assumes 1.4 uses per day in year one (the current average for urban DCFC stations in Colorado) and is meant to reflect what new stations in urban areas might experience over the next decade. In this scenario, revenue exceeds operating costs in the sixth year of operation and cumulative net revenue would be $39,000 after ten years. However, since most of the surplus comes in the last few years, this scenario still presents a financial challenge for private sector investment.

In a High use scenario where utilization levels are similar to what is currently experienced at Tynan's Nissan in Fort Collins (which is free), about 4.5 uses per day in year one, revenue would exceed costs by the second year of operation and the cumulative net revenue over ten years would be $202,000 which is sufficient to recover the initial capital costs. This initial level of daily utilization is assumed in the High scenario shown in Table 1-7. All other variables remain the same across the three scenarios.

[13] This is the pattern on WCEH DCFC stations. See next footnote.

While these charging station cost and revenue scenarios are not an exhaustive analysis of the financial feasibility for DCFC stations they do illustrate the challenges that station owners and hosts will face in trying to recover operating and capital costs. This is especially the case for the highway stations which are likely to have higher initial costs and lower utilization levels than urban areas.

Funding Considerations for DCFC Stations

Based on the analysis of DCFC station capital and operating costs compared to revenue generated by selling electricity, at current utilization rates, it is not possible for stations to fully recover their capital costs. Even the recovery of operating costs requires several years of increasing utilization under most scenarios. Recovery of costs will be more difficult for DCFC stations situated along highway corridors outside of urban areas as they are expected to experience lower utilization rates than urban stations.

> *DCFC stations will have difficulty recovering their operating and capital costs, especially along highway corridors*

DCFC stations along highway corridors are critical for making long-distance PEV travel possible and the continued growth of the PEV market. To date nearly all the non-Tesla DCFC stations in the state are located along the Front Range in urbanized areas.[14] This indicates that the current business environment is not supportive of DCFC stations along highway corridors. Currently, Charge Ahead Colorado will provide a grant of up to $16,000 for a DCFC station with multiple connection standards.

Table 1-8 shows a cost estimate for two dual-protocol DCFC along the highway in a rural area. The installation would also have the capacity to support up to 1 MW of future demand. The estimated costs could be reduced by requiring sites to already have 480V and three phase power, eliminating the need to extend the utility service, reducing the capacity of the transformer or by not requiring a co-located Level 2 charging station. To avoid the expensive switching out of stations we recommend that the installed stations be modular and able to provide higher levels of power in the future.

One funding option would be to provide 50 to 100 percent of the capital and installation costs (up to $195,000) for this type of DCFC station. The range of funding reflects whether or not a station would be

Table 1-8. Cost Breakdown for Colorado Highway DCFC Station

Component	Cost
Site Work (demo, concrete, mounting, signs)	$15,000
Electric Work (wire, conduit)	$5,000
New Transformer (1,500kVa)	$60,000
Extend Utility Service	$17,500
Level 2 Charger, dual port (optional)	$10,000
Dual Protocol DCFC (two)	$70,000
Subtotal	$177,500
10% Contingency	$17,750
Total	**$195,250**

[14] There is one DCFC station in Ovid along I-76 near the Nebraska border and two in Aspen.

> *DCFC stations should be modular and able to provide higher levels of power in the future*

located in a more urbanized area. This is similar to the model being implemented by the CEC in their effort to provide convenient access to DCFC stations along California's highways. CEC provides 75-100 percent of the capital cost. At this level of funding, CEC has received a large number of proposals to execute their DCFC corridors.[15, 16]

There are several potential funding sources that could be used to support larger investments in DCFC stations in Colorado. RAQC uses federal Congestion Mitigation and Air Quality (CMAQ) funds to provide grants to charging stations in the Denver metro area. CEO uses the Electric Vehicle Infrastructure Fund, which is supported by the annual $20 fee each PEV owner in Colorado pays, and CMAQ funds to support the Alternative Fuels Colorado program. Once the state's "beneficiary mitigation plan" is finalized, the state may use up to 15 percent of its share of VW environmental mitigation settlement funds for charging stations.

The Electric Vehicle Infrastructure Fund and the VW settlement provide greater flexibility than the federal CMAQ funds. CMAQ funded projects must demonstrate an air quality benefit and also meet certain cost effectiveness tests. This may make it difficult for CMAQ to provide large amounts of funding to individual DCFC stations that may experience low utilization rates. The lack of flexibility may make it challenging to fund new elements, such as future-proofed transformers, which have not been funded to date by CMAQ.

Urban DCFC Stations

Table 1-9 provides a breakdown of the estimated costs for an urban station which would have two dual protocol DCFC stations along with the capacity to support up to one MW of future demand. Stations in urban areas have lower overall costs as it is assumed that 480V three phase power is already available and there is less need for a co-located Level 2 charging station. As in the

Table 1-9. Cost Breakdown for Colorado Urban DCFC Station

Component	Cost
Two Dual Protocol DCFC stations	$70,000
New Transformer	$60,000
Labor, Materials and Misc. Costs	$20,400
Level 2 Charger, Dual Port (Optional)	$10,000
Subtotal	$160,400
10% Contingency	$16,040
Total	$176,440

[15] California Energy Commission. 2016. Solicitation GFO-15-603, Notice of Proposed Award. http://www.energy.ca.gov/contracts/GFO-15-603_NOPA.pdf

[16] California Energy Commission. 2016. Solicitation GFO-15-601, Notice of Proposed Awards. http://www.energy.ca.gov/contracts/GFO-15-601_NOPA.pdf

Highway option, modular stations that can be expanded if needed rather than requiring new hardware are preferred.

Stations in more urban areas would be expected to have higher utilization rates than those along rural highways; therefore a lower percentage of funding compared to highway stations should be sufficient. One option would be to use public funds to provide between 50 to 80 percent of the costs for the purchase and installation of the stations with the site host providing the remainder of matching funds.

An additional consideration would be to develop a funding mechanism that would support the operating costs of DCFC station operators over the next few years. This could be especially focused on defraying demand charges from the stations which can make up 80 percent of the electric bill for DCFC stations. Currently, the available funding sources (CMAQ, VW settlement funds and the Electric Vehicle Infrastructure Fund) are only available for capital purposes.

Defraying short-term demand charges is essential

Key Findings

- Demand charges, which vary widely across the state, often make up 80 percent of the electric bill for DCFC station operators.
- Utilities should be engaged to develop tariffs that limit the impact of demand charges on DCFC stations.
- Battery storage systems can be cost effective at reducing the impact of demand charges in areas with higher demand charges, around $20 per kW.

Utilities and Demand Charges

Commercial customers who operate publicly-available DCFC stations will likely be subject to demand charges in addition to a per kWh energy charge. Demand charges are generally based on the highest level of electricity demand (over a 15 minute period), measured in kW for a billing cycle. If the highest level of electricity demand was 30 kW the customer would be charged 30 times the per kW rate for the month. Demand charges can be especially challenging for DCFC stations (especially if they are separately metered) which can have high levels of peak demand for short periods of time compared to their overall consumption of electricity. These demand charges are often monthly, rather than daily, and are typically not calculated to assess demand at the system, substation, or feeder peak, and thus may be recovering costs from PEV charging stations in excess of the costs they actually impose on the system.

Utilities across Colorado offer a wide variety of rates and tariffs under which DCFC stations would be billed. To better understand the impact that demand charges might have on the deployment of DCFC along interstates in Colorado, the study authors reviewed which utilities served each area along the state's interstates and the tariffs which would likely apply to DCFC stations. To estimate the annual bill it is assumed that there are two co-located 50 kW DCFC along with one Level 2 charger. Customers at these stations will purchase 1,096 kWh per month based on each station being used 1.4 times per day and the average consumption per use being 10.6 kWh. The Level 2 station is assumed to use 205 kWh per month. It is assumed that each station would be assessed the maximum demand charge of 106 kW each month.

Table 1-10. Energy and Demand Charges for Utilities Along Colorado's Interstate Corridors[17]

Monthly Meter	Monthly Meter Charge	Demand Charge per kW	Energy Charge per kWh	Estimated Annual Bill	Demand Charge % of Bill
I-25 South to North					
San Isabel Electric Association	$150	None	$0.15 Peak $0.12 Off-Peak	$3,509	0%
Black Hills	$66.75	$26.81	First 200 kWh: $0.0071 201+ kWh: $0.004	$34,977	99%
Mountain View Electric Association	$105	$11	$0.067	$16,133	87%
Colorado Springs	$22.25	None	$0.0618	$1,080	0%
Intermountain REA	-	-	-	-	-
Large Power Service Demand Metered	$120	$14	$0.0645	$20,096	87%
Large Power Service	$120	None	$0.1236	$3,065	0%
Xcel Energy	$34.40	$5.63	$0.14[18]	$9,420	76%
United Power	-	-	-	-	-
Small Commercial	$20	None	$0.11	$1,673	0%
Large Commercial	$175	$17.50	$0.05	$25,030	89%
Poudre Valley REA	$108	$19.01	$0.06	$26,272	92%
Fort Collins	$9.62	$6.63 + Summer Coinci-dent Peak of $9.43 or $12.38	$0.05	$23,158	97%
I-70 East to West					
KC Electric Association	-	-	-	-	-
Small Commercial	$41.50	None	$0.09	$1,650	0%
Large Commercial	$141	$9.01	$0.06	$13,943	82%
Mountain View Electric Association	See Above	-	-	See above	-
Intermountain REA	See Above	-	-	See Above	-
Xcel Energy	See Above	-	-	See Above	-
Holy Cross Electric Association	$28	$6.11	$0.06	$8,961	87%
Grand Valley Power	$75	$16	$0.06	$21,983	93%
I-76 East to West					
Highline Electric Association	$73.50	$14.09	$0.05	$19,513	92%
Morgan County REA	$86.25	$11.50	First 400 kWh: $0.07 401+ kWh: $0.05	$16,560	88%
United Power Inc.	See Above	-	-	See Above	-

[17] For utilities where two tariffs could be applied to a DCFC station or if it was unclear which tariff would apply both of the tariffs are listed.

[18] This is the average of the summer and winter per kWh charges.

This review shows a wide range of demand charges. Several utilities (Colorado Springs, San Isabel Electric Association) would not apply demand charges to this type of customer. A number of utilities (Xcel Energy, Holy Cross Electric Association) offer tariffs with relatively low demand charges of $4-$6 per kW, while others (Black Hills, Poudre Valley REA) have demand charges around $20 per kW.

These differences in demand charges lead to large differences in the annual electric bill that a DCFC station would likely incur. The difference between Xcel Energy's demand charge of $5.63 and Black Hills' demand charge of $26.81 adds up to an annual bill over $25,000 higher for a DCFC station operating in Black Hill's service territory.

In almost all cases where a demand charge is incurred, demand charges make up over 80 percent of the cost of electricity service to operate the DCFC station. As a result, service territories with high demand charges and their associated high operating costs will likely have a limited number of fast charge stations. Demand charges could have an even greater impact on DCFC station costs as higher power stations start to come on line.

Demand charges account for over 80 percent of electric bills

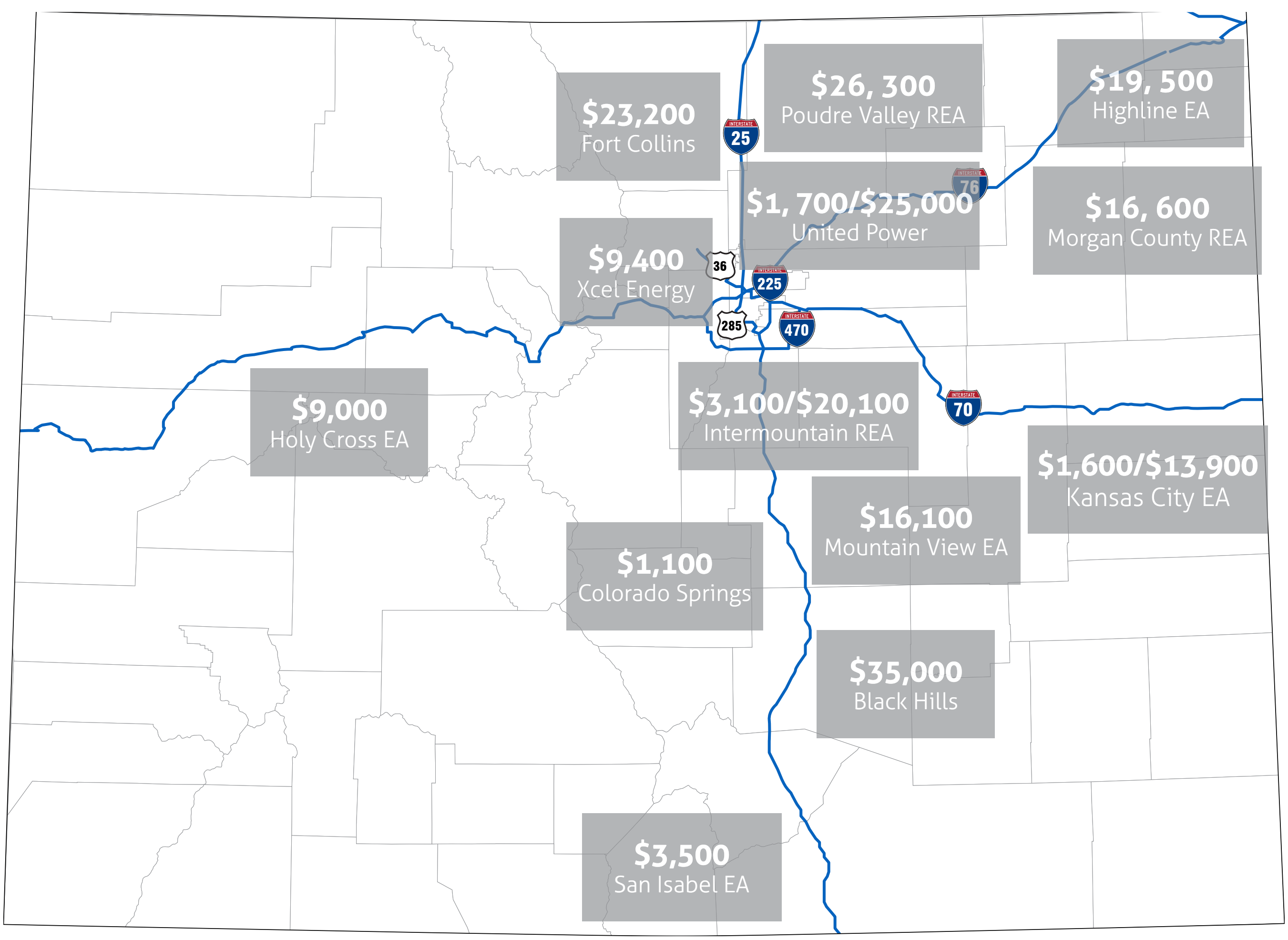

Figure 1-2. Estimated Annual Electric Bill for a DCFC for Utilities Along the Interstates

Mitigating Demand Charges Through Utility Tariff Pilots

One way that utilities could reduce the impact of demand charges on DCFC stations is to offer a commercial tariff that has a lower demand charge but higher energy charges. Often, the energy charge is much lower for commercial customers who are assessed a demand charge. One example is Xcel Energy's SGL commercial tariff, which compared to its SG commercial tariff, offers a relatively low demand charge and higher per kWh prices. This type of rate structure currently makes economic sense for DCFC stations because they experience high spikes in demand but have relatively low energy consumption.

Table 1-11. Comparison of Two of Xcel Energy's Commercial Tariffs[19]

	Per kW	Per kWh
SG	\$19.65 (Summer) \$15.45 (Winter)	\$0.00461
SGL	\$5.63	\$0.17561 (Summer) \$0.12293 (Winter)

There are a number of other ways that utilities and states across the country are experimenting in an effort to reduce the impact of demand charges. In Nevada, NV Energy and the Governor's Energy Office have a program to reduce demand charges by DCFC operators who are part of the Nevada Electric Highway program, which is locating DCFC stations along major highway corridors in the state. For the first five years of a DCFC station's operation, they will receive a subsidy from the Governor's Energy Office to offset any increases in the site's demand charge due to the DCFC station.[20]

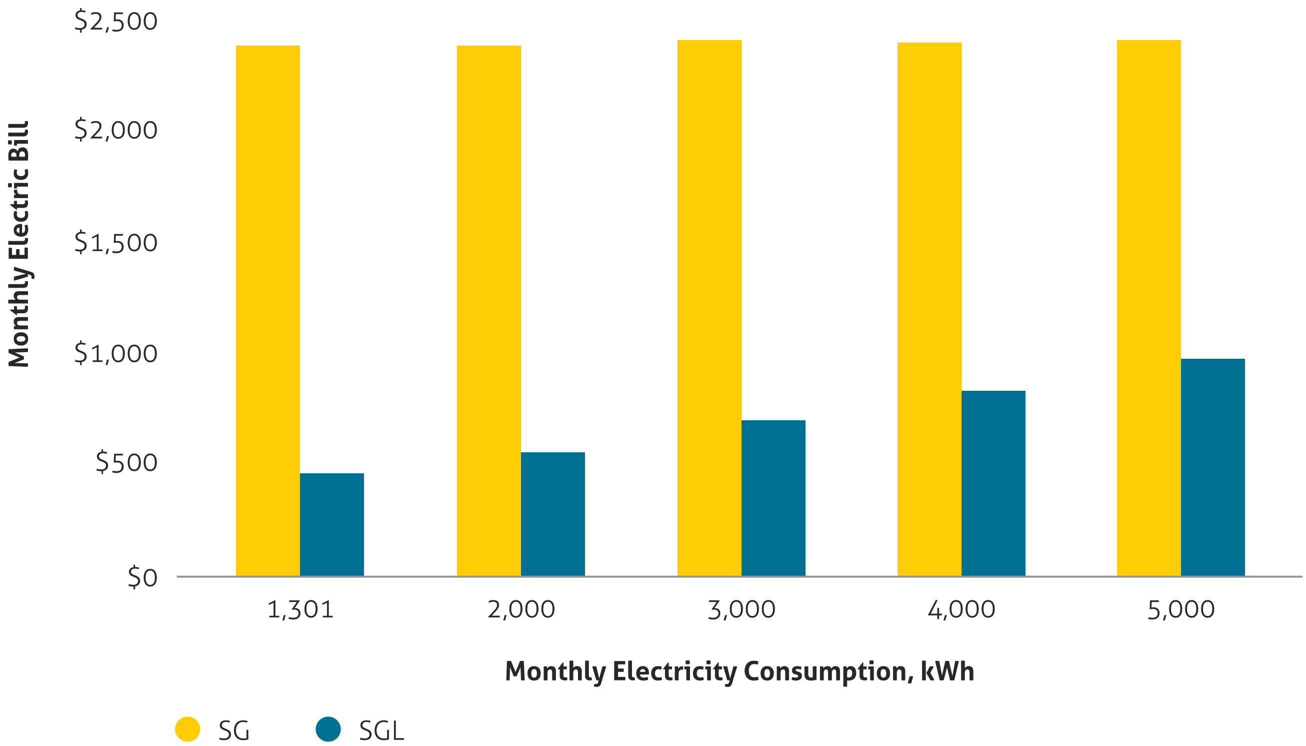

Figure 1-3. Comparison of Average Monthly Electric Bill for a DCFC under Two Xcel Energy Commercial Tariffs

[19] Xcel Energy. 2017. Colorado Commercial and Industrial. https://www.xcelenergy.com/staticfiles/xe/Regulatory/COBusRates.pdf

[20] Nevada Governor's Office of Energy. 2016. Nevada Electric Highway. http://www.nevadadot.com/Home/ShowDocument?id=2707

Other utilities are offering pilot tariffs focused on DCFC. For example, the Hawaiian Electric Company has a pilot tariff for DCFC stations using up to 100 kW of power. This tariff does not apply a demand charge but does have time of use rates for energy consumption with off-peak rates $0.10 higher than regular rates and peak rates $0.15 higher.[21]

In Oregon, Pacific Power has filed a transportation electrification plan with the Public Utilities Commission (PUC) that contains an innovative DCFC delivery service transitional rate.[22] The concept is to enable DCFC while still making the system function efficiently by encouraging charging to take place at off peak times. The proposal allows DCFC sites with a total load less than one MW to opt in. The tariff would charge an energy rate that is three times as high as the standard nonresidential rate during peak hours, the standard energy rate during off peak, and no demand charges. The company estimates that this tariff would reduce electricity costs for DCFC stations by about 66 percent. They are proposing that this tariff be in place for a 10 year period. This proposal is currently under review by the PUC.

Another potential approach to consider is to allow a charging network to aggregate the demand from multiple stations within the utility service territory and pay based upon the peak demand aggregated across sites. The concept is that at low usage levels DCFC events will be spread out over time, and generally speaking there will not be charging events taking place at every charger at the same time. Thus, the peak coincident demand on the system will be lower than the sum of the peak demand from each charger.

As an example – a network with twenty 50 kW stations, averaging 1.4 charging events per day, with charging primarily taking place between 7 a.m. and 9 p.m. In an average day there would be 28 charging events, or on average two per hour. If each station were paying a separate demand charge, the network would pay a demand charge for 1,000 kW. By contrast, the coincident peak demand would likely be only about 100 kW if charging events are randomly distributed, so the demand charges would be much smaller.

Mitigating Demand Charges With Battery Storage Systems

Another possible method for DCFC station owners to lower demand charge costs would be to include a battery storage system with their station. The energy stored in the batteries would limit the peak demand charge and the overall electric bill. The installed cost of a lithium-ion battery storage system is between $475-$1,082 per kWh.[23] A battery energy storage system rated at 100 kWh/50 kW would then cost between $47,500 and $108,200 to install. This system would be able to limit peak demand by approximately 40 kW.

To recover these additional capital costs over a projected ten year lifetime of the station would require annual savings between $4,750 and $10,820. In situations with relatively high demand charges (around $20 per kW) and low cost installations it could make financial sense for a DCFC station to incorporate battery storage. DCFC stations located in the service territories of Black Hills and Poudre Valley REA may be good candidates for the use of battery storage. As the cost of lithium-ion batteries is forecast to fall by 50 percent over the next five years the cost of these battery storage systems should decrease considerably, making them more economically advantageous.[24]

Battery storage can help minimize DCFC costs

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[21] Hawaiian Electric. 2017. Commercial Pilot Rates. https://www.hawaiianelectric.com/clean-energy-hawaii/electric-vehicles/electric-vehicle-rates-and-enrollment/commercial-pilot-rates

[22] Pacific Power. 2016. Public DC Fast Charger Delivery Service Optional Transition Rate. http://edocs.puc.state.or.us/efdocs/UAA/uaa162950.pdf

[23] Lazard. 2016. Lazard's Levelized Cost of Storage-Version 2.0. https://www.lazard.com/perspective/levelized-cost-of-storage-analysis-20/

[24] Lazard, 2015. Lazard's Levelized Cost of storage. https://www.lazard.com/perspective/levelized-cost-of-storage-analysis-10/

Table 1-12. Estimates of Savings due to a 40 kW Battery Storage System

Demand Charge	Annual Demand Charge Savings	Payback Period Low Cost	Payback Period High Cost
$5 per kW	$2,400	19.8	45.1
$10 per kW	$4,800	9.9	22.5
$20 per kW	$9,600	4.9	11.3

DCFC Business Models

Key Findings

- Currently, DCFC stations in Colorado are subsidized by the private or public sector.
- The present number of DCFC stations is perceived to be inadequate by most PEV drivers.
- If current legislative barriers to utility involvement can be removed, utilities could be a significant source of investment in DCFC stations. Utilities may be able to play an important role in investing in electrical service to support fast charging under current statutes.
- Municipal and cooperative utilities do not face the same restrictions as investor-owned utilities and could invest in both charging stations and electrical service.

Assessing the financial viability of a potential charging station involves a few key market factors, such as: the customers' willingness to pay; the amount and type of charging infrastructure necessary to accommodate the local PEV market; market opportunities where PEV charging gaps may exist; and the ancillary benefits (such as increased retail sales) that PEV customers may bring.[25] Furthermore the profitability of these charging stations is negatively influenced by high upfront costs, high utility demand charges, and relatively low charging station utilization. For example, PEVs on average use public charging for less than five percent of total charging needs presently.[26]

As outlined in the section on DCFC station costs, it is challenging for owners of DCFC stations to generate enough revenue from selling electricity to PEV drivers to cover their operating and maintenance costs at current utilization levels.[27] With over 80 percent of charging taking place at the homes of PEV drivers and only about five percent of charging taking place at public stations there is a limited capacity for selling charging services to PEV owners and expecting to make a profit.[28] Utilization levels would need to be approximately three times higher than the current Colorado average for a DCFC station to earn sufficient revenue to exceed its operating costs and the current level of utilization is based on many customers getting free charging. In these high utilization scenarios, it may be possible for a DCFC station to earn enough revenue to recover its capital and installation costs but this would take over seven years. Business models will need to successfully increase revenue while

[25] Center for Climate and Energy Solutions. 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdf

[26] Center for Climate and Energy Solutions. 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdfhttps://www.c2es.org/docUploads/ev-charging-guide.pdf

[27] Idaho National Laboratory. 2015. Plugged In: How Americans Charge Their Electric Vehicles. https://avt.inl.gov/sites/default/files/pdf/arra/SummaryReport.pdf

[28] Center for Climate and Energy Solutions. 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdf

decreasing capital and operating costs as well to improve the financial prospects.[29]

Another possible revenue stream for DCFC station owners is whatever increase in ancillary sales they might experience from PEV owners spending more time and money at their site. If a DCFC station is co-located with a retail site this would likely result in some increase of sales. This is not dissimilar from the business model for gas stations today, which relies more on convenience store purchases to make a profit rather than selling gasoline.

The following assessment by the Center for Climate and Energy Solutions from their 2015 report, "Business Models for Financially Sustainable EV Charging Networks" remains valid in 2017:

> *"It is currently challenging to construct a profitable business case for publicly available EV charging investments for several reasons. These include high initial investment costs, low and uncertain near-term demand for publicly available charging, and commercial charging competing with home charging."*

To date, the market for DCFC stations in Colorado reflects this reality, as nearly all of the stations have been supported by public and private subsidies.

Current DCFC Station Business Models in Colorado

Currently there are 50 publicly-available DCFC locations in Colorado which have a variety of different ownership models.[30] Ten of these locations are owned by Tesla, nine by vehicle dealerships, 26 by private networks such as EVgo and Greenlots and the remainder by local governments. This is a higher number than is referenced in the NREL research report which limits the existing DCFC station network to eighteen locations as the NREL report does not include Tesla stations and stations without both a CHAdeMO and Combo Charging System (CCS) plug.

Ten of the locations are owned and operated by Tesla for the exclusive use of Tesla owners. Until the start of 2017, all Tesla owners received unlimited free charging at Tesla Superchargers. However, beginning in 2017, people who buy new Teslas will receive 400 kWh of free charging each year (good for about 1,200 miles in a Tesla) and will have to pay for any additional charging.[31] In Colorado, new Tesla owners will have to pay $0.13 per kWh to charge their vehicles at the company's Superchargers. Based on electricity prices in Colorado, this cost will likely be sufficient to recover the company's cost per kWh expenditures in operating the station but will likely be too little to recover all the station's operating costs, the majority of which are likely to come from demand charges. So while some station costs will be recovered it is likely that Tesla will still be providing heavily subsidized stations to its customers.

Another set of nine locations are operated by vehicle dealerships (mostly Nissan dealerships) which provide free charging. Note that several Nissan dealerships host stations operated by EVgo or Greenlots.

Approximately half of the DCFC locations in Colorado are operated by private charging networks, such as EVgo and Greenlots. EVgo installs and operates the stations and pays for the ongoing electricity and maintenance costs and the site host supplies the needed parking space(s). EVgo has partnered with several vehicle

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[29] Center for Climate and Energy Solutions. 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdf

[30] This is slightly different than the total number of DCFC stations as locations may have multiple stations.

[31] People who bought their Tesla prior to 2017 still have unlimited, free charging.

manufacturers to offer free charging for a certain period of time for owners of new vehicles, such as Nissan in their "No Charge to Charge" program, which offers free charging to LEAF owners for two years after the LEAF is purchased. Likewise, EVgo partners with BMW on their ChargeNow program, which offers free charging for two years after an electric vehicle purchase. While not currently available in Colorado, EVgo and Ford offer Ford EV 1-2-3 Charge in California and Maryland, which provides free Level 2 charging for three years. EVgo's business model appears to rely on funding from Nissan and BMW to build out and operate their existing network of stations.

Customers using EVgo stations pay $0.10 per minute for DCFC along with a monthly fee of $12.95.[32] It is possible that many of the users are using the stations for free as part of the free charging programs outlined above.

Several stations are operated by local governments which are paying the operating and maintenance costs for these stations.

Almost all of the DCFC stations in Colorado are being supported by some level of ongoing subsidization either through private companies (EVgo, Tesla, Nissan dealerships) or the public sector (local governments). This indicates that the majority of DCFC stations are not likely recovering any significant costs by charging PEV drivers for use.

One promising result from the survey conducted as part of this research is that PEV drivers seem to be willing to pay for the use of DCFC stations.[33] The authors surveyed both

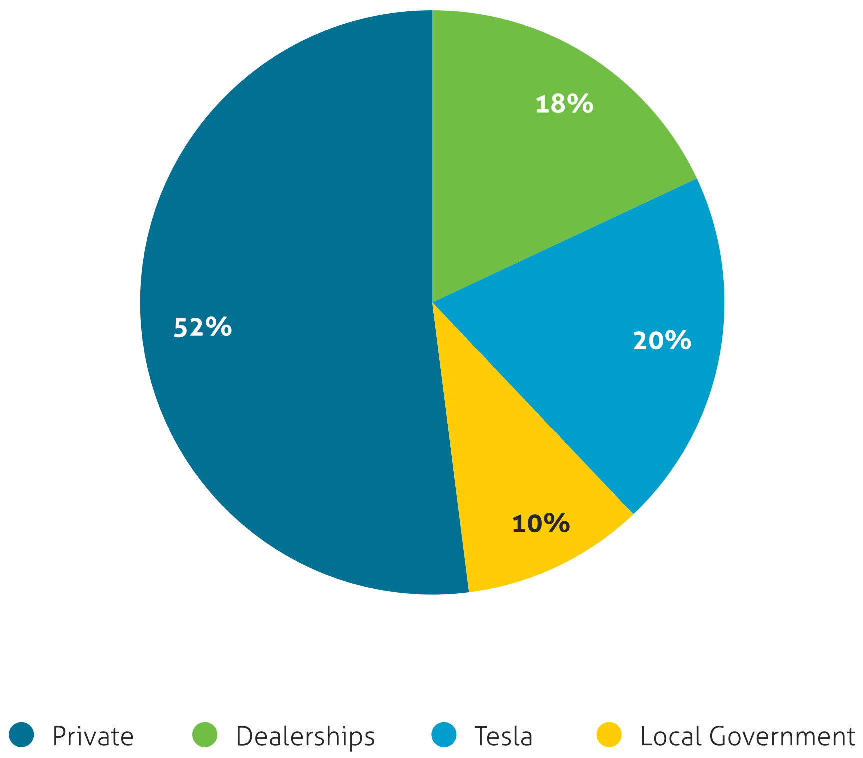

Figure 1-4. Breakdown of Owners/Operators of DCFC Locations in Colorado (50 Total Locations)

[32] EVgo. 2017. EVgo Charging Plans. https://www.evgo.com/charging-plans/[27] Idaho National Laboratory. 2015. Plugged In: How Americans Charge Their Electric Vehicles. https://avt.inl.gov/sites/default/files/pdf/arra/SummaryReport.pdf

[33] Refer to Appendix B for the complete results of the survey.

PEV owners and a small group of potential PEV buyers to better understand their perceptions about public charging, especially around DCFC stations.[34] Responses were received from 264 PEV owners (representing about three percent of the PEVs in Colorado) and fourteen potential owners in Colorado. The PEV owners were asked how much they would be willing to pay for a hundred miles of range in 30-40 minutes at a fast charging station. Only four percent said 'zero' or that they would not be willing to pay. The average cost named by PEV owners was $6.39 and the median cost named was $5. The results were similar for LEAF and Tesla owners, with LEAF owners willing to pay an average cost of $6.49 and Tesla owners willing to pay $6.12. The median for both LEAF and Tesla owners was also $5.

The average efficiency of most PEVs is three miles/kWh, so this type of 'fill-up' would require about 33 kWh of electricity. Several major charging networks would charge customers the prices shown in Table 1-13 to buy this amount of electricity.

The willingness of PEV drivers to pay for DCFC corresponds with what is offered. One caveat is that many PEV drivers (Tesla owners and customers enrolled in No Charge to Charge) currently receive free charging. Another important note is that the Tesla supercharger network provides much faster charging (120 kW compared to 50 kW) than other current DCFC networks. This means that drivers are able to add this amount of range in about half the time as other DCFC stations.

Table 1-14 provides a summary of different business models being used by charging station networks and companies.

Table 1-13. Cost for Fill Up at DCFC Stations

Network	Base Price	Total Price for 33 kWh
Tesla (new purchases)	$0.13/kWh[35]	$4.29
EVgo	$0.10/minute[36]	$4.00
Blink Network	$6.99/session[37]	$6.99

[34] These potential PEV buyers had expressed interest in purchasing a PEV through a group purchase program but did not actually make the purchase.

[35] Tesla. 2017. Supercharging. https://www.tesla.com/support/supercharging

[36] EVgo. 2017. EVgo Charging Plans. https://www.evgo.com/charging-plans/

[37] Blink. 2016. Driving Electric. http://www.blinknetwork.com/drivingelectric

Table 1-14. Network Feature Pros and Cons[38]

Network type	Pros	Cons
Subscription-based	A fob or access card will grant access to all chargers in that network. Charging proceeds will offset installation costs. Drivers know what to expect with relatively consistent monthly rates.	Drivers without a subscription to the network are unable to charge at that location. Monthly/annual fees are not necessarily commensurate with use.
Pay-per-charge	There is flexibility for the EVSE operator—charge can be a flat or per-kWh (where legal) fee. EV owners are only charged per event and not on a monthly basis.	Drivers could end up paying more for one-off charging.
Mobile application	Anyone with a smart phone can instantly access the network to charge. No credit cards or cash are needed. Drivers can track electricity use and program charge events accordingly.	If the station is in an area with patchy service, it may be difficult to initiate a charging event. Not all drivers may have a smart phone.
Free charging	Free charging can rapidly expand PEV deployment with drivers seeking free fuel. Free charging can attract drivers or employees to the business or location of EVSE.	There may be real or perceived issues of fairness if PEV drivers are getting free fuel while owners of gasoline-powered vehicles are not. The EVSE owner/operator absorbs all costs and has no opportunity to pass on costs to drivers.

[38] BCS Incorporated, Iowa Economic Development Authority. 2016. Advancing Iowa's Electric Vehicle Market. https://www.iowaeconomicdevelopment.com/userdocs/documents/ieda/AdvancingIowasElectricVehicleMarketReport.pdf

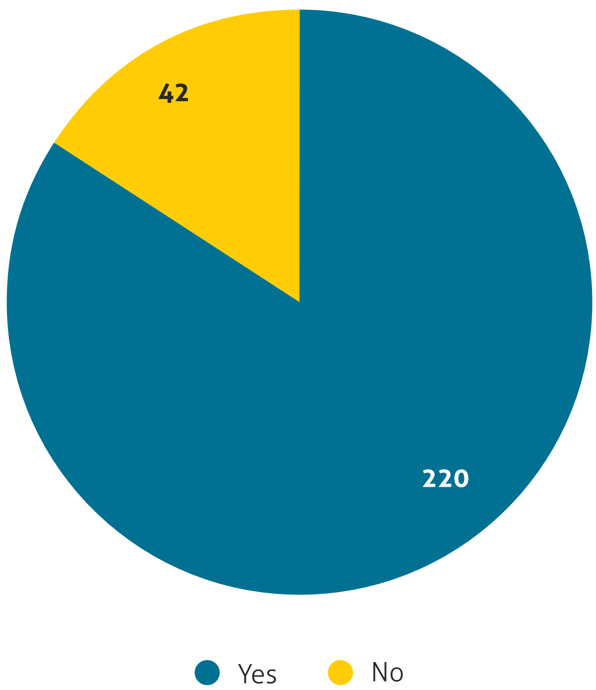

Figure 1-5. Does availability of public charging affect where you drive? (262 Responses)

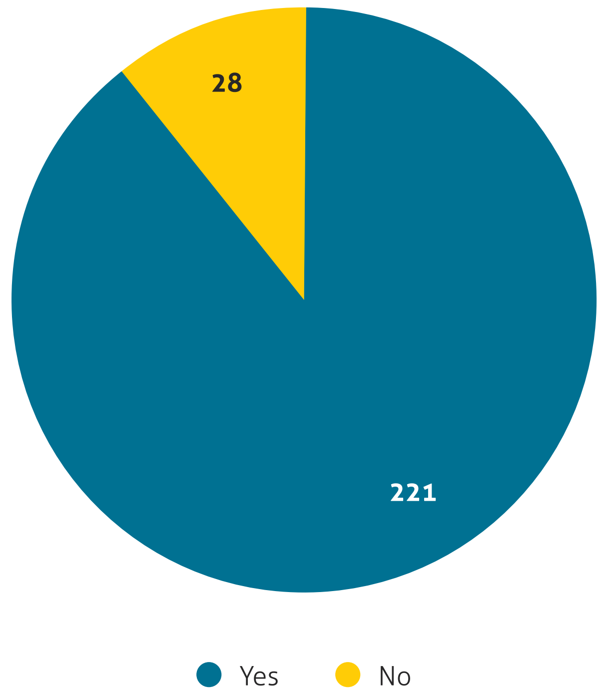

Figure 1-6. If you had reliable and frequent access to fast charging along Colorado's major highways, would that change where or how you drive your EV? If so, how? (249 Responses)

The current business model for DCFC stations does not appear to be supplying enough DCFC stations to satisfy current or prospective PEV owners based on responses from the surveys conducted as part of this research. Eighty-four percent of PEV owners responded that the availability of public charging affects where they drive and 89 percent of respondents stated that access to fast charging along major highways would change where and how they drive their PEV. Of those 89 percent, nine in 10 stated that having access to this type of fast charging would encourage them to take more trips and longer trips with their PEV.

> *There are too few DCFC stations in Colorado today*

Respondents named a wide variety of locations across Colorado where they were less likely to go due to a lack of charging, especially major Front Range cities, Denver International Airport and destinations in the mountains. Among the potential PEV buyers surveyed, nearly half identified the lack of public charging as a significant factor in their decision to not yet purchase a PEV.

The Role of Utilities in Supporting the Deployment of Charging Stations

Utilities can play many different roles in the rapidly-growing PEV charging network such as that of facilitator, managers, or providers of PEV charging stations, as shown below.[39] PEVs represent a huge demand-side opportunity to utilities as they consume the equivalent of a quarter of an average household's annual electricity use. Proactive utilities and regulators who are leaders in the PEV industry are likely to see their activities result in a more positive impact than those who are reactive to the market.

[39] Rocky Mountain Institute. 2016. Electric Vehicles as distributed energy resources. http://www.rmi.org/Content/Files/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf

Table 1-15. Roles of utilities and regulators in different frameworks

Framework	Who Owns Charging Equipment?	Role of the Utility	Role of the Regulator	Pricing of Charging Service	Consumer Protection
Facilitator	Customer	Electric service only	Regulate tariff for electric service to location	Unregulated	Same as retail
Manager	Customer	Electric service plus dispatch	Lower tariff for electric service	Unregulated	Same as retail
Provider or Exclusive Provider	Utility	Electric service and charging service	Regulated tariff for charging service	Fully regulated	Through utility regulator

Table 1-16. Proactive and Reactive Utility Results[40]

Proactive	Reactive
Avoid new investment in grid infrastructure	Shorten the life of grid infrastructure components
Optimize existing grid assets and extend their useful life	Require greater investment in gas-fired peak and flexible capacity
Enable greater integration of variable renewables	Make the grid less efficient
Reduce electricity and transportation costs	Increase costs of electricity for all consumers
Reduce petroleum consumption	Inhibit integration of renewable sources
Reduce emissions of CO_2 and conventional air pollutants	Increase grid-power emissions
Improve energy security	Make grid less stable and reliable
Provide multiplier benefits from increased money circulating in the community	
Supply ancillary benefits to the grid such as frequency regulation and power factor correction	

[40] Rocky Mountain Institute. 2016. Electric Vehicles as distributed energy resources. http://www.rmi.org/Content/Files/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf

The experience utilities have with electrical infrastructure may help reduce DCFC installation costs. For example, a municipally-owned utility, the Orlando Utilities Commission, installed five DCFC fast charging stations at a cost of 82 to 89 percent lower than projects implemented in Washington State.[41] This reduction in costs is attributed to selecting sites with pre-existing electricity infrastructure, lowered costs by the utility through its extensive relevant experience as the electrical grid operator and avoidance of an interconnection fee since it was performing the work itself.

One California study found that each PEV brings net benefits between $2,788 and $9,799 to the utility and its ratepayers during its useful life, while a Washington state study found that PEV drivers subsidize the grid and lower power rates for everyone else with a value of at least $1,250 per car and $120,000 per transit bus.[42]

Utilities must also weigh the costs and benefits of charging infrastructure with the entire electricity rate-paying base as a whole. An example of how government and regulators are playing a role here is Washington State's law that explicitly allows utilities to provide and subsidize PEV charging service, up to a maximum impact on nonparticipants of a 0.25 percent increase in electricity prices.[43] To date, PEV infrastructure plans submitted by utilities in other states have typically had rate impacts of 0.1-0.2 percent.

The national consulting firm MJ Bradley and Associates has just completed a cost benefit analysis of the impact of adding PEVs in Colorado. The study is titled *Electric Vehicle Cost-Benefit Analysis: Plug-in Electric Vehicle Cost-Benefit Analysis: Colorado*.[44] The study looked at three areas: impacts on utility ratepayers, costs and benefits to PEV owners, and the value of reductions to carbon pollution.

The study examined two different scenarios: one with a level of PEV penetration (nine percent of light-duty vehicles by 2030, growing to 21 percent by 2050) that is between the medium and high scenarios in the Colorado Energy Office's 2015 EV Market Implementation Study and one with a much faster growth rate (25 percent of light-duty vehicles by 2030, growing to 98 percent by 2050).

For the moderate scenario, the study found a Net Present Value (NPV) of $7.6 billion in reduced costs to vehicle owners, savings to utility customers, and reduced carbon pollution. In particular, the NPV of savings to utility customers is approximately $300 million. For the fast growth scenario, the total NPV for all benefits is $43 billion, with savings to utility customers of $4.1 billion. Under this scenario, by 2050 utility rates are four percent lower due to the PEVs.

The benefits to utility customers are greatest when the utility adopts time of use pricing for PEV charging, encouraging customers to do most of their charging at night when there is excess generating capacity available on the grid. The utility will collect more revenue from electric sales than the incremental cost of serving this load, thus generating net revenue. By 2030, the NPV of net utility benefits during the lifetime of the vehicle is about $60 per year per PEV on the system – that is, for every additional PEV added, utility customers in aggregate receive $630 in benefit.

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41 Center for Climate and Energy Solutions 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdf

42 Drive Oregon. 2016. Charging Oregon's Future: A state of the industry report.

43 Rocky Mountain Institute. 2016. Electric Vehicles as distributed energy resources. http://www.rmi.org/Content/Files/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf Rocky Mountain Institute. 2016. Electric Vehicles as distributed energy resources. http://www.rmi.org/Content/Files/RMI_Electric_Vehicles_as_DERs_Final_V2.pdf

44 M.J. Bradley and Associates. 2017. Electric Vehicle Cost-Benefit Analysis. http://mjbradley.com/sites/default/files/CO_PEV_CB_Analysis_FINAL_13apr17.pdf

To quote from the study, "Under PUC rules net revenue from additional electricity sales generally offsets the allowable costs that can be passed on via higher rates. As such, the majority of projected utility net revenue from increased electricity sales for PEV charging would in fact be passed on to utility customers in Colorado, not retained by the utility companies. In effect this net revenue would put downward pressure on future rates, delaying or reducing future rate increases, thereby reducing customer bills."

PEV charging reduces costs for all utility customers

The chart below, taken from the MJ Bradley Study, shows the utility bill savings that a typical residential customer would experience due to the addition of PEVs under the moderate scenario (on the left) and the high

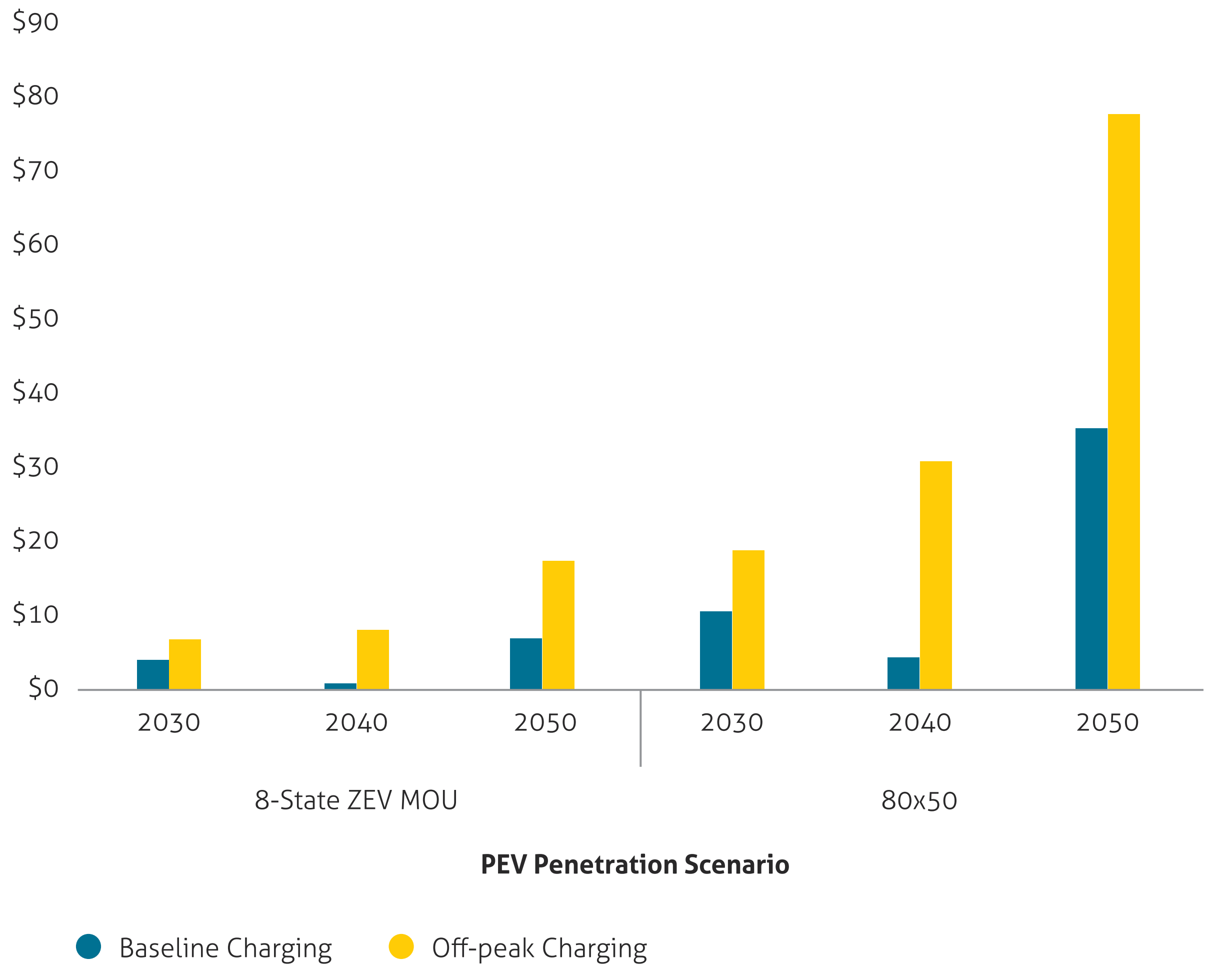

Figure 1-7. Annual Savings for Colorado Utility Customers from PEV Charging

scenario (on the right), both with and without time of use rates.[45] Under the high scenario with time of use rates, savings grow to $77 per year per customer in 2050, representing approximately a four percent rate reduction.

This analysis suggests that the benefit to utility customers of increased deployment of PEVs could be up to four percent, while the rate impact of utility investment in charging infrastructure is likely a fraction of a percent, thus justifying rate basing investment in infrastructure.

Utilities and DCFC Stations

To date, most of the focus for utilities in supporting the PEV and charging station markets has been through Level 2 stations at residences, workplaces and public locations. The three largest investor-owned utilities in California have already received approval from the California Public Utilities Commission to make investments of nearly $200 million on 12,500 Level 2 stations at workplaces, multi-family dwellings and in disadvantaged communities. None of the first round of approved plans contained any investments in fast charging stations.

In January of 2017, San Diego Gas and Electric (SDG&E), Southern California Edison (SCE) and Pacific Gas and Electric (PG&E) all filed new proposals which focus in part on the electrification of medium and heavy-duty vehicles but also include pilots to advance DCFC stations in their service territories.

SCE's proposal contains a pilot for up to 50 DCFC station ports at up to five urban sites at a cost of $3.9 million. SCE will provide and maintain the 'make-ready' infrastructure while the customer will own and operate the DCFC station with help with rebates from SCE.[46] The focus on urban areas (especially near residential areas) is meant to provide customers without access to home charging additional opportunities to conveniently recharge their vehicles.[47]

SDG&E is proposing to invest $4 million to install 20 Level 2 and two DCFC stations apiece at four CalTrans park and rides which are planning to undergo new construction or upgrades. While there is customer demand for charging at park and rides, CalTrans does not want to install, own and operate the charging stations themselves, and to date has not found a third-party that would meet all their needs. SDG&E plans to install, own and operate the stations. As the park and rides are generally located along highways they would serve both customers parking there and PEV drivers passing by the area.[48]

PG&E is seeking approval for a $22.4 million project to provide 'make-ready' infrastructure to support 234 DCFC stations at 52 sites. PG&E's make-ready investment will cover, "the distribution circuit, service drop transformer, conductor, connectors, conduit, electric meter, and breaker panel up to the charger stub. In addition, PG&E will install appropriate safety equipment at the site (e.g., lighting, parking lot painting, and bollards) and ensure the site meets relevant state and local ADA." [49] A third-party (customer) will own and operate the stations and rebates of up to $25,000 per charger are available for site hosts in disadvantaged communities. PG&E's program will focus on

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[40] The Moderate scenario in the MJ Bradley Study is more aggressive than the Medium Scenario outlined in the Colorado EV Market Study. The Moderate Scenario from the MJ Bradley Study forecasts that six percent of on road vehicles are PEVs by 2025 while the Medium Scenario forecasts five percent of on road vehicles as PEVs by 2030. Currently, the PEV adoption rate in Colorado is more in line with the Medium Scenario.

[46] Southern California Edison. 2017. CPUC Open Proceedings. http://www3.sce.com/law/cpucproceedings.nsf/vwMainPage?Openview&RestrictToCategory=2017%20TE%20Application&Start=1&Count=25

[47] Southern California Edison. 2017. Testimony of Southern California Edison Company in Support of its Application of Southern California Edison Company (U 338-E) For Approval of its 2017 Transportation Electrification Proposals http://www3.sce.com/sscc/law/dis/dbattach5e.nsf/0/F5582C9D0A9A3659882580AE007F74A4/$FILE/A1701XXX-SCE%20TE%20Testimony%201-20-17.pdf

[48] San Diego Gas and Electric. 2017. Prepared Testimony of Randy Schimka on Behalf of San Diego Gas and Electric Company. https://www.sdge.com/sites/default/files/regulatory/Direct%20Testimony%20Chapter%203%20-%20Priority%20Review%20Projects.pdf

[49] Pacific Gas and Electric. 2017. Pacific Gas and Electric Transportation Electrification SB 350 Prepared Testimony. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452859

redundancy and having multiple DCFC stations at one site to ensure that stations will be available for PEV drivers when they arrive. They also plan to have sites that are capable of handling the higher capacity 350 kW stations expected in the near future.

Utility support (in the case of SCE and PG&E) will lower the upfront cost for the installation of DCFC stations and improve the business model for operating this type of station. Utility ownership of DCFC stations (SDG&E) will provide more fast charging options to PEV drivers as well. The utilities are allowed to make a regulated rate of return on their capital investment, recovered through electric rates. This means that unlike a typical private sector charging provider, a utility can make a profit in installing DCFC even if it is just breaking even on the costs of operating a station. Investor-owned utilities in Colorado are currently prohibited from recovering the costs of charging station investments through general rates.

However, while the existing state statute does not allow investor-owned utilities to rate base any investment in chargers, it does not prohibit rate basing utility investment in the cost of electrical service to the site such as the make ready model. If another source of funding were available for the chargers themselves, such as CMAQ funding or VW funds, it could be possible to create a partnership in which the utility would pay to provide the electrical service and the other sources would provide rebates or grant funding for the chargers. Municipal and cooperative utilities do not face the same restrictions as investor-owned utilities and could invest in both DCFC stations and electrical service.

Identify Potential DCFC Station Site Hosts

Key Findings

- Due to dwell times, restaurants, large retail shopping centers , malls, big box stores and grocery stores (if they have 480V and three phase power) make good locations for DCFC stations.

The EV Project results showed that while most PEV charging is done at homes, 70 percent of the vehicles still took advantage of away-from-home charging opportunities.[50] Retail locations are primed to offer both DCFC and Level 2 charging because they anticipate a boost in sales from extended customer dwell time.[51] Instead of focusing on longer dwell times for Level 2 charging, DCFC station site hosts would want to consider locations with shorter dwell times.

In 2013, SWEEP completed a research project with CEO and RAQC that examined the average dwell times at different types of locations in the Denver metro area. The research was based on data from the Denver Regional Council of Government's (DRCOG) 2011 Front Range Travel Survey which recorded over 80,000 destinations from over 7,000 households. While originally focused on determining the best locations for Level 2 charging stations, the same data could help inform what types of destinations make the most sense for DCFC stations.

[50] Colorado Energy Office. 2015. Electric Vehicle Market Implementation Study. https://www.colorado.gov/pacific/sites/default/files/atoms/files/EV%20Market%20Implementation%20Study_0.pdf

[51] Center for Climate and Energy Solutions. 2015. Strategic planning to implement publicly available EV charging stations: a guide for business and policy makers. https://www.c2es.org/docUploads/ev-charging-guide.pdf

Rather than focusing on those destinations with the longest dwell times, destinations where drivers stay for between 15 minutes and an hour would be the best fit with the length of time people spend at DCFC stations. Another important criterion to think about when looking for new DCFC sites is the likelihood that the site already has three-phase 480V service as the cost of upgrading to this level of electrical service can be expensive.

From this list it would appear that the types of sites that would be the best candidate for DCFC stations would be restaurants, large retail shopping centers such as Costco, Walmart, malls, big box stores and grocery stores. In Colorado's urban areas, EVgo has placed their DCFC stations in large retail centers. Of the eighteen current EVgo DCFC stations in Colorado, seven are located at large shopping centers, four are located at large outdoor retail stores and four are located at Wal-Marts.

Table 1-17. Median Dwell Times by Destination

Destination	Dwell time (minutes)
Sit down Restaurant (not fast food)	60
Local Park	60
Health	55
Mall (shopping center, department store)	50
Grooming (hair, salon, nails)	45
Big Box Grocery (Costco, Sam's Club)	40
Wal-Mart/Target	33
Government Office	32
Bookstore	30
Sporting Goods	25
Thrift	25
Grocery	25
Craft	25
Veterinarian	24
Fast Food	23
Hardware	22
Repair/Maintenance (Oil Change, Dealership, Emission)	20
Library	20
Other Big Box	20
Auto Parts	17
Pet Store	16
Office Store	15

Impact of DCFC Stations on PEV Adoption Rates

Key Findings

- Cities and states with higher concentrations of DCFC stations tend to also have higher rates of PEV adoption.

There are a wide variety of factors that influence the adoption rates of PEVs, such as 'electric vehicle model availability, consumer incentives, public charging infrastructure, and local promotional activities'.[52] The International Council on Clean Transportation (ICCT) has done extensive research on the variables that impact sales of PEVs in cities and regions and a recent ICCT report concluded that "[t]he benchmarks of 200 to 300 Level 2 chargers and about 30 DCFC stations per million population correspond with the areas of highest electric vehicle adoption." [53] Per the same report, in 2015, Denver had approximately eight DCFC stations per million residents and PEVs made up less than one percent of new vehicles sales. The twelve large cities that had higher rates of PEV sales than Denver all had larger numbers of DCFC stations per capita.[54]

While the ICCT report does not explicitly quantify the influence of DCFC and Level 2 charging, the provision of large numbers of DCFC stations does have a positive relationship with PEV adoption rates. The figure below shows the relationship between these two variables based on data from the ICCT report for the fifty most populous cities in the US and indicates that higher levels of one variable correspond with higher levels of the other.[55]

More DCFC stations correlates with higher PEV sales rates

Table 1-18. DCFC Stations per Capita and PEV Sales Rates

City	Approximate DCFC/Million Residents	2015 PEV Sales Rate
San Jose	33	9.0%
San Francisco	29	5.2%
Los Angeles	13	2.5%
San Diego	22	2.4%
Sacramento	19	2.0%
Seattle	13	2.0%
Atlanta	12	2.0%
Portland	25	1.9%

[52] ICCT. 2016. Sustaining Electric Vehicle Market Growth in U.S. Cities. http://www.theicct.org/leading-us-city-electric-vehicle-2016

[53] ICCT. 2016. Sustaining Electric Vehicle Market Growth in U.S. Cities. http://www.theicct.org/leading-us-city-electric-vehicle-2016

[54] The data was taken from Figure 2. Charging infrastructure per million population in 50 most populous metropolitan areas in 2015 for public fast charging (three types), public Level 2, and estimated workplace charge points (ordered by most total charging) and Figure 6. Electric vehicle promotion actions and share of new vehicles. ICCT. 2016. Sustaining Electric Vehicle Market Growth in U.S. Cities. http://www.theicct.org/leading-us-city-electric-vehicle-2016

[55] The data was taken from Figure 2. Charging infrastructure per million population in 50 most populous metropolitan areas in 2015 for public fast charging (three types), public Level 2, and estimated workplace charge points (ordered by most total charging) and Figure 6. Electric vehicle promotion actions and share of new vehicles. ICCT. 2016. Sustaining Electric Vehicle Market Growth in U.S. Cities. http://www.theicct.org/leading-us-city-electric-vehicle-2016. These two sets of data were then combined to create Figure JJJ.

City	Approximate DCFC/Million Residents	2015 PEV Sales Rate
Riverside	17	1.6%
Austin	10	0.9%
Salt Lake City	24	0.9%
Nashville	13	0.9%
Denver	8	0.9%

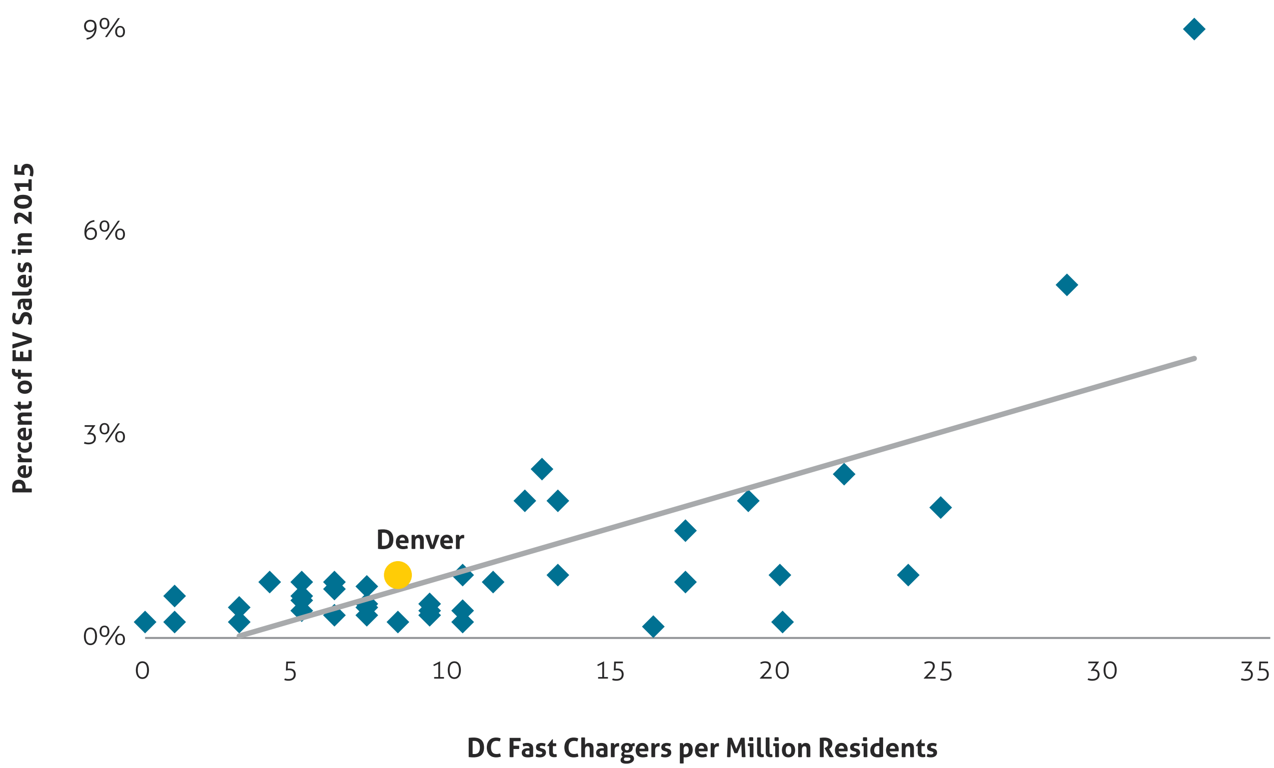


Figure 1-8. Relationship between PEV Sales Rate and DCFC Stations per Capita by City

It is also instructive to look at the provision of statewide fast charging stations as making longer distance trips outside of urban areas is a principle reason for having fast charging stations. Figure 1-9 compares the PEV sales rate in 2016 and the number of per capita DCFC ports available for each state.[56, 57]

[56] Auto Alliance. 2017. ZEV Sales Dashboard. https://autoalliance.org/energy-environment/zev-sales-dashboard/

[57] The data on DCFC by state is through April 8th, 2017 so does not perfectly match the sales data's timeline. Alternative Fuels Data Center. 2017. Alternative Fueling Station Locator. http://www.afdc.energy.gov/locator/stations/ and US Census Bureau. 2017. State Population Totals Tables: 2010-2106. https://www.census.gov/data/tables/2016/demo/popest/state-total.html

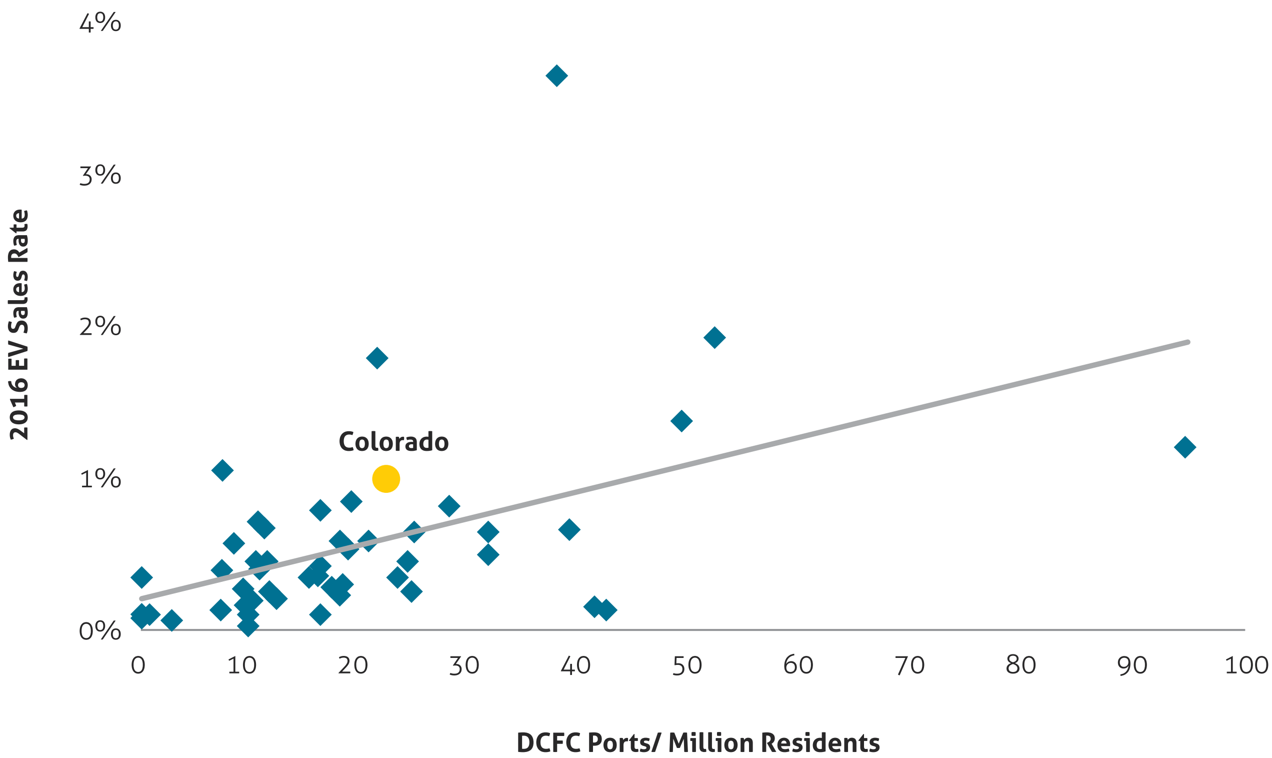


Figure 1-9. Relationship between PEV Sales Rate and DCFC Stations per Capita by State

Table 1-19. Statewide DCFC Ports per Capita and PEV Sales Rates

State	DCFC Ports/Million Residents	2016 PEV Sales Rate
California	37.6	3.66%
Oregon	52.0	1.93%
Washington	21.3	1.81%
Hawaii	49.0	1.39%
Vermont	94.5	1.22%
District of Columbia	7.3	1.05%
Colorado	22.2[58]	1.00%

[58] The number of ports per capita is higher in Colorado in 2016 than in the Denver metro area in 2015 for several reasons. First, over half (68) of the 123 DCFC stations (as pulled from AFDC) in the state are Tesla Superchargers which are almost all located outside of the Denver metro area. In addition, a number of DCFC stations were added in 2016 in both areas so only the statewide numbers reflect these new stations.

Currently, there are approximately 38 DCFC ports in the Denver metropolitan area. While increasing this number is not a guarantee that PEV sales will increase (both Phoenix and Richmond have higher per capita DCFC numbers but lower PEV sales rates than Denver), it is surely one important element contributing to greater PEV sales. The ICCT report also concludes that, "public charging infrastructure is significantly linked to electric vehicle market growth". If the Denver metro area were to increase the number of charging stations (along with continuing to expand Level 2 charging and implementing other supportive policies) it could reasonably expect to see increases in PEV sales.

Based on the experiences of other metropolitan areas, a doubling of DCFC stations in the area could help lead to a PEV market share doubling from current levels while a tripling of DCFC stations could help lead to PEV sales going up by a factor of three or more.

As discussed previously, the survey of potential PEV owners does suggest that additional DCFC stations could have an impact on the willingness of this set of potential owners to purchase a PEV. When asked what the major factor was that made them choose not to purchase a PEV, lack of charging options was the most frequent response.

Another national survey in 2015 of over 2,000 PEV owners and potential PEV owners found that they believed that "more abundant EV charging" was the "best way to promote EVs and spread the EV revolution." Potential PEV owners ranked more public charging as the second most important way to promote PEVs just behind better financial incentives.[59] The same survey also asked potential owners what features they most desired in a PEV and the top answer was access to Tesla Superchargers or a similar network (if it existed).

Input on Siting of DCFC Stations

Key Findings

- PEV owners identified fast charging along the interstates and at ski areas and recreation areas as the places they would be most likely to use DCFC stations if they were available.
- Access to DCFC stations along the interstates would increase overall electric miles traveled as PEV owners would feel comfortable taking their PEV on longer trips rather than their gasoline vehicle.
- The NREL BLAST-V modeling of fast chargers in Colorado did find that DCFC within the urbanized front range would have the highest utilization.

Surveys

The authors conducted a survey of over 250 PEV owners and 14 potential PEV owners from mainly the Denver metro area in an effort to better understand what locations would be most valuable to these people for fast charging stations.

We asked the respondents to name three destinations where they are less likely to go due to lack of charging. Answers broke down into several general categories: Front Range cities and destinations and mountain and skiing destinations.

Respondents were then asked to rank six types of potential fast charging locations (from 1 to 5) based on how likely there were to use them Overall, respondents valued fast charging along interstate corridors and at recreational destinations the most.

[59] Important Media. 2015. Electric Cars: What Early Adopters and First Followers Want. https://gallery.mailchimp.com/a897522b53d-0853c85abbf9fa/files/Electric_Cars_What_Early_Adopters_And_First_Followers_Want.pdf

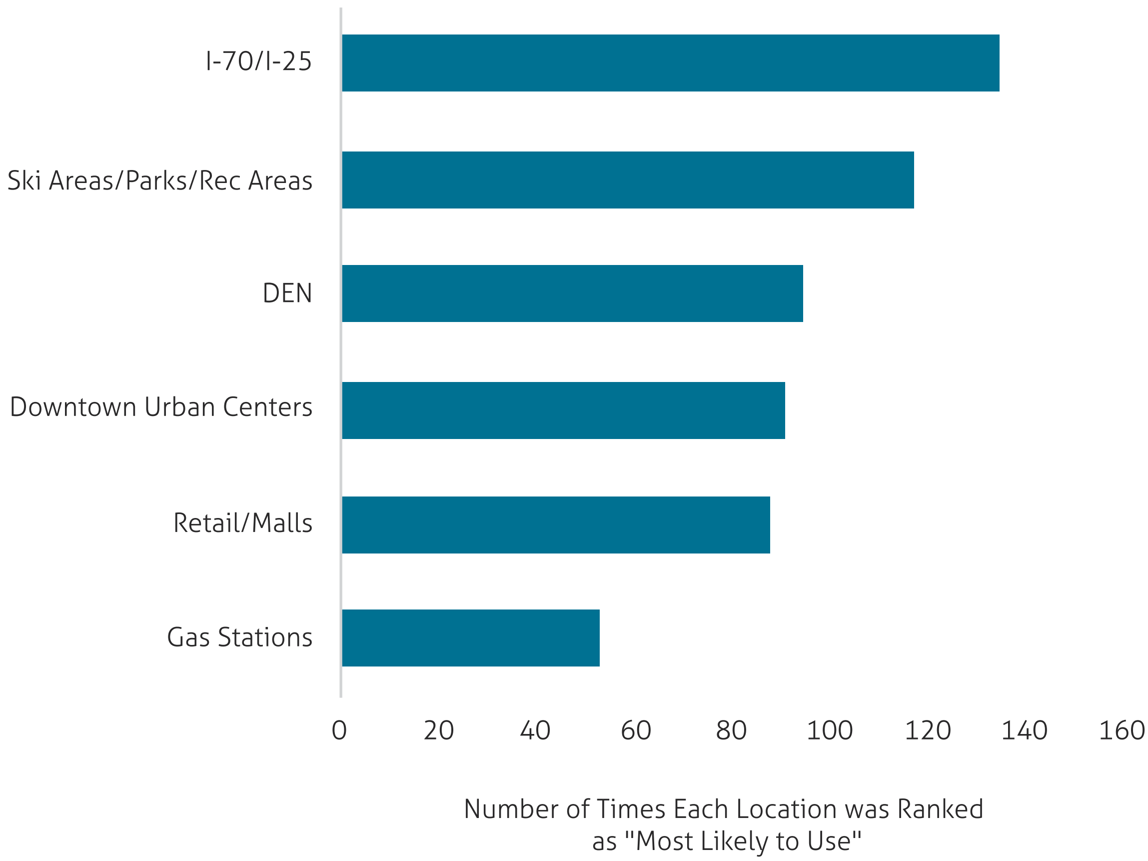


Figure 1-10. Locations for DCFC Stations Most Likely to be Used by PEV Drivers

If the results from this question are broken down between LEAF and Tesla owners one can see slightly different preferences. For LEAF owners, charging along interstates was rated as the most likely to be used, followed by DEN, downtown urban centers and recreational destinations. For Tesla owners, recreational destinations were rated the most likely to be used. Retail locations were less likely to be used by Tesla owners, which makes sense as these would fall into more local driving where Teslas would not have serious range concerns. Tesla owners also may have not placed as much priority on interstate locations because the Supercharger network already fills this need for them. For both LEAF and Tesla owners, gas stations were the least likely to be used.

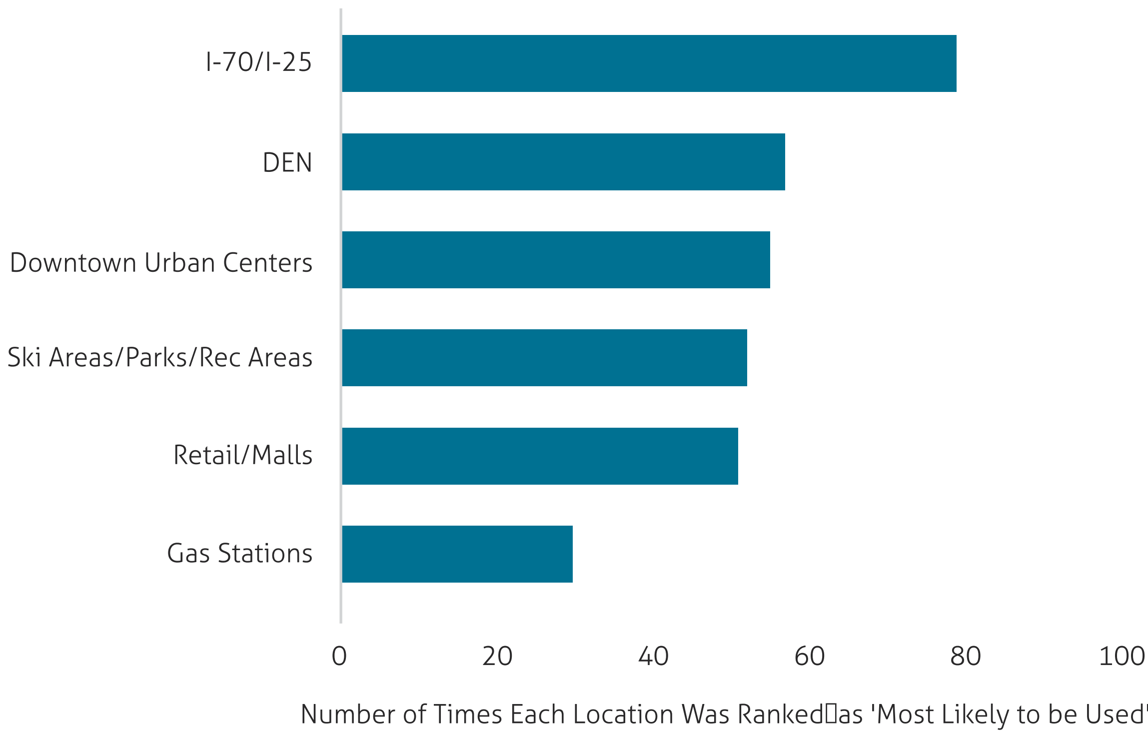


Figure 1-11. Ranking of DCFC Destinations by LEAF Owners

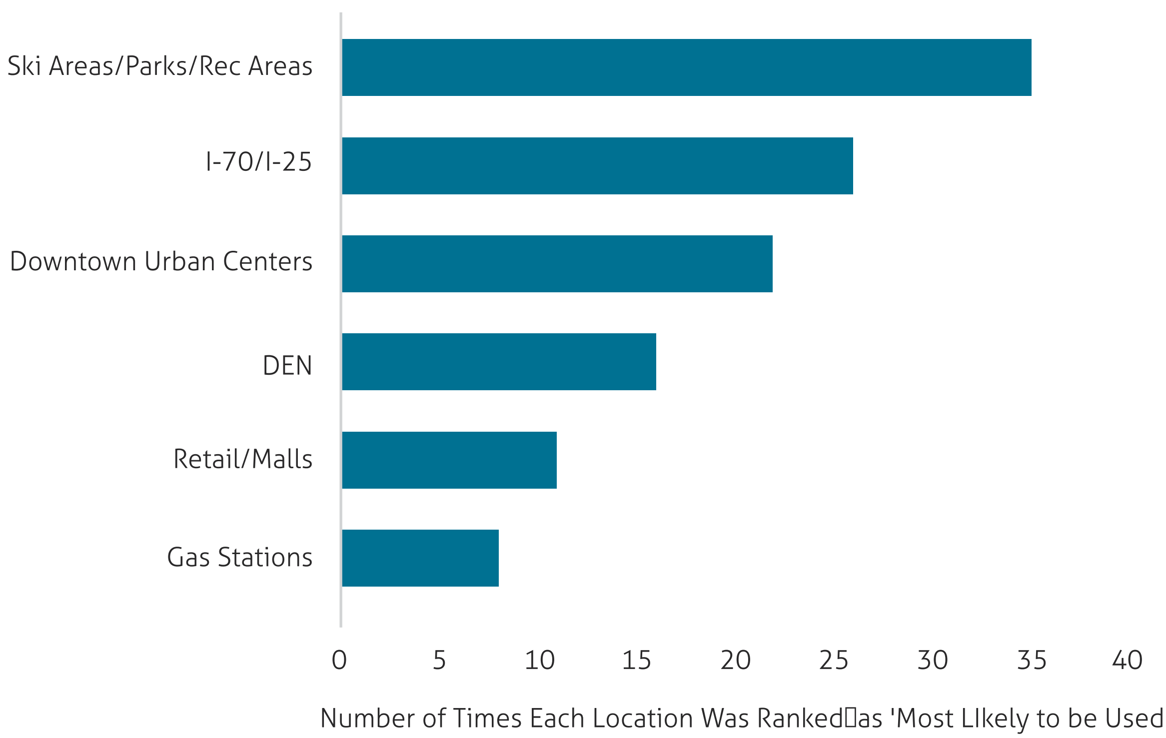


Figure 1-12. Ranking of DCFC Destinations by Tesla Owners

Unsurprisingly, looking at the crosstabs of which drivers most value charging at DEN, LEAF drivers from more distant counties (especially Boulder) are most likely to want to use DCFC stations at DEN. Of the 57 LEAF drivers who stated that they would be most likely to use fast charging at DEN, 37 were from Boulder with 18 others coming from more distant counties such as Jefferson, Douglas, Larimer and Broomfield.

The respondents were then asked, “If you had reliable and frequent access to fast charging along Colorado’s major highways, would that change where or how you drive your EV? If so, how?”

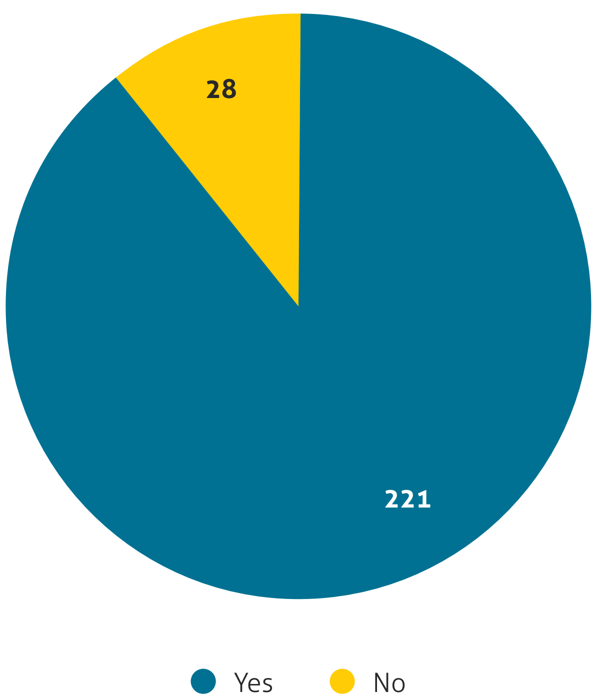


Figure 1-13. Would access to fast charging along major highways change where or how you drive?

Eighty-nine percent of respondents stated that access to fast charging along major highways would change where and how they drive their PEV. Almost all of these PEV drivers went on to state that they would drive their PEV more often and farther and many mentioned that they would be able to use their gasoline vehicle less or get rid of it altogether. Of those drivers who said ‘No’, 11 drive plug-in hybrids and five Tesla owners stated that they felt they already have access to this type of charging.

More DCFC stations would increase electric miles and reduce gasoline miles

Another survey was conducted of potential PEV owners. These are individuals who had expressed an interest in buying a PEV (as part of a group purchase program) but had decided not to. Like the PEV owners, these non-owners were asked to rank how the availability of fast charging at different location types would impact their likelihood to purchase a PEV. Like PEV owners, these potential owners identified charging along highway corridors as the top location for DCFC stations.

Input from Transportation Network Companies

The authors interviewed the Colorado general manager (GM) for Uber, and also interviewed an Uber driver who drives a BEV (a BMW i3) in order to get qualitative input on the impact that additional charging could have on adoption of BEVs by Transportation Network Company (TNC) drivers. While this is a small sample it does provide some anecdotal insight into how TNCs view DCFC stations. Both the GM and the driver stated that there is substantial interest in BEVs among those drivers who drive essentially full time and put many miles on their vehicles, driven primarily by the potential to reduce fueling costs. However, there are two major barriers they cited to greater adoption.

First is the absolute imperative to be able to complete a trip. When a driver picks up a passenger, they need to know that they will not strand that passenger partway to the destination. This makes range anxiety a significant issue.

A second issue was described as “time is money”. Drivers seek to maximize their revenue per hour, and long periods of time spent charging during the working day are not

acceptable. They stated that an Uber driver will often travel over 150 miles in a day, and that widespread adoption by Uber drivers would require an ability to comfortably drive this far in any weather conditions. The GM felt that would probably mean that Uber drivers will only move to BEVs in large numbers when 200 mile+ range BEVs are easily available. He also believed that once these are available, there will be a limited number of locations that are particularly important for fast charging. The longest trips tend to be trips from the far fringes of the Denver metro area to DEN. Both the driver and the GM stated that DCFC at the airport was the single most important location. The GM believed that a limited amount of fast charging in downtown Denver and in the communities at the edge of the metro area would be useful, but that drivers would primarily use Level 2 charging overnight once 200-mile range vehicles are available. The current driver, however, described often using charging located along metro area corridors. The GM stated that Level 2 charging at Regional Transportation District (RTD) stations would be helpful, as this would be a location where drivers without access to home charging could leave a vehicle overnight and be able to access the vehicle by transit at the start of their driving day.

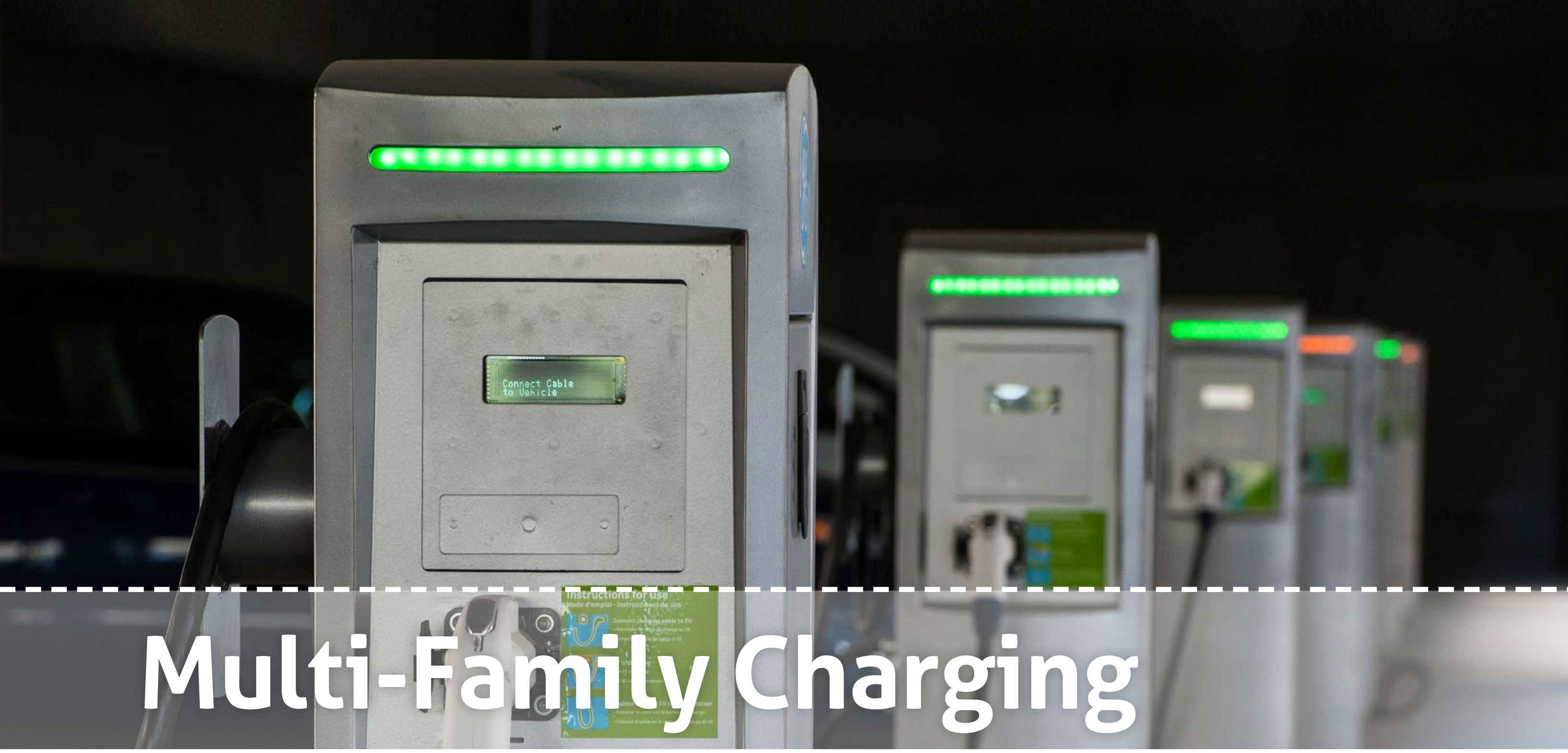
Findings and Recommendations for DCFC Stations

Findings

- DCFC stations have difficulty generating enough revenue to offset their operating costs, much less paying back their capital costs due to current utilization rates and high demand charges.
- Demand charges, which vary widely across the state, often make up 80 percent of the electric bill for DCFC station operators.
- Battery storage systems can be cost effective at reducing the impact of demand charges in areas with higher demand charges, around $20 per kW.
- The capital cost for a new, future-proofed DCFC station in an urban area is approximately $170,000.
- The capital cost for a new, future-proofed DCFC stations along an interstate highway is approximately $200,000.
- Access to DCFC stations along the interstates would increase overall electric miles traveled as PEV owners would feel comfortable taking their PEV on longer trips rather than their gasoline vehicle.
- Cities and states with higher concentrations of DCFC stations tend to also have higher rates of PEV adoption.
- A survey of PEV owners in Colorado found that:
    - PEV owners feel limited in where they drive due to lack of public charging.
    - PEV owners identified fast charging along the interstates and at ski areas and recreation areas as the places they would be most likely to use DCFC stations if they were available.
- Electric utilities could be a significant source of investment in the DCFC sector.

Recommendations

- New DCFC stations should be future-proofed to allow for higher capacity charging when these stations are available.
- New DCFC stations should be modular to allow for additional capacity to be added without the need for replacing hardware.
- Provide increased capital cost funding for new DCFC stations.
- Develop new funding to support the operating costs of DCFC stations.
- Work with utilities to develop tariffs that limit the impact of demand charges on DCFC stations.
- Engage with utilities to encourage them to invest in DCFC stations.



Multi-Family Charging

Challenges for Charging Station Deployment in Multi-Family Properties

Key Findings

- Most PEV charging takes place at home, so the availability of home charging is critical to PEV adoption.
- NREL's analysis shows that the provision of charging at multi-family residences increases electric vehicle travel by multi-family residents more than a robust set of urban DCFC stations.
- Twenty-four percent of Colorado residents and 44 percent of residents of the City and County of Denver live in multi-family housing and without access to charging at their homes these residents will be unlikely to purchase a PEV.
- The temporary nature of apartment dwellers' residency makes it challenging to convince either the tenants or building owner to invest in charging stations.
- Residents of lower income apartments face even greater barriers to access to charging.
- Compared to a single-family home, the cost of retrofitting a multi-family property may be much more challenging and expensive due to panel upgrades, trenching and new wiring.
- Research should be conducted on the financial benefits to building owners of adding charging stations to a multi-family property.

Providing charging for PEV owners who live in multi-family buildings has been a significant challenge since PEVs such as the Nissan LEAF and Chevy Volt appeared on the market in 2010 and 2011. Multi-family properties span a wide range of housing types, from triplexes to condos to large apartment buildings. There are a number of barriers that have made it difficult for multi-family residents to gain access to charging at home – and charging at home is critical as this is where over 80 percent of PEV charging has been taking place.[60]

Being able to charge at home is critical

As most vehicles spend a large proportion of each day parked at their residence, charging at home is typically the most convenient. Without access to either Level 1 or Level 2 charging at one's residence, it can be much less convenient and affordable to own a PEV. NREL's analysis of potential PEV charging scenarios in Colorado found that provision of charging at multi-family residences provided much greater benefit to these PEV owners than a robust network of DCFC stations in urban areas. With access to charging at their residences, multi-family residents driving a 100-mile range BEV are able to meet about 85 percent of their daily demand under mild ambient conditions. Without home charging (and even with a significant increase in DCFC stations in urban areas), about one-third of daily travel cannot be completed electrically.

For people living in apartment complexes, the temporary nature of their residency makes it less appealing for either the building owner or the tenant to invest time and money into setting up charging stations for the tenant. The concept of split incentives - where the owner of the building bears the costs of upgrading infrastructure but does not reap the benefits - is a challenge in many areas of energy efficiency, and PEV charging is no exception. Building owners often do not see how providing charging stations for tenants' use improves their bottom line and so are reluctant to make the initial investment necessary to install charging stations.

Initial investments in charging stations at multi-family properties (and other types of commercial properties as well) can also be expensive. In addition to purchasing a charging station, retrofitting an existing property for charging stations may involve upgrading the electrical panel to handle the new electrical load and running new wiring from the panel to the parking area which may involve digging up and resurfacing a parking lot.

Data provided by the RAQC on the costs of retrofits of multi-family buildings shows a wide range of costs. On a per-station basis, construction costs (not including the cost of the charging station) were between $2,500 and $8,000, with an average per station cost of $5,200. This nearly matches the average cost of the stations themselves which was $5,500 per station.

There are several general estimates of the expense of retrofitting a commercial property (which is similar to what would be expected for a multi-family property) for charging stations.

The CARB estimated that the median cost to retrofit a commercial property to accommodate a curbside PEV charging station would be $6,975 per charging space.[61]

Another estimate from RMI on the costs of commercial installations estimated the installation of a curbside Level 2 charging station at $5,300 to $10,150 (without including the cost of the charger). The higher end of the

[60] Idaho National Laboratory. 2015. Plugged In: How Americans Charge Their Electric Vehicles. https://avt.inl.gov/sites/default/files/pdf/arra/SummaryReport.pdf

[61] California Building Standards Commissions. 2015. EV Charging Infrastructure Provisions. https://www.documents.dgs.ca.gov/bsc/2015Tri-Cycle/CAC/GREEN/Exhibit-B-CARB-Cost-Analysis-and-Technical-Report.pdf

cost estimate reflects the need for extensive retrenching or boring of parking lots. Their analysis estimated the charging station itself would make up between 23 and 28 percent of the total installation cost.[62]

Table 2-1. Cost Estimates to Retrofit Multi-Family and Commercial Properties for a Charging Station

	Average Cost Estimate without Charging Stations
CARB	$6,975
RMI	$5,300-$10,150
RAQC	$5,200

On top of that, building owners may be reluctant to bear the ongoing costs of station maintenance, network fees and operating costs which are not always recoverable even if tenants are charged for their electricity consumption.

Higher-end apartment buildings may already offer a variety of attractive amenities such as swimming pools, common areas, and workout facilities, so including PEV charging as an additional amenity may not seem like a stretch. However, lower to moderate income buildings generally offer fewer such amenities and the tenants may be far more concerned with keeping rents affordable than having amenities. This barrier in lower income apartments is especially important because new and used PEVs are affordable in Colorado and the reduced fuel costs of PEVs could be financially beneficial to lower income families which spend more than 20 percent of their income on transportation.[63]

Condominiums, which are often owned by the resident, can present different challenges. While some condos come with an individual garage or adjacent parking area, making their situation similar to charging at single family homes, others have shared parking areas in larger garages or surface lots. When common parking areas are involved, upgrading electrical infrastructure to accommodate PEV charging stations will likely involve the HOA. With a large number of building owners involved, it can be difficult to convince a majority of residents that all residents should bear the costs of installing PEV charging stations if only a few residents are currently planning to use the stations.

And if the provision of PEV charging in multi-family housing is not addressed, a significant portion of the state's population will be much less likely to make the switch to PEVs. Statewide, about a quarter of the population lives in buildings with three or more units.[64] In the Denver metro area, this percentage increases to 29 percent and in Denver, this percentage rises to 44 percent.[65]

Without charging at their homes, multi-family residents are unlikely to buy a PEV

The Electric Vehicle Market Study's Medium EV Growth Scenario assumes a 24 percent increase in annual PEV sales in Colorado.[66] If this rate persists through 2020, there will be approximately 28,000 PEVs in the state.[67]

[62] Agenbroad and Holland. 2014. Pulling Back the Veil on EV Charging Station Costs. http://blog.rmi.org/blog_2014_04_29_pulling_back_the_veil_on_ev_charging_station_costs

[63] Mile High Connects. 2014. Reducing Transportation Costs in the Denver Region through Expanded Transit Pass Programs. http://milehighconnects.org/wp-content/uploads/2015/01/RTD-Pass-Program-Report-2015.pdf

[64] US Census. 2017. Table B25024: Units in Structure 2011-2015 American Community Survey 5-Year Estimates. https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t

[65] US Census. 2017. Table B25024: Units in Structure 2011-2015 American Community Survey 5-Year Estimates.

[66] Colorado Energy Office. 2015. Electric Vehicle Market Implementation Study. https://www.colorado.gov/pacific/energyoffice/atom/14086

[67] This is based on there being 8,500 EVs in the state at the end of 2016.

If approximately two-thirds of all PEV sales continue to take place in the Denver metro area, this would mean that there would be approximately 18,500 PEVs in this region.

If the number of PEVs was evenly distributed between those in single/two family homes and those in multi-family dwellings, there would need to be about 5,300 PEV owners who lived in multi-family dwellings in the Denver metro area. This would be a good metric to consider when thinking of the level of charging access the region needs.

This research details the challenges and barriers faced by multi-family residents and provides potential solutions to overcome these barriers. The following section is based on interviews with residents of multi-family housing (both apartments and condos), developers and building owners and gives their different perspectives and experiences regarding PEV charging. The second section examines some of the regulatory measures that local governments could adopt to make new multi-family housing more likely to support PEV charging stations. The final section details ways to increase access to charging at existing multi-family dwellings.

Summary of Insights from Interviews with Multi-Family Residents, Developers and Building Owners

The following discussion of the dynamics around charging in multi-family dwelling units is based on a number of interviews conducted with:

- Residents of various types of multi-family dwellings who own PEVs
- Developers
- Apartment building owners and managers

When discussing the installation of charging stations in multi-family dwelling units it is helpful to distinguish between types of multi-family dwellings because the challenges and barriers are not the same for different housing types. One general category of multi-family housing is occupant-owned condos which are generally run by a homeowners association (HOA) and another general category is rented apartments or condos run by either an HOA or a property management company.

Owned Multi-Family Units

This type of housing can be further broken down by the type of parking that is available: either dedicated garages, larger shared garages, dedicated surface parking or shared surface parking.

While installing charging stations in owned condos does present a number of challenges, many of these challenges are similar to what the owner of a single-family home might experience. This is especially the case when condo owners have individual garages connected to the same electric meter as their unit. In this case, the challenges faced by the condo owner are the potentially high costs to run new wiring or upgrade their electrical panel. As the owners of the property, they are generally responsible for this type of upgrade and have the ability to makes this type of upgrade without the need for approval by the HOA.

For condo owners using a larger shared garage or surface parking there may be a number of additional challenges. First, each parking space (which is often deeded to an individual unit) may not already have the infrastructure to support a PEV charging station. This may require wiring to be run to serve the individual space. An additional challenge is that the parking space of the resident interested in installing a charging station may not be located near the existing electrical infrastructure. The further from the existing infrastructure the space is, the higher the likely installation costs. While hypothetically it would be easy for a resident to switch parking spaces with another resident whose space is located next to the existing electrical infrastructure, several interviewees noted that people may be unwilling to change their parking spaces.

An additional challenge is that in a shared garage or parking lot situation, the existing electrical panel serving this area is unlikely to be that of the residents interested in installing a charging station. In the situation where

an electrical panel upgrade is necessary to accommodate one or more charging stations, it becomes difficult to determine how to pay for the upgrades. Should the residents interested in installing charging bear the entire cost of the upgrade even though it is for a shared panel or should the community pay for an upgrade that would mostly benefit one or two residents in the near-term?

A different set of challenges exist when a community is interested in providing shared PEV charging stations (rather than ones dedicated to individuals). A number of interviewees stated that there was significant pushback to the idea of providing 'free' charging to residents as this was an amenity that only a few residents would benefit from. While HOA members may be willing to pay for infrastructure upgrades to the property, providing a continual subsidy to PEV owners appeared to be a sticking point. One solution to this is to have the PEV owners pay for the electricity they use via a smart charging station.

Another challenge with shared PEV charging stations is that the community may not have extra parking spaces that it can dedicate to PEV charging. If the community is in a situation where there is already more demand for parking spaces than available spaces it may be extremely difficult for the HOA to dedicate one or more spaces to PEV charging. If there is sufficient additional parking it becomes much easier for the community to dedicate spaces to PEV charging as the community will not feel like they are giving anything of value up. This barrier also exists in rented multi-family communities.

Rented Multi-Family Units

Perhaps the largest barrier identified by both multi-family residents and building owners to installing PEV charging is the temporary nature of the residents. For residents, it may not make sense to pay to upgrade a garage or a parking area with a charging station if they are unsure how many more years they will live in that apartment. Likewise, building owners are unlikely to spend hundreds or thousands of dollars to upgrade individual units or parking areas to accommodate PEV charging if they have no guarantee that the PEV owning tenant will be there one year from now or if future tenants will value the charging station.

One piece of evidence that may help to convince building owners to install PEV charging for their residents is information on how this investment pays off for them. If a building owner does not think that they will be able to charge higher rent, increase tenant retention or that charging stations will increase the resale value of the property, then they are unlikely to invest in charging. If the building owner believes that they can recover their initial investment costs and make a profit by installing charging stations, then they will be more receptive to the idea. For most building owners and developers, the bottom line is more important than a desire to be perceived as environmentally friendly. To date, there has not been any research done on the impact that the existence of charging stations (or PEV Ready design) has on multi-family property values.

> *Without a clear financial benefit, building owners may be reluctant to provide access to charging*

An interesting historical parallel may be found in the solar photovoltaic (PV) world. For many years, builders and developers were reluctant to install or offer rooftop solar panels because they did not believe it added enough value to a property or that customers desired this feature. Eventually, after a number of years of sale and resale of properties with solar PV, it became clear that rooftop panels do add value to a property.[68]

[68] EnergySage. 2016. FHA and Fannie Mae agree: A solar panel system adds value to your home (if you own the system). http://news.energysage.com/fannie-mae-solar-financing-owning-vs-leasing/

Figure 2-1. Continuum of Difficulty for Multi-Family Charging Stations

	Easiest	
New Build	↕	Owned Condos w/Garages Owned Condos w/Shared Garages/Lots • Dedicated EVSE • Shared EVSE
Retrofit		Apartments • Low Income Apartments
	Hardest	

Key Findings

- Adopt building codes that, at a minimum, require the provision of conduit or wiring between the electrical panel and the parking area and sufficient additional panel capacity for future charging stations.
- Include charging station readiness or provision as an option in discretionary review processes.

Additional Challenges in Lower Income Apartments

In the short-term it may make sense to focus efforts on higher end apartment complexes that offer a variety of amenities such as swimming pools, hot tubs, workout facilities, and coffee bars to residents. This is the type of community where PEV charging may be seen as an attractive amenity. A review of rental properties in the Denver metro area found a handful of apartment complexes offering PEV charging as a building amenity. However, the average price for the least expensive one bedroom apartment option in these complexes offering PEV charging was $1,600 per month, above the average rent of $1,367 for a one bedroom apartment in the area.[69]

Regulatory Approaches for Encouraging Charging Stations in Multi-Family Housing

One way to make PEV charging more available in multi-family developments is to require it to be incorporated into any new multi-family housing. While this will only directly impact new construction or properties undergoing major remodels, this type of requirement should put market pressure on existing multi-family developments that will be competing with new buildings for tenants and owners.

Discretionary Review

As part of applying for building or construction permits, some municipalities require builders or developers to undergo some kind of review, above and beyond what the local building codes mandate. Several examples are given below.

In the City of Boulder, larger residential developments that generate over 20 vehicle trips per hour are required to undergo a site review which involves a Transportation

[69] Rent Jungle. 2017. Rent Trend Data in Denver, Colorado. https://www.rentjungle.com/average-rent-in-denver-rent-trends/

Demand Management (TDM) plan to reduce vehicle travel. The installation of charging stations is one option that new developments can choose to help complete their TDM plan.

In order to help meet the city's Climate Action Plan, the City of Chino, California requires that new developments in the city achieve energy savings of three percent beyond the California Energy Code. One of the ways to achieve the additional GHG savings is to include PEV charging for the new building.[70]

The City of Menlo Park in California allows the installation of PEV charging stations to serve as a potential mitigation measure to reduce the overall greenhouse gas impacts of new developments.[71]

The City of Redmond, Washington allows builders and developers the possibility of receiving different incentives such as height bonuses, floor area ratio bonuses and building setback flexibility for commercial properties that incorporate certain green building and green infrastructure features. Two ways for a commercial property to receive a point towards the incentive are to install two PEV charging stations on-site or to reserve five percent of required parking spaces for low-emission vehicles.[72]

Parking

Another municipal tool that could be used to encourage PEV stations in new multi-family developments is to allow spaces with charging stations "extra credit" towards meeting the site's parking requirement. The City of Grand Rapids, Michigan allows the provision of one reserved, signed and enforced PEV parking space complete with charging outlet-to count for the provision of four regular parking spaces with regards to off-street parking requirements.[73] This is an interesting approach, which combines an incentive for PEV adoption with a reduction in the total number of parking spaces, which may fit well in more urbanized areas where space is limited.

PEV Ready Building Codes for Multi-Family Developments

States and municipalities across the country have adopted building codes that require that new multi-family developments have some level of PEV readiness. PEV readiness may be as simple as extra panel capacity and conduit run to the parking area for future PEV charging or as much as requiring the installation of a certain number of Level 2 charging stations. This type of requirement could also be incorporated into a municipal zoning code, as has been done in Salt Lake City.

> *PEV Ready building codes have been adopted across the country*

Below is a table that summarizes the PEV Ready building codes adopted by a number of jurisdictions. This list is not meant to be exhaustive (many other communities have adopted these type of codes) but rather to provide examples of the different levels that could be adopted. The actual code language from each of these jurisdictions is provided in Appendix C.

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70 Chino, CA. 2017. Chpater15.45 Climate Action Plan Implementation. https://www.municode.com/library/ca/chino/codes/code_of_ordinances?nodeId=TIT15BUCO_CH15.45CLACPLIM_15.45.070GHPESTNEDE

71 Menlo Park. 2014. Attachment A. Mitigation Measures. https://www.menlopark.org/DocumentCenter/View/4635

72 Encodeplus. 2014. Green Building and Green Infrastructure Incentive Program. http://www.zoningplus.com/regs/redmond/acc/docview.aspx?tocid=005.004

73 Grand Rapids, Michigan. 2010. Zoning Ordinance. http://grcity.us/design-and-development-services/Planning-Department/Documents/13873_ZONING%20ORDINANCE%20TEXT%20last%20amended%20September%2028,%202010%20FOR%20WEB.pdf

Table 2-2. Summary Table of PEV Ready Building Codes for Multi-Family Developments

Jurisdiction	Minimum Requirement	Minimum Development Size	Percentage of Spaces
State of California	Panel capacity and conduit for future stations	17 or more units	3% of spaces
Boulder County	240V outlet installed	All new multi-family	2-4% of spaces
Palo Alto, CA			
• Resident Parking	240V outlet installed	All new multi-family	One outlet for each unit
• Guest Parking	Panel capacity and conduit for future stations	All new multi-family	25% of guest parking spaces. 5% of guest spaces must have an EVSE
City of Boulder	One 240V and one 120V outlet installed;	25 or more parking spaces	10% of spaces; 2 spaces must have an EVSE
Salt Lake City (Proposed)[74]	Panel capacity and conduit for future stations	All new multi-family	20% of spaces

Innovative Charging Solutions for Multi-Family Dwellings

Streetlight Conversion and Charging

One way that multi-family dwellings could provide charging while avoiding potentially expensive electrical infrastructure upgrades would be to take advantage of the energy savings of converting lighting to light emitting diodes (LEDs).

The City of Oakland retrofitted a parking garage with LED lights with controls and reduced energy use by 45 percent. This allowed the city to install a number of PEV charging stations at the garage without the need for extensive electrical work. The entire project was paid for with the electricity savings from the lighting replacement.[75]

Key Findings

- Increase the maximum funding for multi-family properties in Charge Ahead Colorado, especially for apartment buildings.
- Focus the deployment of DCFC stations in mixed-use areas that would be convenient for multi-family housing residents.
- If current legislative barriers to utility involvement can be removed, investor-owned utilities could be a significant source of investment in charging stations in the multi-family sector. Utilities still can play an important role in investing in electrical service to support multi-family charging under current statutes.
- Municipal and cooperative utilities do not face the same restrictions as investor-owned utilities and could invest in both charging stations and electrical service.

[74] Salt Lake City's requirement is actually in the City's zoning code as municipalities in Utah are not able to adopt their own building code which is set by the state legislature.

[75] Charged Electric Vehicles Magazine. 2014. How to avoid electrical infrastructure upgrades when installing EVSE. https://chargedevs.com/features/how-to-avoid-electrical-infrastructure-upgrades-when-installing-evse/

Common parking areas (outdoor parking lots and indoor parking garages) at multi-family buildings will have lighting which may be older technologies such as incandescent or high pressure sodium lights. By replacing these lights with much more efficient LED lights, the property could provide the same amount of light using one-third the energy.[76] In addition, properties should experience reduced maintenance needs as LEDs have a longer lifespan and need to be replaced less frequently.

For outdoor lighting, each light pole may have energy savings between 50 and 300 watts, depending on the size of the current fixture. With the capacity saved by converting multiple fixtures to LEDs there should be enough amperage to install charging stations without the need for an expensive panel upgrade. To free up enough capacity for a Level 1 charging station between four and twenty lights would need to be replaced. So the number of stations or outlets that could be installed would depend on the number of lights in the parking lot. Wiring may need to be upgraded depending on where the stations or outlets would be installed and the current wiring situation.

Installing regular Level 1 outlets would likely be the least expensive way to provide charging access in the parking area though Level 1 charging stations would also be an option that would limit the need for PEV owners to use their own cord. One challenge may be if outlets or non-networked chargers are used to reduce capital costs, the building owner will likely have to pay for the cost of the electricity used by the PEVs.

BMW has developed a streetlight called the "Light and Charge" that comes with chargers for PEVs and a prototype of this system is currently being tested in Los Angeles and Seattle.[77]

Utilities

California's three major investor-owned utilities all have California Public Utilities Commission (CPUC) approved plans to provide chargers at multi-family units, workplaces and in disadvantaged communities. The active involvement of these utilities will greatly reduce the costs for multi-family properties interested in installing charging stations.

SCE's plan will spend $22 million to install 1,500 charging stations at multi-family units and workplaces. SCE will own all of the infrastructure save the charging stations and will offer customers rebates to defray the cost of buying and installing the stations. Ten percent of the sites are to be located in disadvantaged communities. Multi-family installations will receive 50 percent off the cost of buying and installing the stations. Other commercial properties receive 25 percent off the cost.[78]

PG&E's plan aims to install 7,500 charging stations at a cost of $130 million in its service territory with the goal that half of these stations are located at multi-family dwellings.[79] Generally it will not own or operate the stations, but in the case of installations at multi-family developments it will be able to own and operate up to 35 percent of the stations. This should help overcome reluctance from some multi-family building owners

[76] U.S. Department of Energy US Department of Energy. 2016. Caliper. https://energy.gov/sites/prod/files/2016/10/f33/snapshot2016_outdoor-area.pdf

[77] BMWBlog. 2016. Future Mobility Solutions: Light and Charge. http://www.bmwblog.com/2016/01/05/future-mobility-solutions-light-and-charge/

[78] Southern California Edison. 2017. Charge Ready Program. https://www.sce.com/wps/portal/home/business/electric-cars/Charge-Ready/!ut/p/b1/pZJNc4IwEIb_ihePTJaAEI7R0hD8_qxwcUKMSquokNb674utPbOzap3uaXfm2Xfe3XlRjKYozsRbuhQ63WZifZpjZxbyB2oyG_PuqImBjge9Fnm0wWFmCUQlABeKws99aAQ1oEEjZO2xCbxZQ08oRrHM9E6vUFRINZPbTKtMz1RWhXNfheS1SDNVFFVQayV1nsqKFHk5ypX-Il6qSKzE_npR2Mp2jSIHEGBNpKFMkhu25tiEcd2FIIUE6yvUStTg7v2LtxuWfzq8jX4BJGA34EDgZMR94vQnepIdD0nZ-A2zgYuDhxG916yYGG-58Bj4EfhN0SGPUt4FYfOkNKLYBvhSv_j8oz3YsmiY2Gd_7thqBzt2D4h4ylz_t9TMuknBLxrtH0n1HZbcYbYh2Nl4G_6HQMkZDj4QP5yuE2/dl4/d5/L2dBISEvZ0FBIS9nQSEh/

[79] Sierra Club. 2016. California Public Utilities Commission Unanimously Approves Electric Vehicle Charging Program. http://content.sierraclub.org/press-releases/2016/12/california-public-utilities-commission-unanimously-approves-electric-vehicle

to host stations. The other 65 percent of multi-family stations will receive rebates from PG&E for up to 50 percent of the installation cost of the stations.[80] The PG&E program provides the full cost of electrical service to the site and provides higher rebates for the charging stations for multi-family than for workplace charging, in recognition of the extra challenges.

SDG&E's program will spend $45 million to support the installation of 3,500 charging stations at 350 sites in their service territory. Ten percent of the sites are to be located in disadvantaged communities. SDG&E will own and operate the charging stations meaning building owners will not need to pay any upfront or ongoing costs to host the stations though a participation payment fee will be assessed.[81]

The Los Angeles Department of Water and Power (LADWP) (not one of the investor-owned utilities) has a program to provide $21.5 million of rebates to residential and commercial customers. Multi-family building owners can receive up to $4,000 for each installed Level 2 station with the number of rebates available per site dependent on the number of parking spaces in the lot.[82]

Austin Energy is another utility offering rebates and assistance to multi-family properties interested in installing charging stations. Multi-family properties can receive up to $4,000 off the capital and installation costs for a Level 2 stations and up to $10,000 off the cost of DCFC station.[83]

Currently in Colorado, investor-owned utilities are prohibited from recovering the costs of investments in charging stations from all ratepayers. A bill that would give the state's IOUs the ability to do so failed to pass during the 2017 Legislative session in Colorado. However, while the existing state statute does not allow the utility to rate base any investment in chargers, it does not prohibit rate basing utility investment in the cost of electrical service to the site. If another source of funding were available for the chargers themselves, such as CMAQ funding or VW funds, it could be possible to create a partnership in which the utility would pay to provide the electrical service and the other sources would provide rebates or grant funding for the chargers. Municipal and cooperative utilities do not face the same restrictions as investor-owned utilities and could invest in both charging stations and electrical service.

Public Grants

Currently, the public charging that is available in Colorado is offered through the Charge Ahead Colorado program, which offers grants for both Level 2 and DCFC stations for a variety of sites, including multi-family, workplace, and public charging. For Level 2 charging stations at multi-family buildings, the maximum grant for a dual-port station is 80 percent of the cost of the station, up to $6,260. Under the current program structure, the maximum grant amount does not vary between multi-family and other types of location. Given the unique challenges associated with installing charging in existing multi-family sites and the importance of

80 Luskin Center for Innovation. 2011. Addressing Challenges to Electric Vehicle Charging in Multifamily Residential Buildings. http://innovation.luskin.ucla.edu/sites/default/files/EV_Multifamily_Report_10_2011.pdf

81 San Diego Gas and Electric. 2016. Power Your Drive. http://www.sdge.com/clean-energy/electric-vehicles/poweryourdrive

82 Los Angeles Department of Water and Power. 2017. Drive Electric. https://www.ladwp.com/ladwp/faces/ladwp/residential/r-go-green/r-gg-driveelectric?_adf.ctrl-state=bfy93z6i4_4&_afrLoop=97606211998771

83 Austin Energy. 2017. Plug-In Austin. http://austinenergy.com/wps/portal/ae/green-power/plug-in-austin/multifamily-properties/!ut/p/a1/jdDBjoIwEAbgZ_HAUTrWuKK3Wgmy6nISsRdTTYEmQJtSl-w-vRgvamDXuU3y_ZnJjxhKEKv4t8y4larixW1nH0fAHl5RwGEwxR6OgC7Wk_hr-NAtHLTg8gsiPlhDGUUyiNYWAjt_M9wyB__KfbxzAZku3GWKa23woq1ShpLwUVqa8lMXPUBulhbFS1DdMqtPYa7ERqTDCuBfTtpBbq-u5Aw40T-eNmSmWFcM-qdKArkqvaouRZoj1if71KfPwKOrq8g_6ydLlLfjdi79lZKMlgcAUMQIOB/dl5/d5/L2dBISEvZ0FBIS9nQSEh/?&projectid=23a0eb71-771f-4e75-8203-0d88e0856d7f

providing access to charging at residences one option to consider would be allowing a larger grant cap for multi-family housing. A related approach would be for a local government to provide additional funding, in addition to the Charge Ahead Colorado funding, for charging in multi-family sites.

Multi-family properties should receive additional funding

Other Potential Solutions

One other potential solution to charging in multi-family units is to try to create partnerships between businesses which have charging stations for their customers or employees which are located in mixed-use areas near multi-family buildings without charging stations. Especially if the business operates during standard workday hours (say from 8 a.m. to 5 p.m.) its charging stations would likely remain unused for the majority of the 24-hour day. These unused hours would correspond well to when most people's vehicles are parked at their residences. By increasing utilization and charging multi-family residents to use the stations during the night, business owners could recover a greater percentage of their costs for installing and hosting the charging stations.

Another potential model would be to install DCFC stations near multi-family buildings which would give PEV drivers living there a convenient charging option that they could use less frequently. Depending on a site's electrical infrastructure, installing one DCFC station may be easier and less expensive than installing several Level 1 or Level 2 stations. These also could be shared stations, used by multiple multi-family buildings and nearby businesses. This may be a particularly attractive option in larger mixed-use developments.

Findings and Recommendations for Multi-Family Buildings

Findings

- Most PEV charging takes place at home, so the availability of home charging is critical to PEV adoption.
- NREL's analysis shows that the provision of charging at multi-family residences increases electric vehicle travel by multi-family residents more than a robust set of urban DCFC stations.
- Twenty-four percent of Colorado residents and 44 percent of the residents of Denver live in multi-family housing and without access to charging at their homes these residents will be unlikely to purchase a PEV.
- Due to the wide range of types of multi-family dwellings there are a variety of barriers and challenges in different types.
- The temporary nature of apartment dwellers residency makes it challenging to convince either the tenants or building owner to invest in charging stations.
- Residents of lower income apartments face even greater barriers
- Compared to a single-family home, the cost of retrofitting a multi-family property may be much more challenging and expensive due to panel upgrades, trenching and new wiring.
- If current legislative barriers to utility involvement can be removed, investor-owned utilities could be a significant source of investment in charging stations in the multi-family sector. Even under current statute, investor-owned utilities could be an important source of investment in electrical service for multi-family charging.

- Municipal and cooperative utilities do not face the same restrictions as investor-owned utilities and could invest in both charging stations and electrical service.
- Residents of condominiums with shared parking areas face challenges in determining who pays for infrastructure upgrades and how to best charge residents for use of chargers.

Recommendations

- Adopt building codes that, at a minimum, require the provision of conduit or wiring between the electrical panel and the parking area and sufficient additional panel capacity for future charging stations.
- Increase the maximum funding for multi-family properties in Charge Ahead Colorado, especially for apartment buildings.
- Include charging station readiness or provision as an option in discretionary review processes.
- Focus the deployment of DCFC stations in mixed-use areas that would be convenient for multi-family housing residents.
- Research should be conducted on the financial benefits to building owners of adding charging stations to a multi-family property.

Air Quality Analysis

The authors have conducted a well-to-wheels emissions analysis showing that in the Denver metro area, light-duty PEVs reduce emissions of pollutants compared to a similar gasoline-fueled vehicle. This analysis uses the average power mix in the Denver metropolitan area.

In 2016, compared to a gasoline vehicle, BEVs effectively eliminated emissions of VOCs and significantly reduced NOx and GHG. Plug-in hybrid eclectic vehicle's (PHEV) provide significant reductions in all three pollutants. As the electric grid serving Denver becomes cleaner over time so will PEVs, and by 2025 they will provide even greater emissions benefits to the region.

The air quality benefits to the metropolitan region are greater than one would conclude by looking at the average electricity mix. Since many power plants (especially coal-fired plants) that supply electricity to the metropolitan region are located outside the urban airshed, they do not contribute to air pollution in Denver.

Denver and the surrounding areas face serious air quality challenges, and mobile source emissions are the leading cause of ground-level ozone in the region. Supporting widespread adoption of PEVs is an important strategy for addressing air quality in the region.[84]

Air Quality Results

Key Findings

- In 2016, a BEV reduced emissions of NOx by 38 percent, VOCs by 99 percent GHG emissions by 30 percent compared to a new gasoline vehicle.
- Compared to an average gasoline vehicle on the road in 2016, NOx is reduced by 63 percent, VOCs by 99 percent and GHG by 43 percent.
- Due to a much cleaner electricity mix by 2025, a BEV will reduce NOx emissions by 84 percent, VOC emissions by 99 percent and GHG emissions by 49 percent compared to a new gasoline vehicle in that year.
- Based on GHG emissions, the equivalent of a BEV would be a gasoline vehicle with a fuel economy of 47 mpg in 2016 and 75 mpg with the 2025 electricity mix.

[84] U.S. Environmental Protection Agency. 2017. Air Emission Sources. Retrieved from https://www.epa.gov/air-emissions-inventories/air-emissions-sources

2016 Results

In 2016, the analysis shows that a PEV charging in Denver on Xcel Energy's average electricity mix reduced emissions of all three pollutants compared to an average existing and a new gasoline-fueled vehicle.[86] Table 3-1 and Figures 3-1 to 3-3 break down the reductions in harmful air pollutants from PEVs. From a GHG emissions perspective, the equivalent gasoline vehicle has a fuel economy of 47 mpg compared to a BEV and 44 mpg compared to a PHEV.

For GHG, A BEV is equivalent to a 47 mpg gasoline vehicle

Table 3-1. PEV Percent Reduction in Emissions in 2016 Compared to Gasoline Vehicles

	BEV		PHEV	
	Average Gasoline Vehicle	New Gasoline Vehicle	Average Gasoline Vehicle	New Gasoline Vehicle
VOC	99%	99%	84%	73%
NOx	63%	38%	57%	28%
GHG	43%[87]	30%	39%	25%

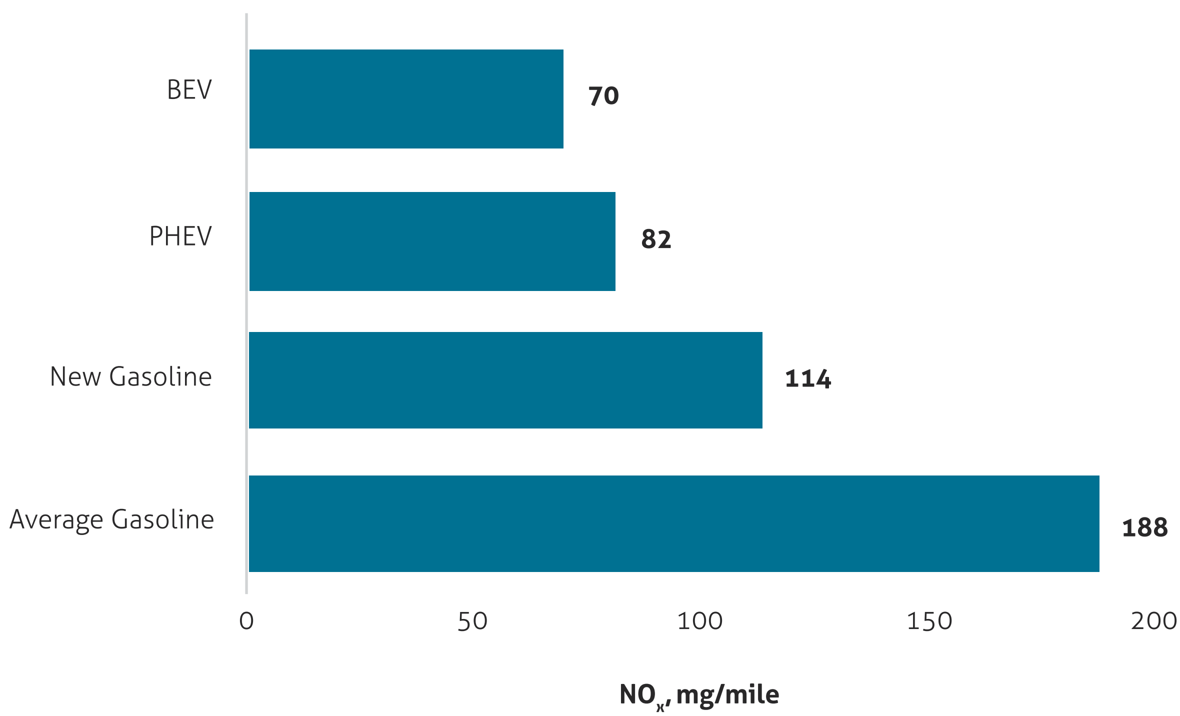

Figure 3-1. NOx Emissions in Denver by Vehicle Type in 2016

[86] The average vehicle on the road is assumed to be 11 years old so this would be a model year 2005 vehicle.

[87] The 43 percent reduction in GHG is similar to what was found in the Colorado Electric Vehicle Market Implementation Study completed in 2015. The Market Study compared an existing gasoline vehicle with a fuel economy of 23 mpg with an electric vehicle based on the 2013 statewide grid mix. This study compared an existing gasoline vehicle with a fuel economy of 26 mpg with an electric vehicle based on Xcel Energy's 2016 grid mix (which is cleaner than the 2013 statewide mix.)

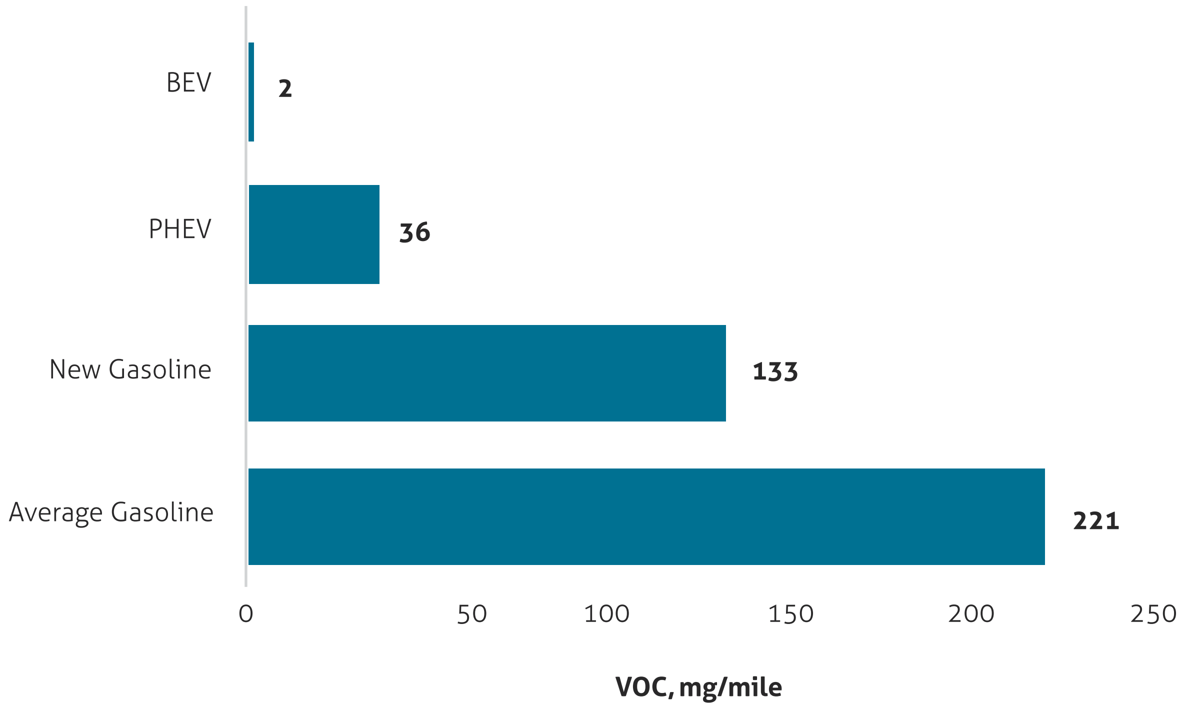

Figure 3-2. VOC Emissions in Denver by Vehicle Type in 2016

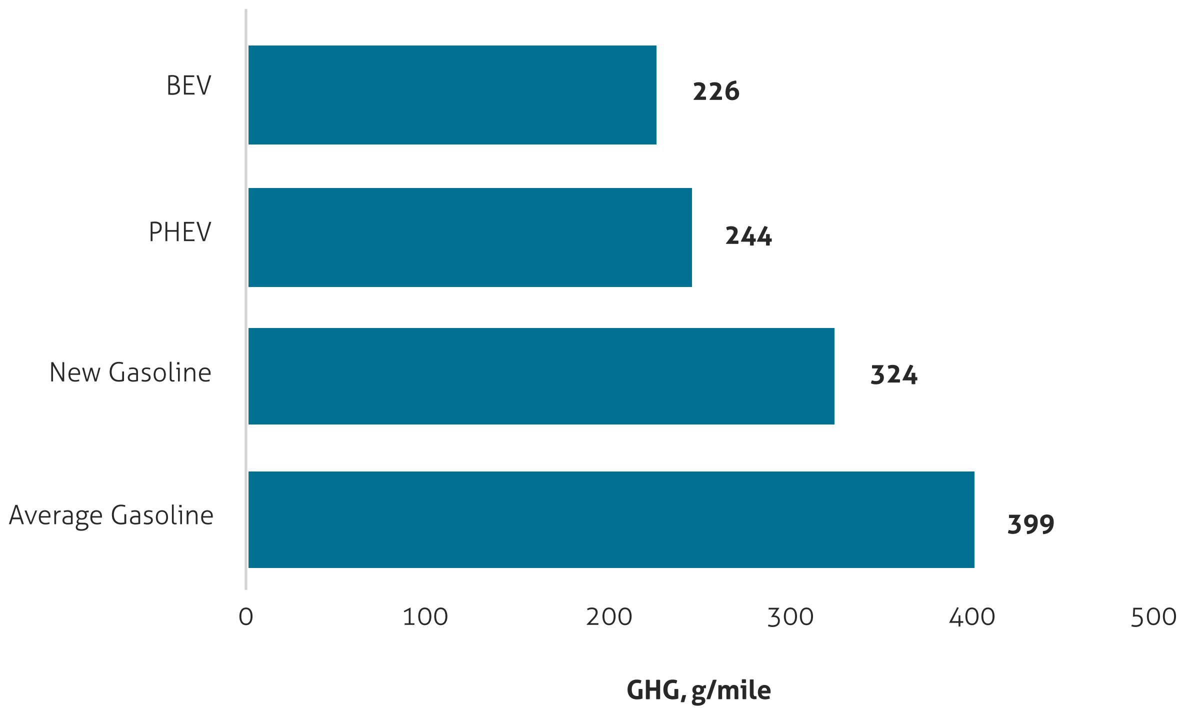

Figure 3-3. GHG Emissions by Vehicle Type in 2016

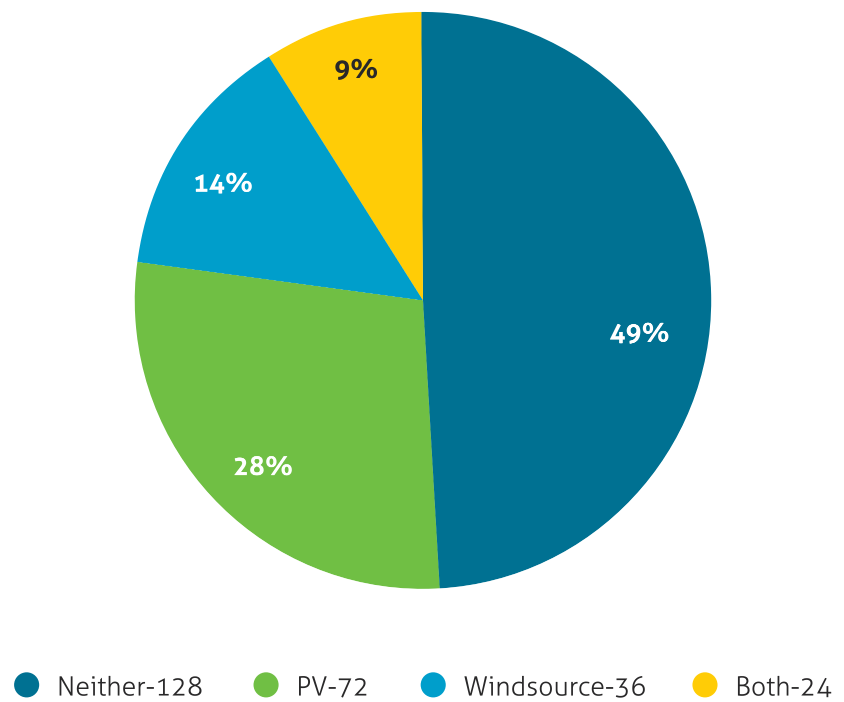

Figure 3-4. Do you have rooftop solar PV panels or are you enrolled in Xcel Energy's Windsource program? (260 Responses)

It is also important to consider the emissions profile of a BEV if it is being powered by a greater share of renewable electricity. Based on surveys conducted by the authors with PEV owners in Colorado, a high percentage of them either have solar PV on their rooftops or are subscribers to Xcel Energy's Windsource program.

Of the 260 respondents, just over half of them have either solar PV, are subscribed to Windsource or both. While the survey population is likely weighted towards early adopters who might be more likely to value renewable energy, it still seems likely that a good proportion of PEV owners are powering their vehicles with an electricity mix cleaner than the existing Xcel mix.

Other surveys have also shown strong connections between people who have solar PV and PEVs. A survey of California PEV owners in 2012 found that 39 percent of PEV owners had solar PV.[88] A more recent survey found that about 50 percent of respondents who have either solar or a PEV have both.[89] A large survey of PEV owners found that 37.5 percent of PEV owners had solar panels on their roof.[90]

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[88] Center for Sustainable Energy. 2012. California PEV Owner Survey. https://energycenter.org/sites/default/files/docs/nav/policy/research-and-reports/California%20Plug-in%20Electric%20Vehicle%20Owner%20Survey%20Report-July%202012.pdf

[89] Smart Grid Consumer Collaborative. 2016. Research finds roughly one-half of consumers who have solar or EV technology have both. http://3593f84chf852yw5d4c5emoe.wpengine.netdna-cdn.com/wp-content/uploads/2016/10/SGCC-Consumer-Driven-Technologies-Release-10-19-16.pdf

[90] Important Media. 2015. Electric Cars: What Early Adopters and First Followers Want. https://gallery.mailchimp.com/a897522b53d-0853c85abbf9fa/files/Electric_Cars_What_Early_Adopters_And_First_Followers_Want.pdf

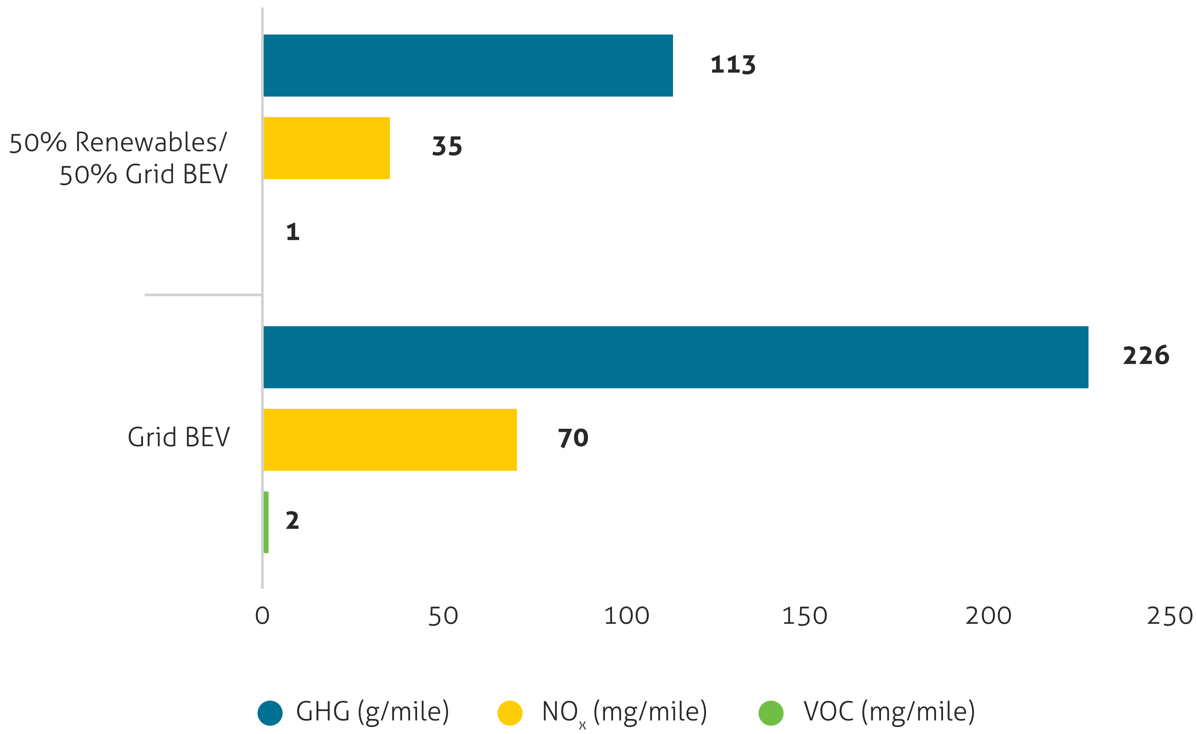

Figure 3-5. Emissions Comparison for a Grid-Powered BEV and a more Renewable Powered BEV in 2016

Another survey revealed that 83 percent of the 10,000 PEV owners polled already have or are considering installing rooftop solar PV.[91]

For Figure 3-5 it is assumed that 50 percent of a BEV owners' electricity is coming from renewable sources (either their rooftop PV system or from their purchasing Windsource blocks) and the remaining half is coming from Xcel Energy's average electricity mix.[92]

Another additional scenario worth examining is what the emissions impact of a BEV would be if it was powered by 100 percent natural gas. If BEVs are adding additional load, it is possible that this new demand would be met by natural gas, which is the easiest generating source to ramp up and down quickly. The emissions for a BEV powered exclusively by natural gas at the margin are lower than the BEV powered by the average electricity mix.

[91] InsideEVs. 2015. Ford EV Owner Survey: 83% Considering Solar, More than 90% Would Buy an EV Again. http://insideevs.com/ford-plug-owner-survey-83-consider-solar-90-buy-another-ev/

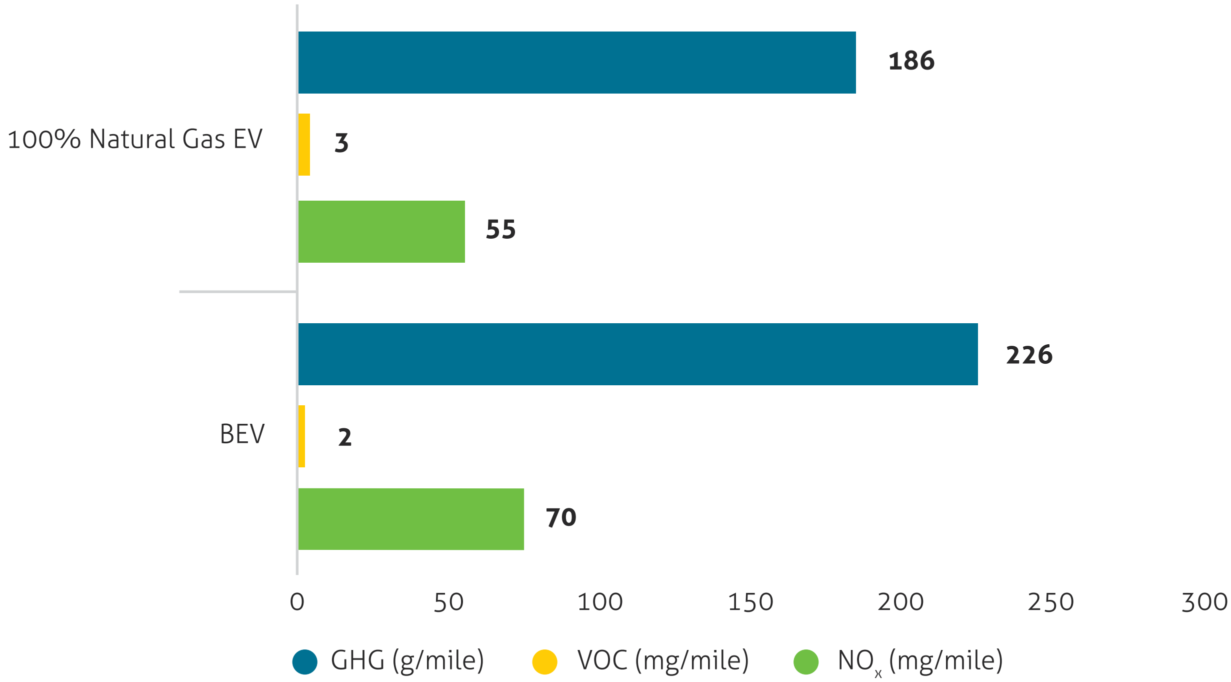

Figure 3-6. Comparison of Average Grid Powered BEV and 100 Percent Natural Gas Powered BEV

A final comparison was done on the emissions of the two top selling BEVs in Colorado, the Nissan LEAF and the Tesla Model S.[93, 94]

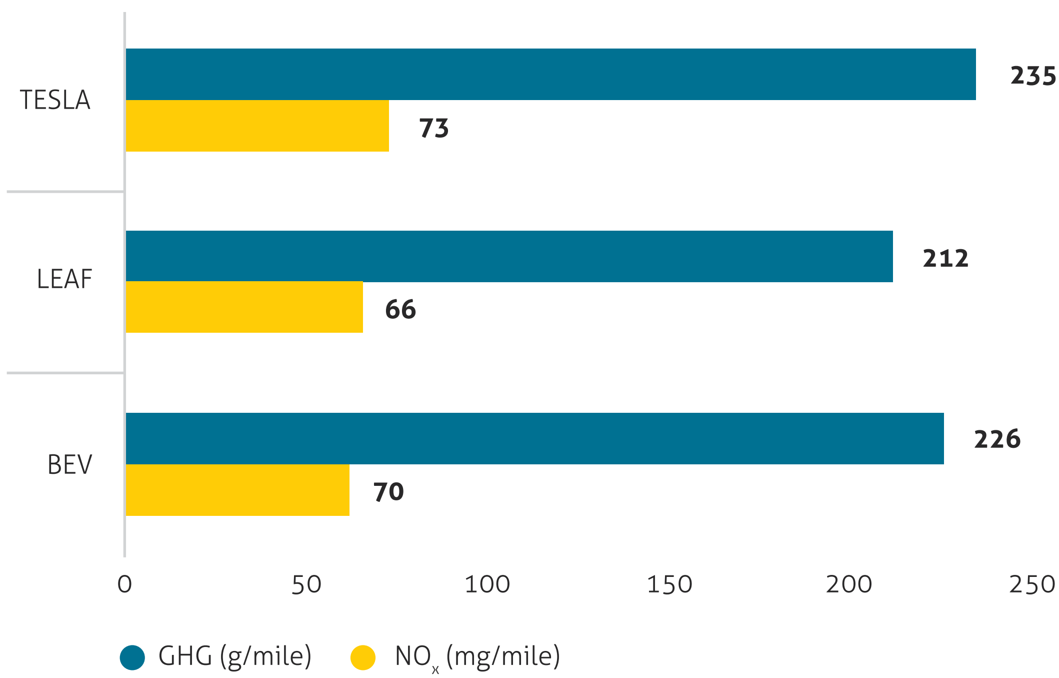

Figure 3-7. Comparison of LEAF, Tesla and Average BEV Emissions

[93] The Nissan LEAF has a fuel economy of 114 mpge

[94] The Tesla Model S has a fuel economy of 103 mpge.

2025 Results

By 2025, as a result of the significant changes that are being made to Colorado's electricity generation system (due mainly to the *Clean Air, Clean Jobs* bill, the Renewable Portfolio Standard, and the additional renewables that Xcel Energy has proposed in their electric resource plan) a new PEV driven in 2025 will have greater benefits than in 2016.[95, 96] From a GHG emissions perspective, in 2025 a BEV will be the equivalent of a 75 mpg gasoline vehicle, while a PHEV will be the equivalent of a 60 mpg gasoline vehicle.

Table 3-2. PEV Percent Reduction in Emissions in 2025 Compared to New 2025 Gasoline Vehicle

	Battery Electric Vehicle	Plug-in Hybrid Electric Vehicle
VOC	99%	56%
NOx	84%	75%
GHG	49%	37%

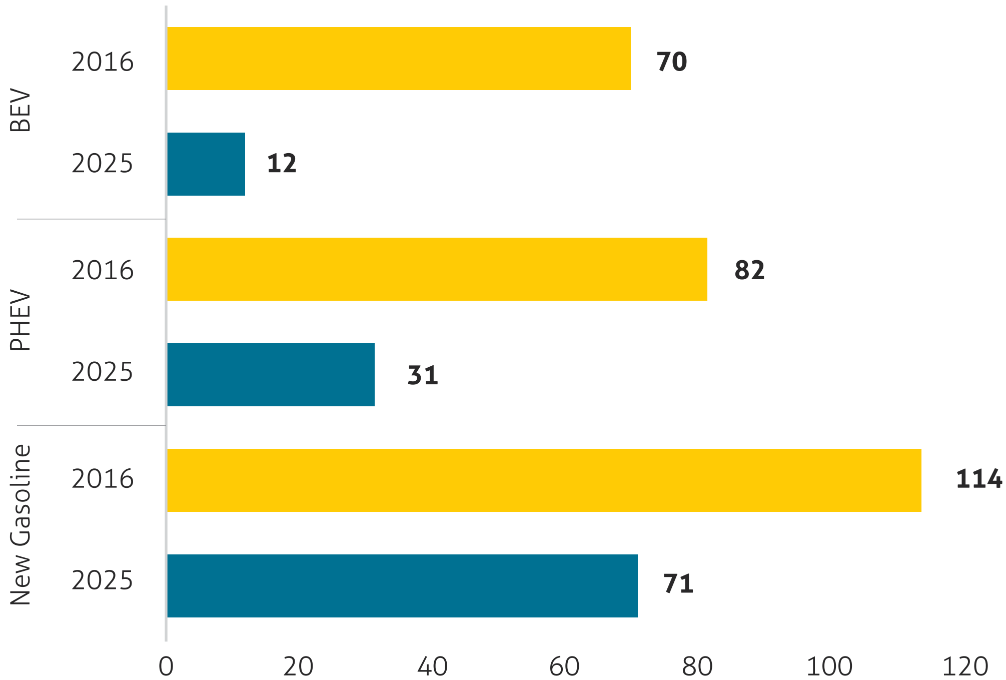

Figure 3-8. NOx Emissions by Vehicle Type in 2025

[95] Colorado House Bill 10-1365. Clean Air, Clean Jobs is expected to result in an 88% reduction in NOx emissions and a 28% reduction in CO_2 emissions from the electricity generating sector. http://rechargecolorado.org/images/uploads/pdfs/Colorado_Clean_Air_Clean_Jobs_Act_GEO_White0Paper.pdf

[96] Colorado's Renewable Portfolio Standard calls for 30% of investor-owned utility electricity generation to come from renewables and 20% of generation from cooperatives and municipal utilities to come from renewables.

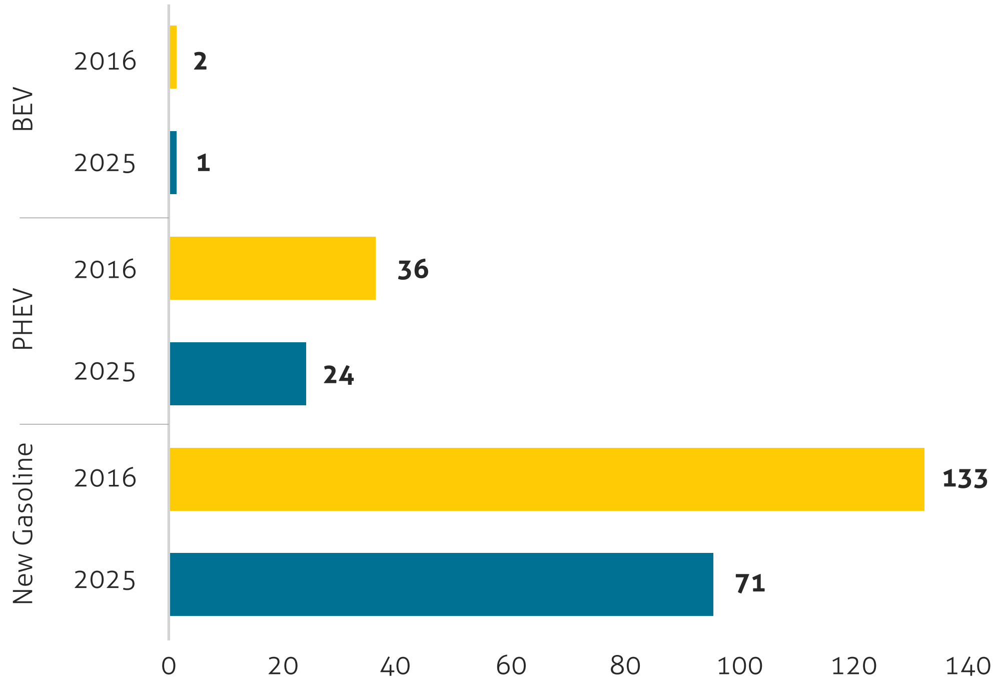

Figure 3-9. VOC Emissions by Vehicle Type in 2025

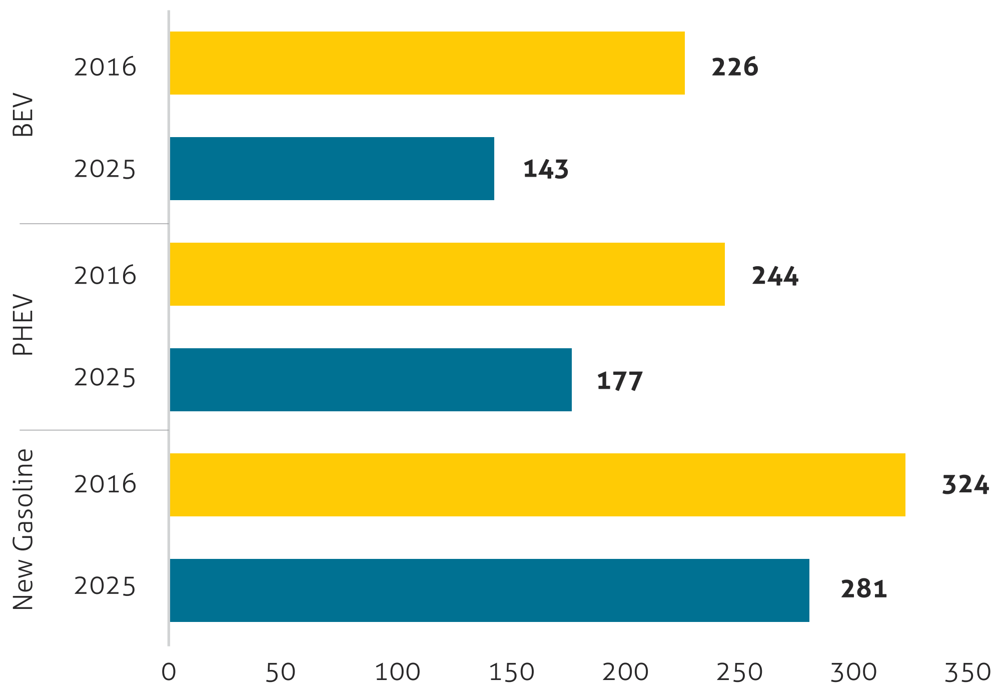

Figure 3-10. GHG Emissions by Vehicle Type in 2025

Table 3-3. Sources of Pollutants as a Percent of Total Emissions in Denver[97]

	NOx	VOC
Mobile Emissions	87%	45%
Light-Duty Vehicle Emissions	32%	28%

Currently, the Denver metro region is in non-attainment for the U.S. Environmental Protection Agency (EPA) standard for ground-level ozone.[98] Table 3-3 shows the contribution of mobile sources and light-duty gasoline vehicles to overall emission levels in the City and County of Denver. PEVs can be effective at reducing ground level ozone (caused by VOCs and NOx) because of the scale of emission reductions and the amount of emissions contributed by light-duty vehicles. BEVs almost completely eliminate urban VOC emissions from vehicles and reduce urban NOx emissions by 47 percent in 2016 and by 84 percent by 2025. In addition, light-duty vehicles make up over a quarter of VOC and NOx emissions in the area as shown in Table 3-3.

Aggregate Emissions Impact

By multiplying the emissions savings from individual BEVs and PHEVs by the total number of PEVs expected on the road one can get an idea of the total emissions impacts from PEVs in the Denver metro area.

By 2025, the Colorado EV Market Study projects that in the Medium EV Growth Scenario there will be approximately 180,000 PEVs on the road in Colorado.[99, 100] Based on the breakdown of PEV sales by County in the Colorado EV Market Study, 70 percent of statewide PEV sales are assumed to take place in the Denver metro region.[101] So in 2025, there will be 126,000 PEVs in the region. To estimate the breakdown between BEVs and PHEVs, the most recent sales figures in Colorado for 2016 were examined. In 2016, 59 percent of sales were BEVs and 41 percent were PHEVs.[102] Based on this breakdown, there would be 74,567 BEVs and 51,433 PHEVs on the road in the Denver metro region in 2025.[103]

To estimate the emissions benefits from all the PEVs on the road compared to the gasoline vehicles that they displaced average vehicles were estimated for each vehicle type. For gasoline vehicles it is assumed that the average displaced gasoline vehicle on the road in 2025 would have the fuel economy and tailpipe emissions associated with a vehicle sold between 2020 and 2021. This is the average of a 2016 and a 2025 gasoline vehicle. For PHEVs, the average efficiency of a gasoline PHEV sold in 2016 and 2025 is used in combination with the electricity mix in 2025. For BEVs, the average efficiency of 2016 and 2025 BEVs is used in combination with the 2025 electricity mix. The emissions profiles of these 'average' vehicles are shown in Table 3-4.

97 U.S. Environmental Protection Agency. 2017. Air Emission Sources. Retrieved from https://www.epa.gov/air-emissions-inventories/air-emissions-sources

98 U.S. Environmental Protection Agency. 2013. Currently Designated Nonattainment Areas for All Criteria Pollutants. Retrieved from http://www.epa.gov/oaqps001/greenbk/ancl.html

99 Colorado Energy Office. 2015. Electric Vehicle Market Implementation Study. https://www.colorado.gov/pacific/energyoffice/atom/14086

100 This number is estimated from Figure 6. Projected EV Sales in Colorado.

101 From Appendix A. Colorado Energy Office. 2015. Electric Vehicle Market Implementation Study. https://www.colorado.gov/pacific/energy-office/atom/14086

102 Auto Alliance. 2017. ZEV Sales Dashboard. https://autoalliance.org/energy-environment/zev-sales-dashboard/

103 With the introduction of more affordable, longer range BEVs it seems likely that the share of BEVs will increase over time and if so the emissions benefits will also increase.

Table 3-4. Average Emissions per Mile in 2025 by Average Vehicle Types

	Avg. Gasoline	Avg. PHEV	Avg. BEV
NOx (mg/mile)	88	32	13
VOCs (mg/mile)	114	26	1
GHG (g/mile)	302	189	162

Multiplying the emissions reductions for individual PHEVs and BEVs by the total number of each vehicle type expected on the road in 2025 results in the following aggregate emissions reductions:

Table 3-5. Aggregate PEV Emissions Savings in 2025

	Pounds/Day	Tons/Day
NOx	562	0.28
VOC	859	0.43
GHG	1,087,713	489

To put these emissions numbers in perspective with emissions in the Denver metro area they can be compared with emissions forecasts prepared by DRCOG to show that the region is in conformity for levels of NOx and VOCs. A recent forecast showed that there would be 36.2 tons of VOCs and 36.8 tons of NOx per day from the transportation sector in 2025.[104] A different forecast from DRCOG estimates that in 2025 there will be 74.4 million pounds of GHG emissions daily from the transportation sector.[105]

In 2016, there were approximately 4.8 million light-duty vehicles in Colorado as a whole with just over half of these vehicles in the Denver metro area.[106, 107] So these emissions savings are based on approximately 4.6 percent of light-duty vehicles in the Denver metro area being PEVs.

Air Quality Analysis Methodology

The authors performed an analysis comparing the emissions associated with several vehicles: an 'average' gasoline vehicle on the road in 2016, a new gasoline vehicle in 2016 and 2025, a new PHEV in 2016 and 2025 and a new BEV in 2016 and 2025.[108, 109, 110, 111]

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104 Denver Regional Council of Governments. 2015. 2015 Cycle 2 Amendments Denver Southern Subarea 8-Hour Ozone Conformity De termination. https://drcog.org/sites/drcog/files/resources/FINAL%202015%20Cycle%202%20Denver%20Southern%20Subarea%208-Hour%20Ozone%20Conformity%20Determination.pdf

105 Email communication with Robert Spotts of DRCOG.

106 Federal Highways Administration. 2017. Highway Statistics 2015. State Motor Vehicle Registrations. https://www.fhwa.dot.gov/policyinformation/statistics/2015/mv1.cfm

107 This is assuming the vehicles are distributed roughly the same as population. In 2015, 56 percent of Colorado residents lived in the Den ver metro area. https://demography.dola.colorado.gov/population/population-totals-counties/#population-totals-for-colorado-counties

108 Per the Bureau of Transportation Statistics, the average age of light-duty vehicles on the road in 2014 was 11.4 years. Therefore, in 2016, the average vehicle was assumed to be a 2005 model with a fuel economy of 26 mpg. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_26.html_mfd

109 Average fuel economy of 33 mpg

110 Average fuel economy of 38 mpg

111 To determine the fuel economy of an 'average' BEV in Colorado, the weighted average of the fuel economy for all BEV models sold in the state in 2015 was calculated, which was 107 mpge.

Table 3-6. Xcel Energy's Electricity Mixes in 2016 and 2025

	Coal	Natural Gas	Wind	Solar	Hydro	Other
2016	46%	25%	23.4%	2.1%	3.4%	1%
2025	38%	29%	26%	7%	0%	<1%

This analysis focused on air quality emissions around the Denver metropolitan area.

An average PHEV was based on the weighted average for the two best-selling PHEVs in Colorado, the Chevy Volt and the Ford Fusion Energi. This results in an average PHEV that has an electric range of 40 miles and 58 percent of miles traveled are electric. The gasoline fuel economy is 42 mpg and the electric fuel economy is 102 miles per gallon equivalent (mpge).

The analysis focuses on the following pollutants: ground-level ozone precursors, such as VOCs, NOx, and GHG. *The NOx and VOC emissions are particularly important as the region is currently in non-attainment for permissible levels of ground level ozone which is formed by the combination of NOx, VOCs and sunlight.*

The authors performed analysis using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) fuel-cycle model developed by the Argonne National Laboratory.[112] The GREET model was used to make a comparison between the life-cycle emissions of two light-duty vehicle fuels: gasoline (with 10 percent ethanol) and electricity. New vehicles purchased in 2016 and 2025 are analyzed as well as the average on the road gasoline vehicle in 2016.

New gasoline vehicles in 2016 would not yet have begun to meet the EPA's new Tier III emission standards, while the 2025 gasoline vehicle reflects the full phase in of these standards. It is assumed new gasoline vehicles purchased in 2025 will meet the existing fuel economy standards that will be in effect in 2025.

Electricity generation mixes were estimated using data provided in Xcel Energy's (the utility serving the majority of the Denver metropolitan area) most recent electric bill and their 2016 Electricity Resource Plan.[113, 114]

Note that the move towards lower percentages of coal generation and higher percentages of renewable generation will likely continue past 2025, so that the emissions of PEVs will continue to decrease over time. In addition, over the last decade Xcel Energy has consistently exceeded projected shares of renewable energy, so this calculation is likely a conservative estimate of emissions benefits. If the actual share of renewables increases more quickly than projected PEV emissions will decrease more rapidly.

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112 Argonne National Laboratory. 2016. Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation. Retrieved from http://greet.es.anl.gov/

113 The author's April 11, 2017 electric bill from Xcel Energy provided a breakdown of the electricity mix for the 2016 calendar year. This information does not appear to be available on Xcel Energy's website yet.

114 Xcel Energy. 2016. 2016 Electricity Resource Plan. Attachment AKJ-1. Figure 1.2-1. https://www.xcelenergy.com/staticfiles/xe/PDF/Attachment%20AKJ-1.pdf

The GREET model calculates the amount of emissions occurring in urban areas to show which emissions would be most likely to contribute to air quality issues. To better represent the impact that electric and gasoline vehicles will have on air quality, the transportation energy system around Denver was characterized to show exactly what emissions are likely to contribute to the Denver metro area airshed.

Regarding relevant upstream emissions from electricity, the authors have calculated that in 2016, 21 percent of Xcel Energy's coal plant emissions and 93 percent of natural gas plant emissions take place in the area around Denver and contribute emissions into the region's airshed.[115] Due to the global impact of greenhouse gas emissions, all upstream emissions are included in the calculations. In 2025, due to the planned retirement of the area's remaining coal plants, zero percent of Xcel Energy's coal plant emissions would take place in this area and 93 percent of natural gas emissions would come from this region. For upstream emissions for gasoline vehicles, 35 percent of the emissions associated with gasoline refining take place in the Denver metro area due to the Suncor refineries located in Adams County which process approximately 35 percent of the gasoline used in the state.

Regarding the extraction of fuel (mining and drilling): it is estimated that 81 percent of the state's oil drilling and 17 percent of natural gas extraction take place in the Denver metro and North Front Range area (the vast majority of which takes place in Weld County).[116] In addition, it was assumed that zero percent of coal mining contributes to urban emissions.

The original intention of this analysis was to obtain data on the hour-by-hour changes in electricity mix across days and across seasons. This would give a much clearer picture of what the environmental impact of charging PEVs during different parts of the day would be. For example, it would be important to know whether or not emissions were lower during the night due to higher amounts of wind in the system. This electricity mix data would have been matched up with hourly charging profiles for PEVs to determine the emissions profile of an average PEV. Unfortunately, we were not able to acquire this data and have done a more general analysis based on annual average electricity mixes.

Findings for Air Quality

- PEVs provide significant environmental benefits when driven in the Denver metropolitan area.
- In 2016, BEV reduced emissions of NOx by 38 percent, VOCs by 99 percent GHG emissions by 30 percent compared to a new gasoline vehicle.
- Compared to an average gasoline vehicle on the road in 2016, NOx is reduced by 63 percent, VOCs by 99 percent and GHG by 43 percent.
- Due to a cleaner electricity mix by 2025, a BEV will reduce NOx emissions by 84 percent, VOC emissions by 99 percent and GHG emissions by 49 percent compared to a new gasoline vehicle in that year.

[115] U.S. Environmental Protection Agency. 2016. eGRID2012 Version 1.0. Retrieved from http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[116] Colorado Oil and Gas Conservation Commission. 2013. COGIS – Production Data Inquiry. Retrieved from http://cogcc.state.co.us/

Appendix A.

Assumptions for DCFC Station Operating Costs and Revenues Analysis

Table A-1. Base Assumptions for Colorado DCFC Stations Operating Cost and Revenue Analysis

		Source
Utilization in Year One	1.4 Times per Day	CO DCFC data collected to date
Increase in Utilization	24.4% annually	CO EV Market Study (Medium Growth Scenario)
Power Consumption	10.5 kWh per Use	CO DCFC data collected to date
Increase in Power Consumption per use	10% annually	Estimate based on increasing battery sizes
Energy Costs	\$0.14 per kWh[117]	Xcel Energy SGL Tariff
Demand Costs	\$5.63 per kW	Xcel Energy SGL Tariff
Meter Costs	\$413/year	Xcel Energy SGL Tariff
Annual Maintenance & Fees	\$2,000/station	C2ES/RMI
General Administrative Costs	5% of Revenue	C2ES Report Assumption
Cost to Charge (DCFC)	\$0.49/kWh	Blink cost to members
Cost to Charge (L2)	\$0.45/kWh	Blink cost to members in CO

Increase in Utilization

Due to expected increases in the number of PEVs on the road in Colorado, an assumption was made about how much the daily utilization of DCFC would increase each year. The assumption of a 24.4 percent annual increase in utilization was taken from the Colorado Electric Vehicle Market Study's Medium Growth Scenario.[118]

Power Consumption

10.5 kWh is the average electricity consumption for each DCFC session. Data was collected from CAC stations in Colorado to arrive at this number. As all of these stations are located in urban areas this may not be an accurate estimate for highway DCFC stations. It is assumed that due to the expected increase in battery sizes that the average amount of electricity consumed during each charging session will also increase over time. As there does not appear to be independent forecasts of this rate of increase, 10 percent has been assumed as a best guess estimate for purposes of this analysis.

[117] This is the average annual price that would be paid under Xcel Energy's SGL tariff. During the four summer months the per kWh rate is \$0.175 and for all other months it is \$0.123, giving an average of \$0.14 per kWh over the course of a year.

[118] Colorado Energy Office. 2015. Electric Vehicle Market Implementation Study. https://www.colorado.gov/pacific/energyoffice/atom/14086

Station Operating Costs

Many of the station operating costs are based on the station using Xcel Energy's SGL tariff. Of available commercial tariffs, this one best serves separately metered DCFC stations because of its lower demand charge.

The average annual maintenance fees and administrative costs were derived by a review of existing studies including the C2ES and RMI work.

Cost to Charge

A rate of $0.49 per kWh was assumed as the rate that a customer would pay for use of a DCFC. This is what the Blink network charges their members for use of their network. While EVgo has the most DCFC in Colorado, their member rate of $0.10 per minute for DCFC (which comes out to about $0.08 per kWh) was seen as too low to ever recover the operating costs for the stations and therefore not a good model for future charging stations.[119]

Additional Assumptions

If future station installations are similar to the CEC requirements (one CHAdeMO and one dual protocol fast charger co-located with a Level 2 station), it is assumed that in early years with low utilization (less than one use per day) the station would incur a demand charge of only 57 kW. In later years when the potential for both DCFC ports to be used simultaneously, 107 kW is assumed for the peak demand.

The cost data cited is for a separately metered DCFC station.

This also assumes that there is some relatively low usage of the co-located Level 2 station. It is assumed that it will be used 25 percent as much as the DCFC, so if there are 4 DCFC events per day there would be 1 Level 2 charge per day.

[119] EVgo. 2017. EVgo Charging Plans. https://www.evgo.com/charging-plans/

Appendix B.

Complete Survey Results

The survey was sent out to PEV owners associated with several PEV group purchase programs in Colorado. Participants from Boulder County, Drive Electric Northern Colorado and Aurora were all contacted. In addition, Plug-In America sent this out to their Colorado members.

There were a total of 264 respondents to the survey, which constitutes about three percent of the PEV owners in Colorado. Because the group purchase programs are largely limited to Nissan LEAFs, the survey respondents are more heavily weighted to LEAFs than Colorado PEV owners as a whole. During 2014 and 2015, 36 percent of PEV sales in Colorado were LEAFs, 20 percent Volts, and 23 percent were Teslas. In this survey, 55 percent of respondents drove LEAFs, nine percent drove Volts, and 22 percent drove Teslas. However, since DCFC is primarily of interest to BEVs, not PHEVs, the under-representation of Volts is not problematic. The survey results are also likely weighted towards residents of Boulder County as they made up a large proportion of the people participating in the group purchase programs.

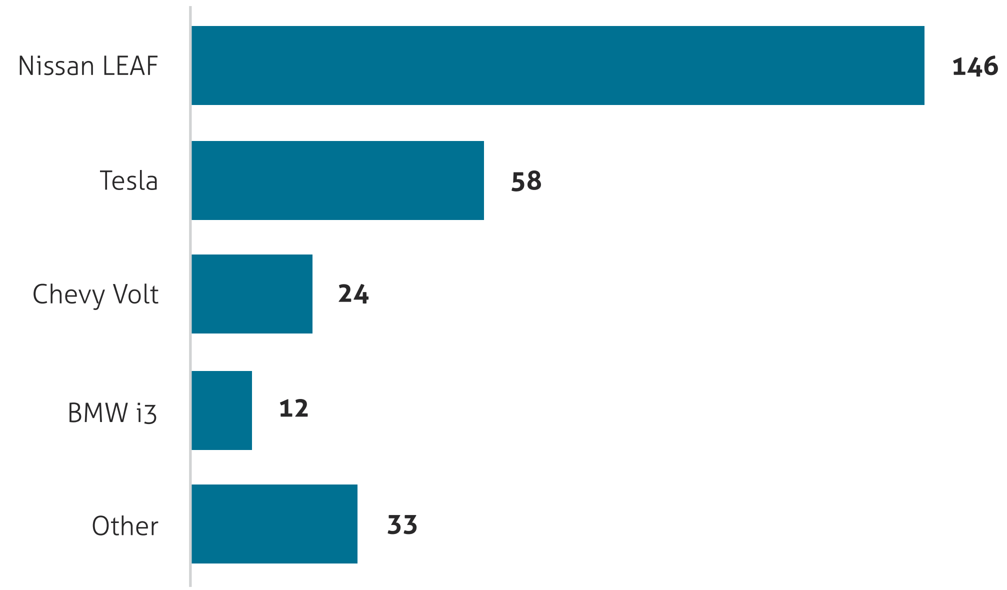

Figure B-1. What type of electric vehicle do you own? (273 Responses[120])

[120] There are more responses than respondents as several respondents own more than one PEV.

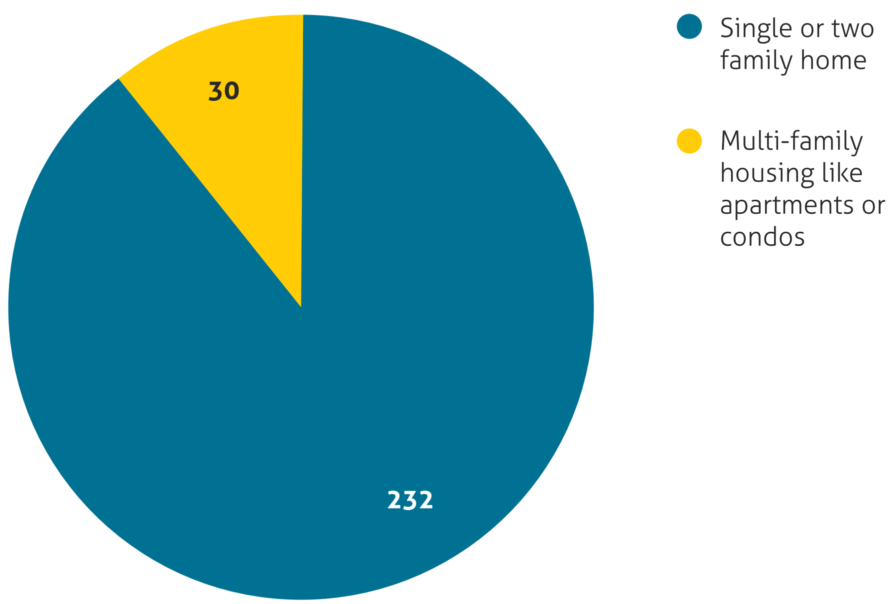

Figure B-2. What type of housing do you live in? (262 Responses)

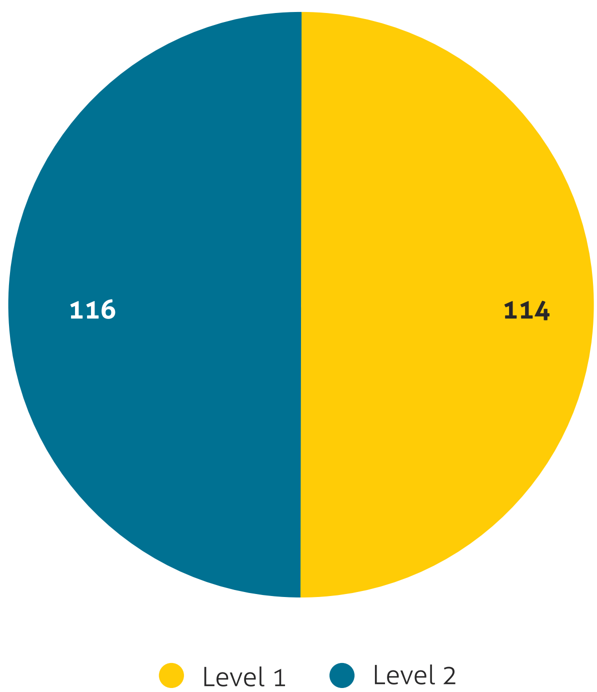

Figure B-3. If living in a single or two-family home, what type of charging do you have? (230 Responses)

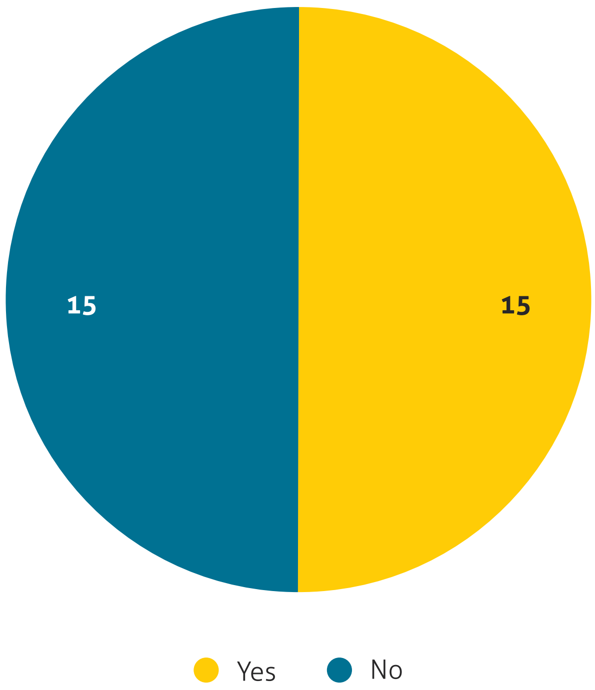

Figure B-4. If you live in multi-family housing, does your residence have access to charging where you park? (30 Responses)

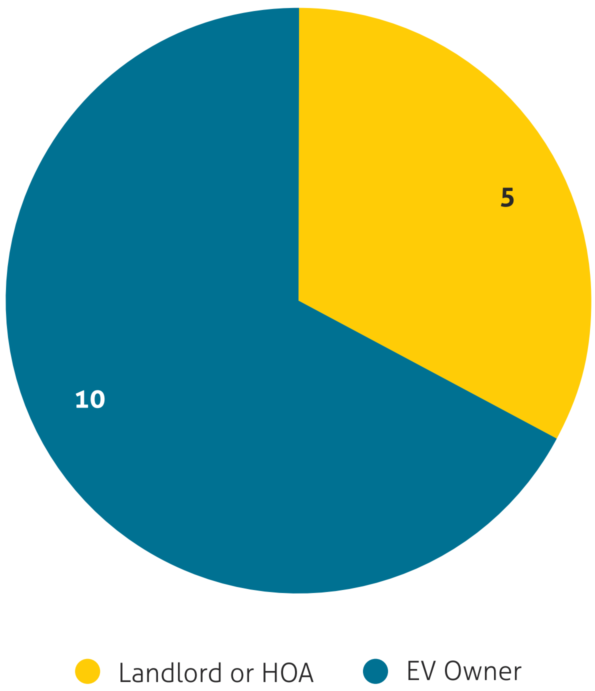

Figure B-5. Did the landlord or HOA provide the charging or did you have to pay for installation? (15 Responses)

Among those multi-family residents who paid for their own charging station, all of them had the charging station dedicated to their own use. For those installed by a landlord or HOA, 4 of the 5 stations were shared charging.

Workplace Charging

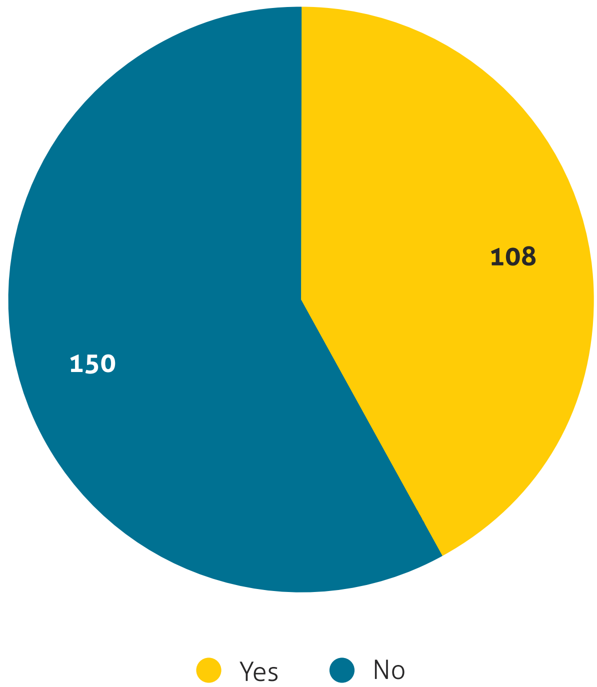

Figure B-6. Is there charging available at your workplace? (258 Responses)

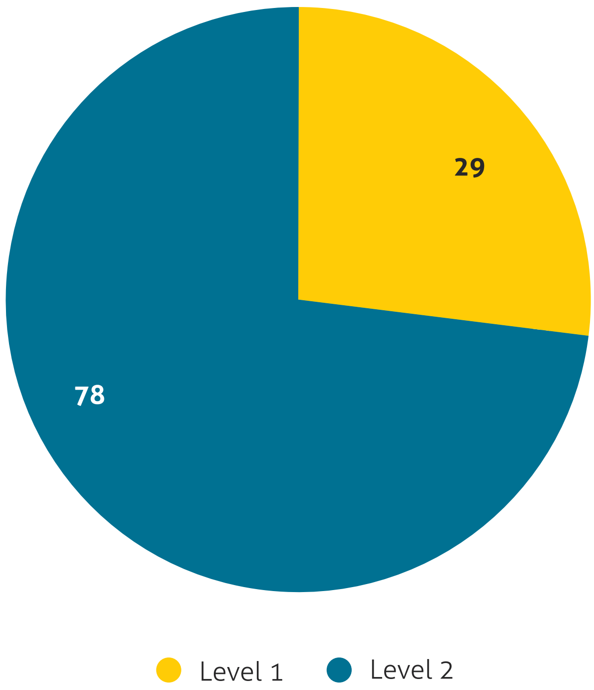

Figure B-7. What type of charging is available at your workplace? (107 Responses)

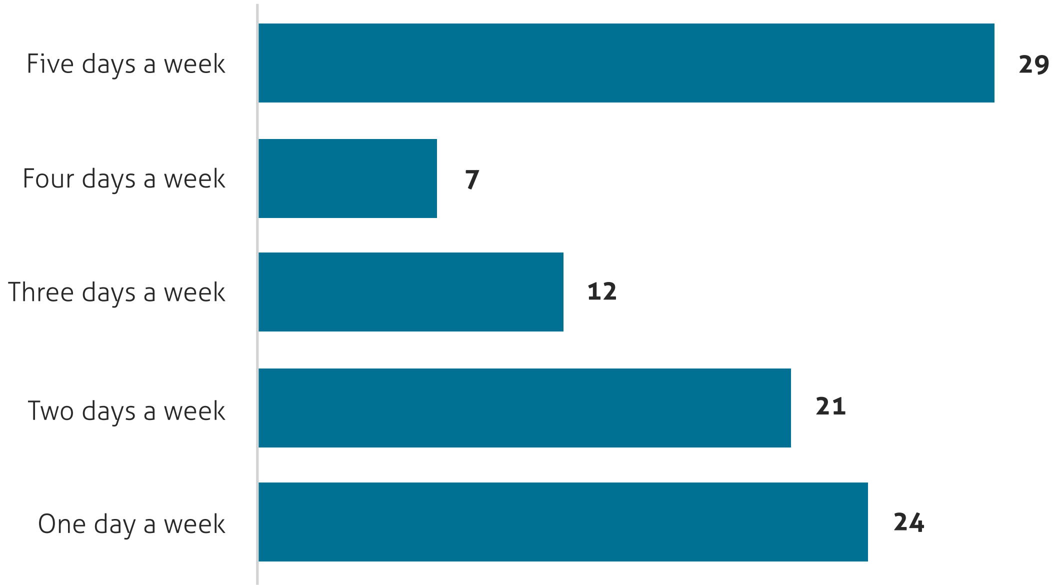

Figure B-8. How often do you charge at work? (93 Responses)

Public Charging

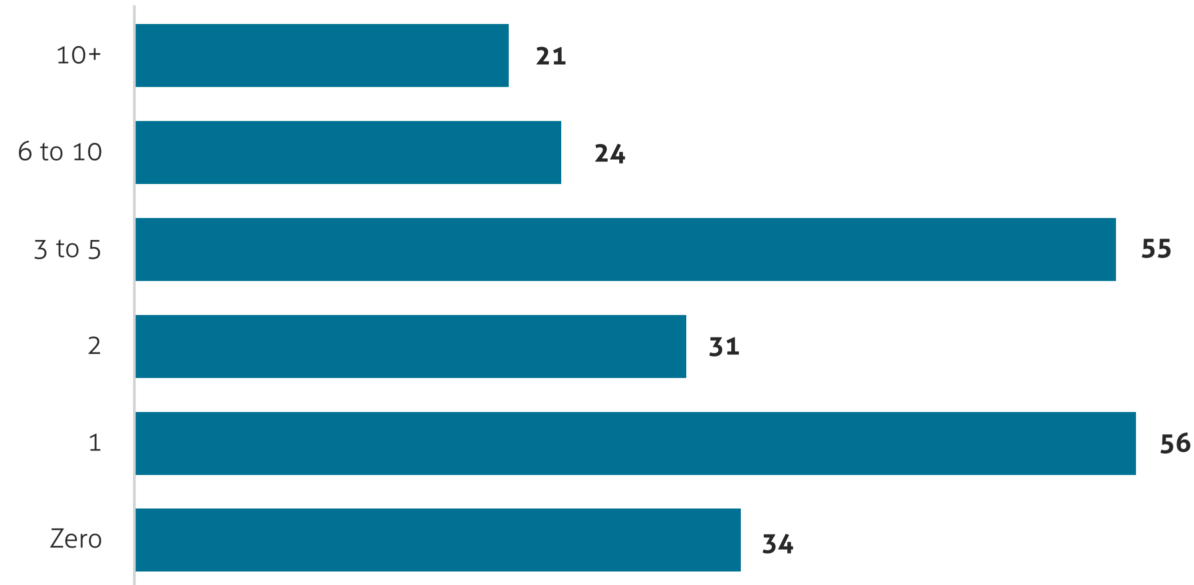

Figure B-9. How many times do you use public charging stations each month? (221 Responses)

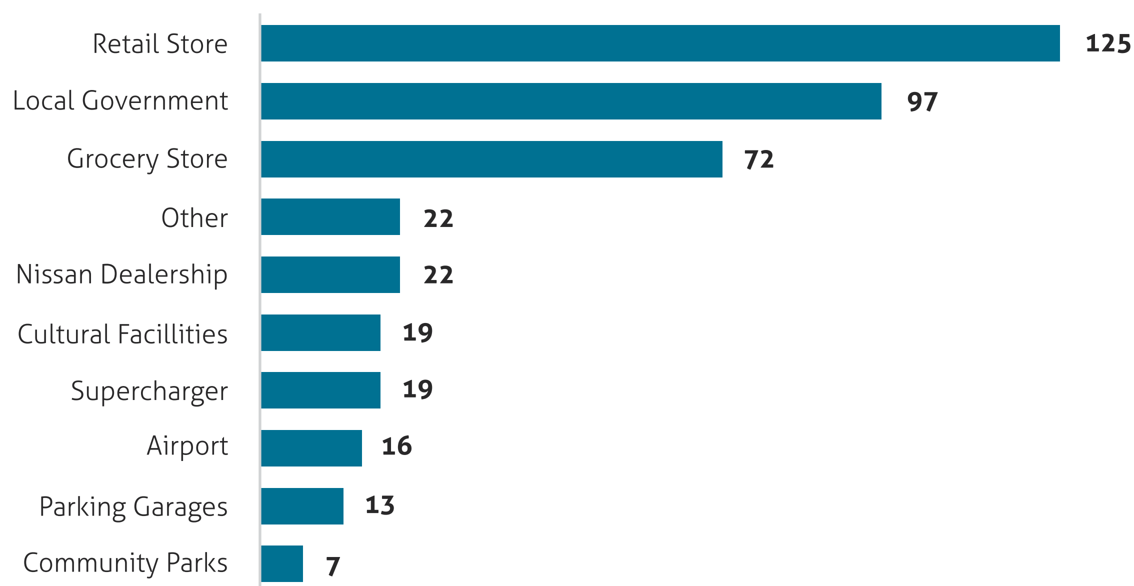

Figure B-10. What public charging locations do you use? Check all that apply. Retail Store, Local Government and Grocery Store were listed options, all other responses filled in by respondents. (412 Responses)

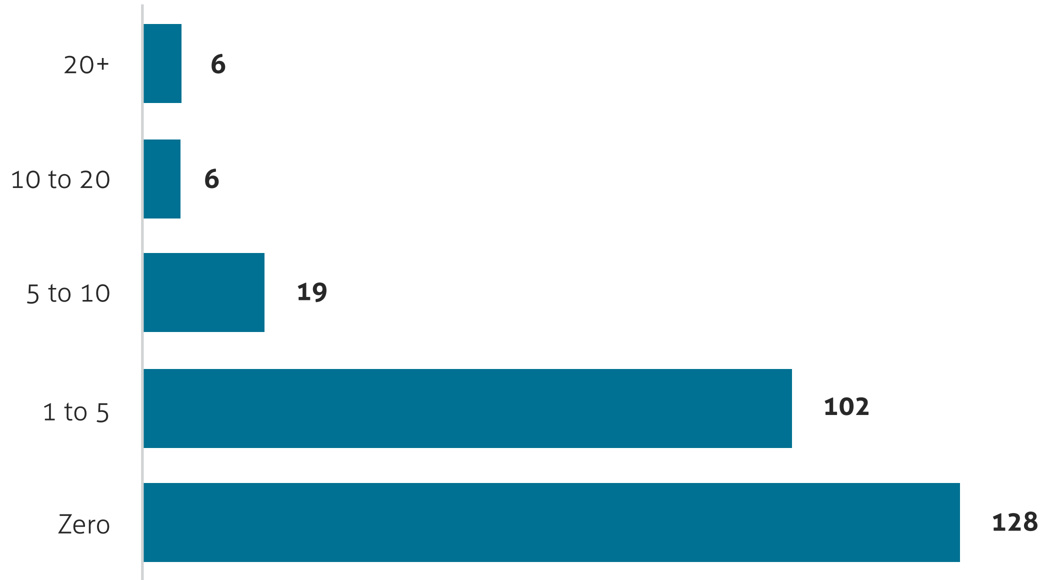

Figure B-11. Higher powered fast charging allows you to fully charge in about 20 minutes. How often do you use fast charging each month? (261 Responses)

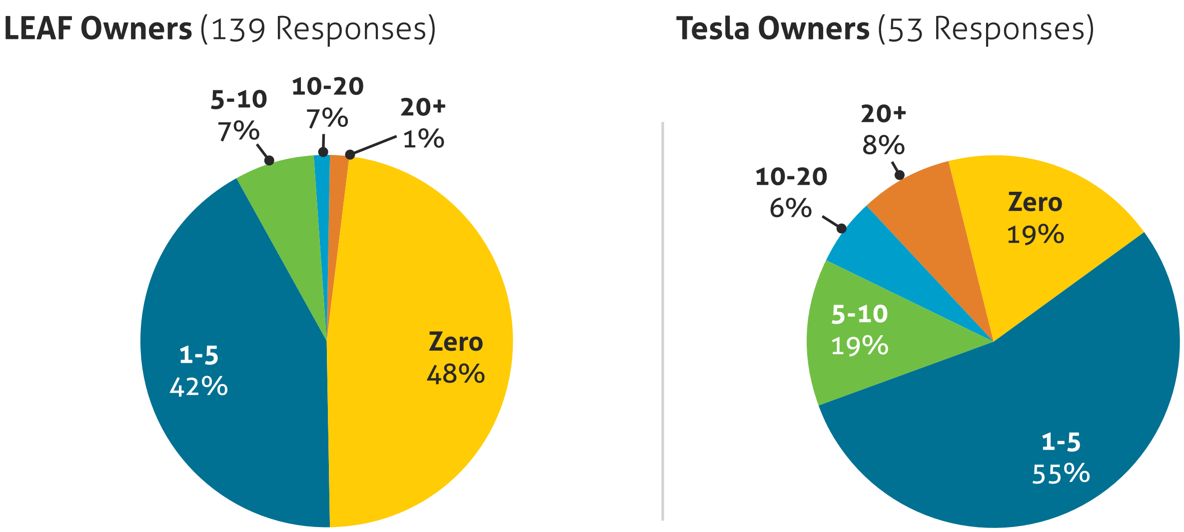

Figure B-12. Number of Times that a Percentage of Owners Use Fast Charging each Month

Comparing the frequency of usage of DCFC between LEAF and Tesla owners shows different levels of use. LEAF owners are more likely to never use fast charging while Tesla owners use fast charging much more frequently than LEAF owners. One explanation for this is that some LEAFs do not actually have fast-charging capability as this was an option and not standard on many models.

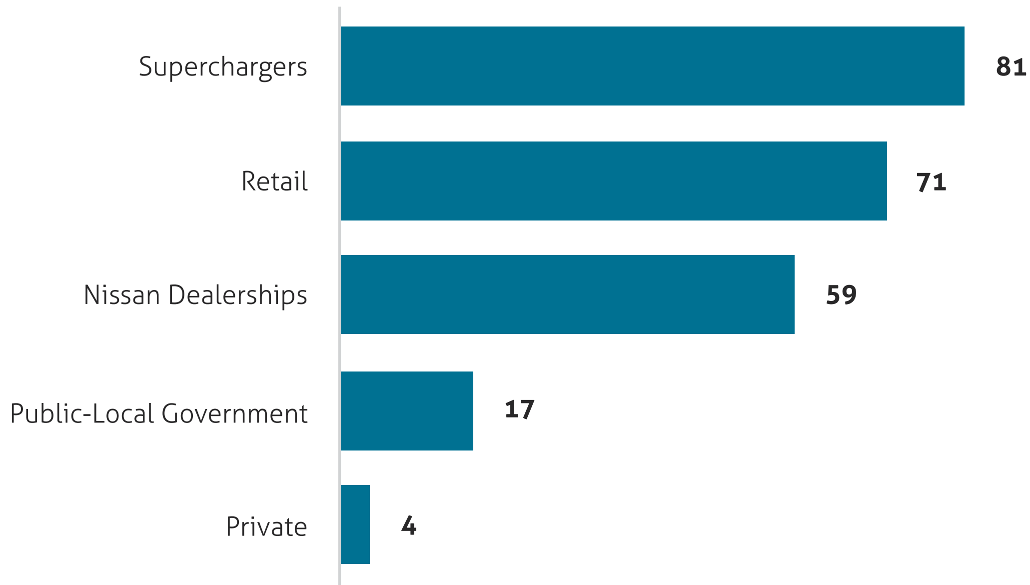

Figure B-13. Where do you use fast charging? Please list all locations where you have used a fast charger in the last 6 months.[121] (232 Responses)

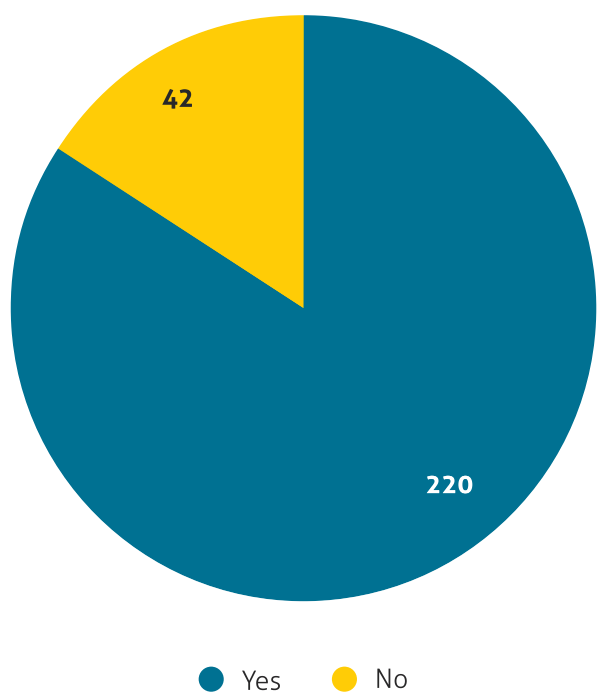

Figure B-14. Does availability of public charging affect where you drive? (262 Responses)

Of the 42 respondents who said that the availability of public charging does not affect where they drive, 18 owned plug-in hybrid vehicles (mostly Chevy Volts).

[121] There are more uses of superchargers listed than Tesla owners in the survey because each owner was able to give multiple responses. Therefore if one Tesla owner listed three different supercharging locations, that would count for three 'Superchargers' in the above graph.

One interesting point from this question is that LEAF and Tesla owners were equally likely to say that the availability of public charging affects where they drive, with 91 percent of each group stating this was the case.

Table B-1. Number of Times Front Range Destinations Were Named

Front Range Cities		Front Range Destinations	
Denver	46	DEN	30
Fort Collins	17	Sand Dunes/Alamosa	11
Colorado Springs	16	DTC	4
Boulder	7	park n Rides	3
Aurora	3	Dick's SG Park	2
Longmont	3	Children's Hospital	2
Castle Rock	3	Other	2
Other	11		

Table B-2. Number of Times Mountain Destinations Were Named

Mountain and Skiing Destinations			
Mountains	33	Steamboat Springs	5
Skiing	15	Vail	5
Estes Park	13	Summit County	4
Durango	9	Breckenridge	4
RMNP	8	Nederland	3
Pagosa Springs	7	Eldora	3
Telluride	7	Fairplay	3
Glenwood Springs	6	Fairplay	3
Salida	6	Loveland	3
Aspen	6	Grand Lake	2
Gunnison	6	Black Hawk	2
Idaho Springs	5	Woodland Park	2
Winter Park	5	Other	16

To better understand why Denver was most often named as the destination where PEV owners were unlikely to go due to lack of charging, the cross tabs were examined of those who named Denver or some part of metro Denver in their responses. Note that respondents who named DEN were not included in this group. The ‘Other’ counties in the graph below are: Garfield, Douglas, Weld and El Paso.

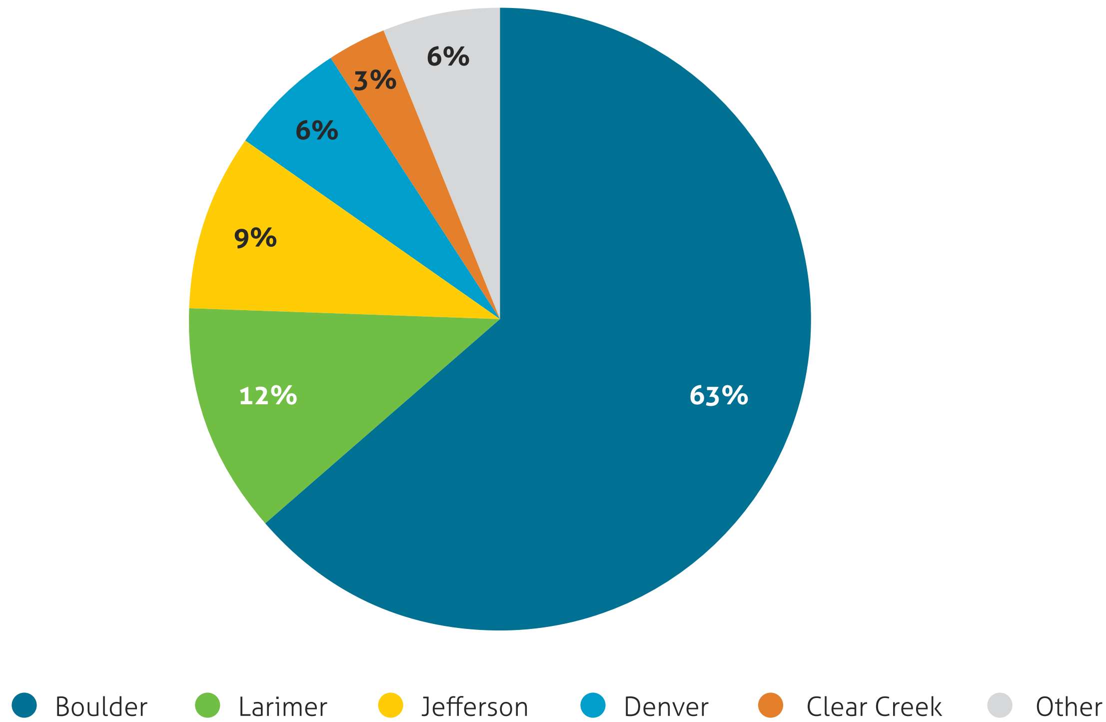

Figure B-15. County of Residence for Respondents who named Denver as a destination they were less likely to go due to lack of charging. (68 Responses)

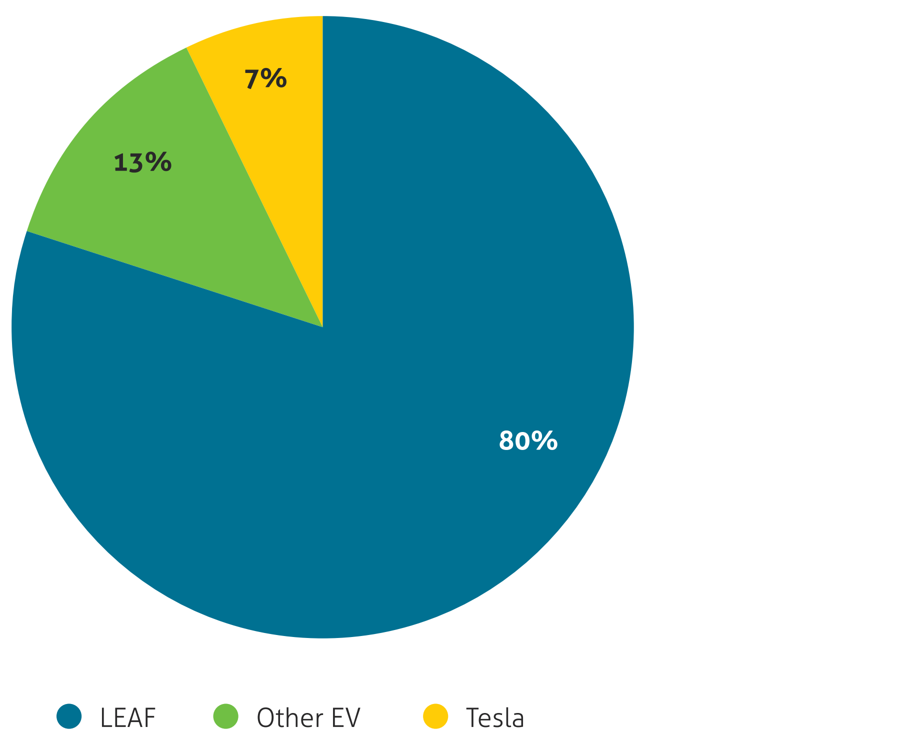

Figure B-16. Types of vehicles driven by those naming Denver as a destination they were less likely to go due to lack of charging. (71 Responses[122])

[122] Three respondents did not identify which County they lived in.

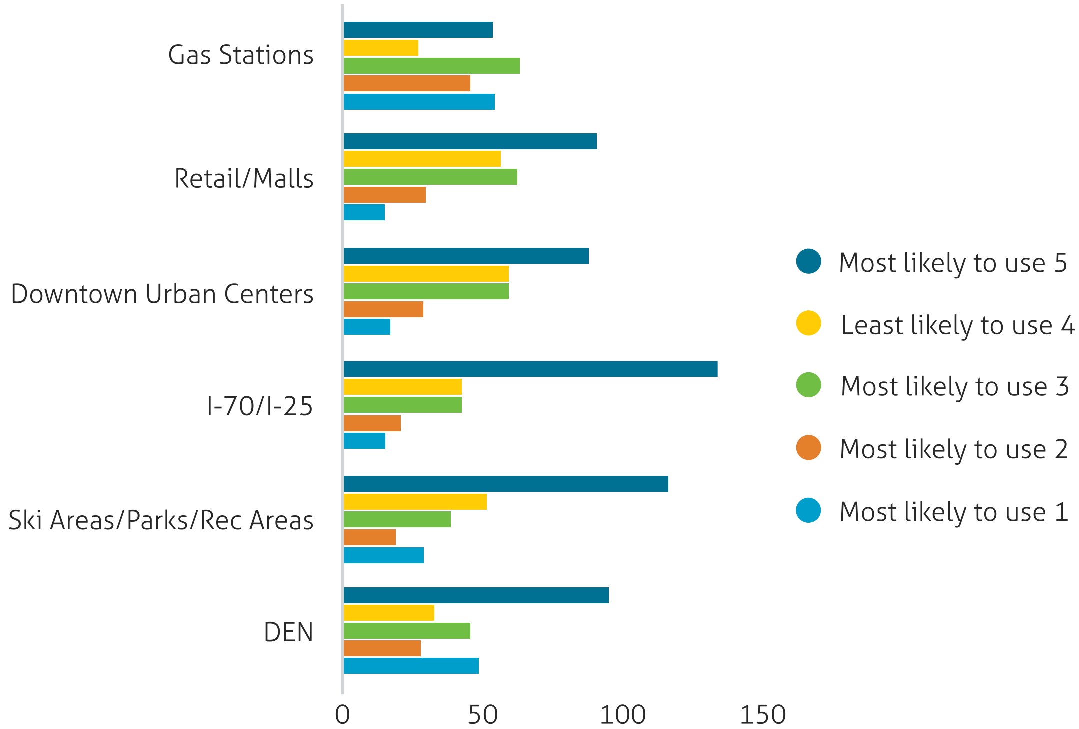

Figure B-17. What locations for fast charging in Colorado would you be likely to use? Please rank from 1-5 (1 = least likely to use, 5 = most likely to use).

Another way to compare the data in this question is to add up all times that a destination was named as the most likely to be used. Overall, respondents valued fast charging along interstate corridors the most. Charging at recreational destinations was valued highly as well.

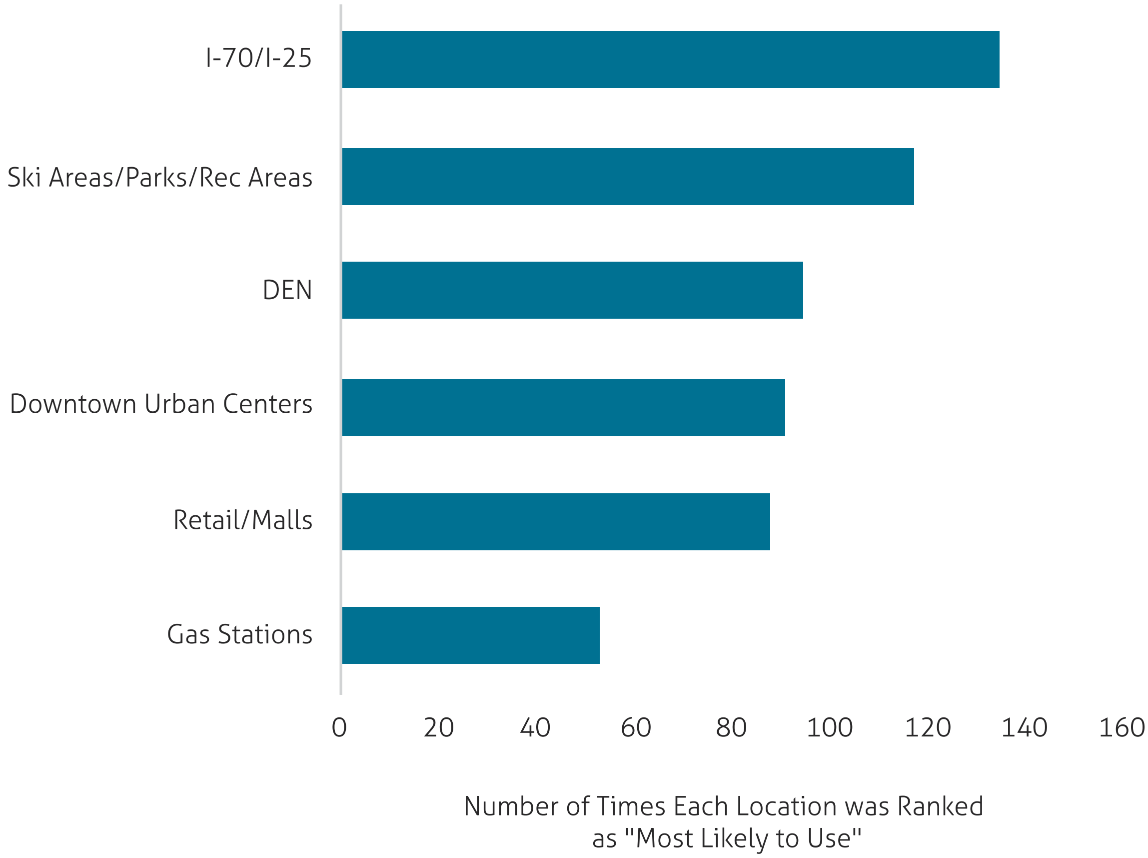

Figure B-18. Number of Times Each Destination was Ranked as "Most Likely to Use"

If the results from this question are broken down between LEAF and Tesla owners one can see slightly different preferences.

For LEAF owners, charging along interstates was most rated the most likely to be used, followed by DEN, downtown urban centers, recreational destinations and retail locations. For Tesla owners, recreational destinations were rated the most likely to be used, followed by interstate corridors. For both LEAF and Tesla owners, gas stations were the least likely to be used.

Unsurprisingly, when you look at the crosstabs of which drivers most value charging at DEN, LEAF drivers from farther away counties (especially Boulder) are most likely to want to use DCFC stations at DEN. Of the 57 LEAF drivers who stated that they would be most likely to use fast charging at DEN, 37 were from Boulder with 18 others coming from further out counties such as Jefferson, Douglas, Larimer and Broomfield.

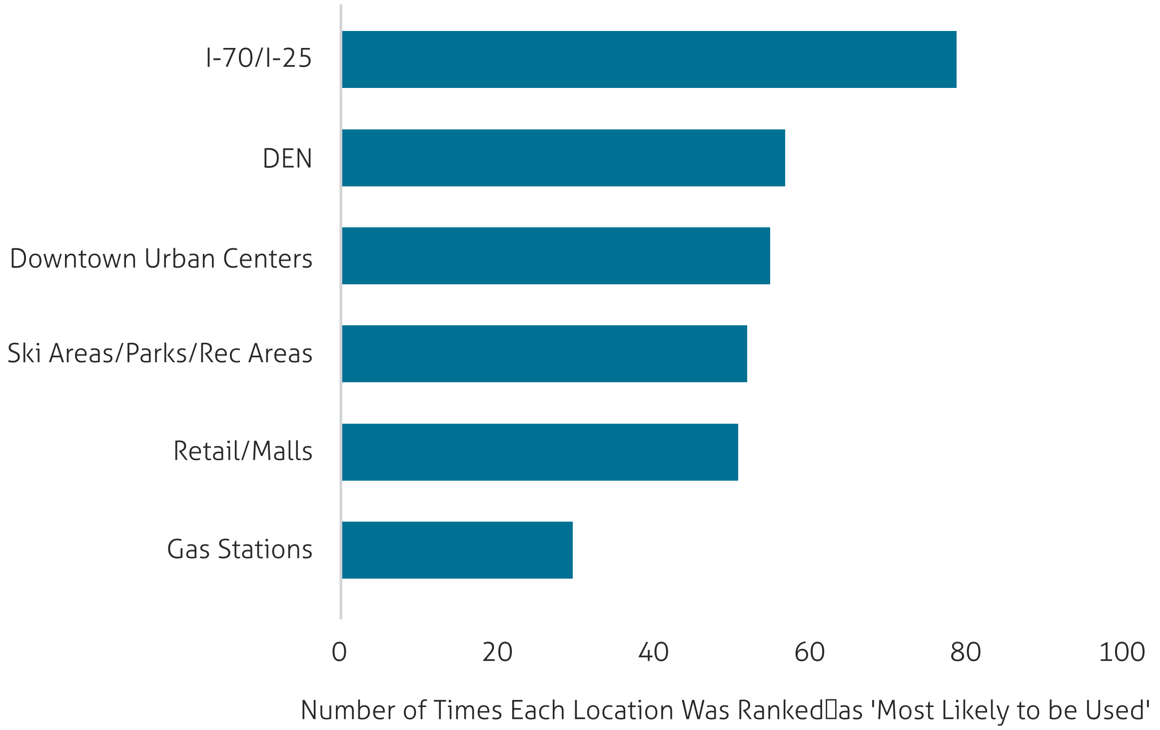

Figure B-19. Ranking of DCFC Destinations by LEAF Owners

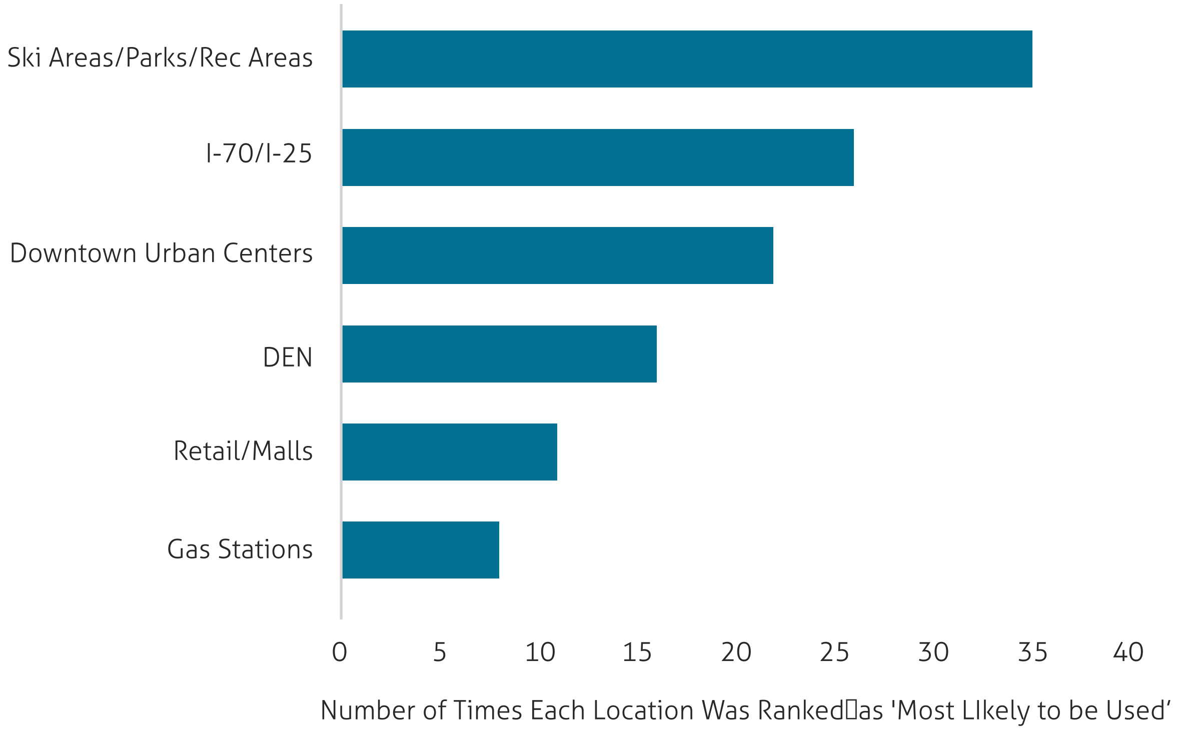

Figure B-20. Ranking of DCFC Destinations by Tesla Owners

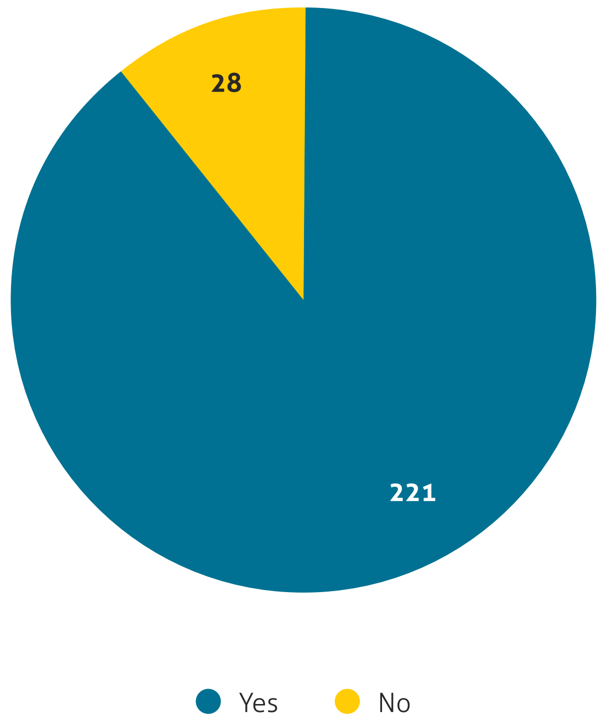

Figure B-21. If you had reliable and frequent access to fast charging along Colorado's major highways, would that change where or how you drive your EV? If so, how? (249 Responses)

Eighty-nine percent of respondents stated that yes, access to fast charging along major highways would change where and how they drive their PEV. Almost all of these PEV drivers went on to state that they would drive their PEV more often and father and many mentioned that they would be able to use their gasoline vehicle less or get rid of it altogether. Of those drivers who said 'No', eleven drive plug-in hybrid owners and five Tesla owners stated that they felt they already have access to this type of charging.

How much would you be willing to pay for a hundred miles of range in 30-40 minutes at a fast charging station?

The average cost named by PEV owners was $6.39 and the median cost named was $5. The results were similar for LEAF and Tesla owners, with LEAF owners willing to pay an average cost of $6.49 and Tesla owners willing to pay $6.12. The median for both LEAF and Tesla owners was also $5.

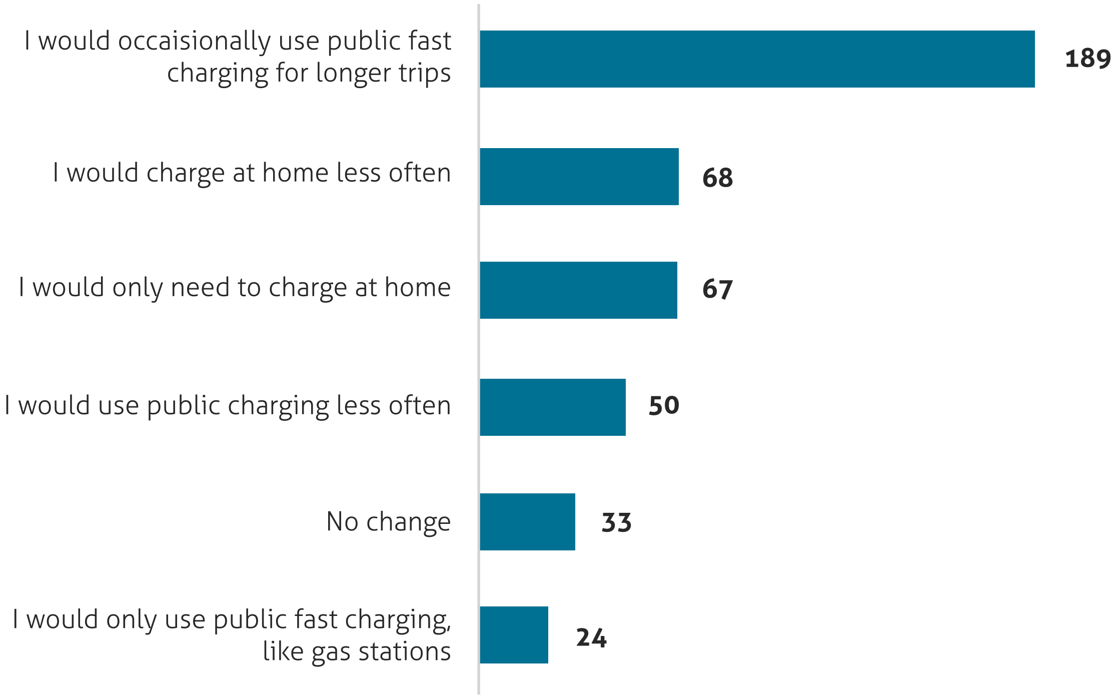

Figure B-22. In the next year, affordable longer range electric vehicles (with ranges around 200-250 miles) will become available. Based on your experience as a PEV driver, if you shifted to a longer range vehicle, how do you think this would change your charging behavior? Choose all that apply. (431 Responses)

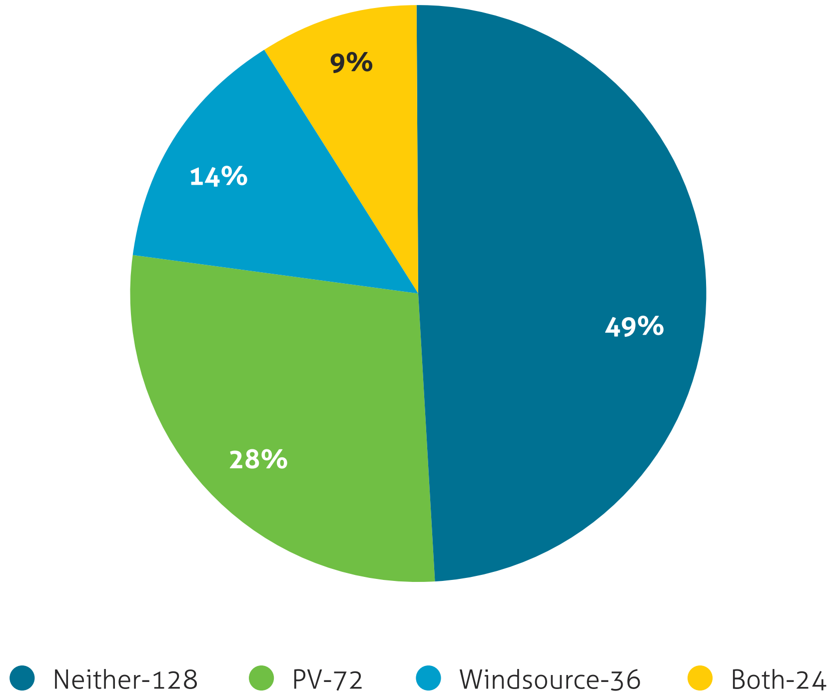

Figure B-23. Do you have rooftop solar PV panels or are you enrolled in Xcel Energy's Windsource program? (260 Responses)

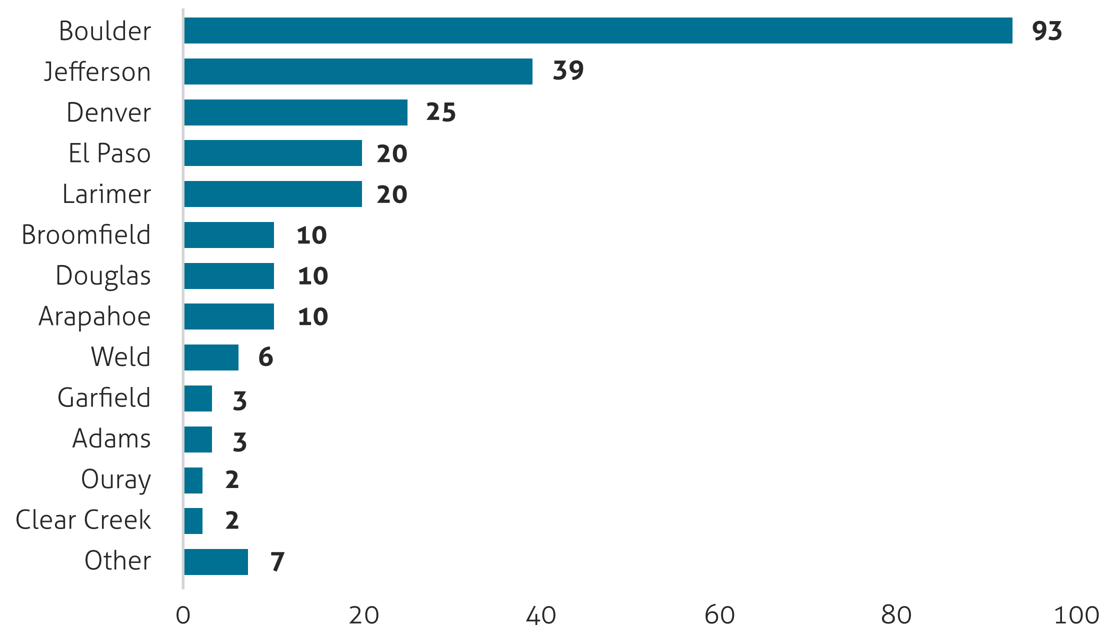

Figure B-24. Please let us know what County you live in. (255 Responses)

Survey for Non-EV Owners

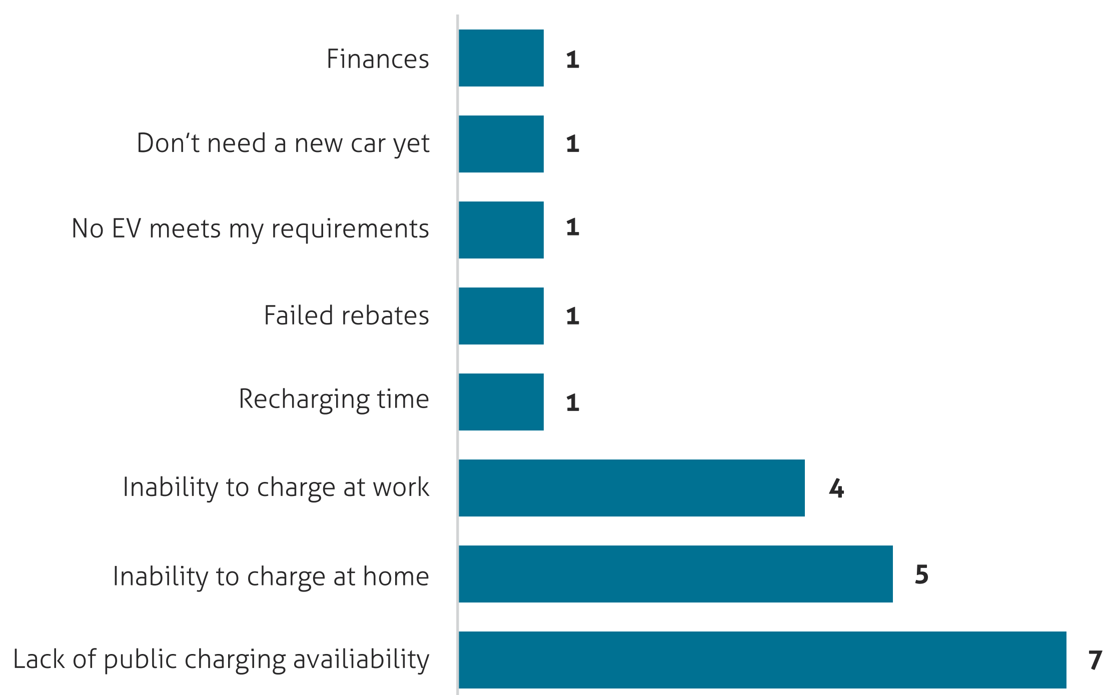

Figure B-25. What were the significant factors in your decision not to purchase an EV? Check all that apply. (21 Responses)

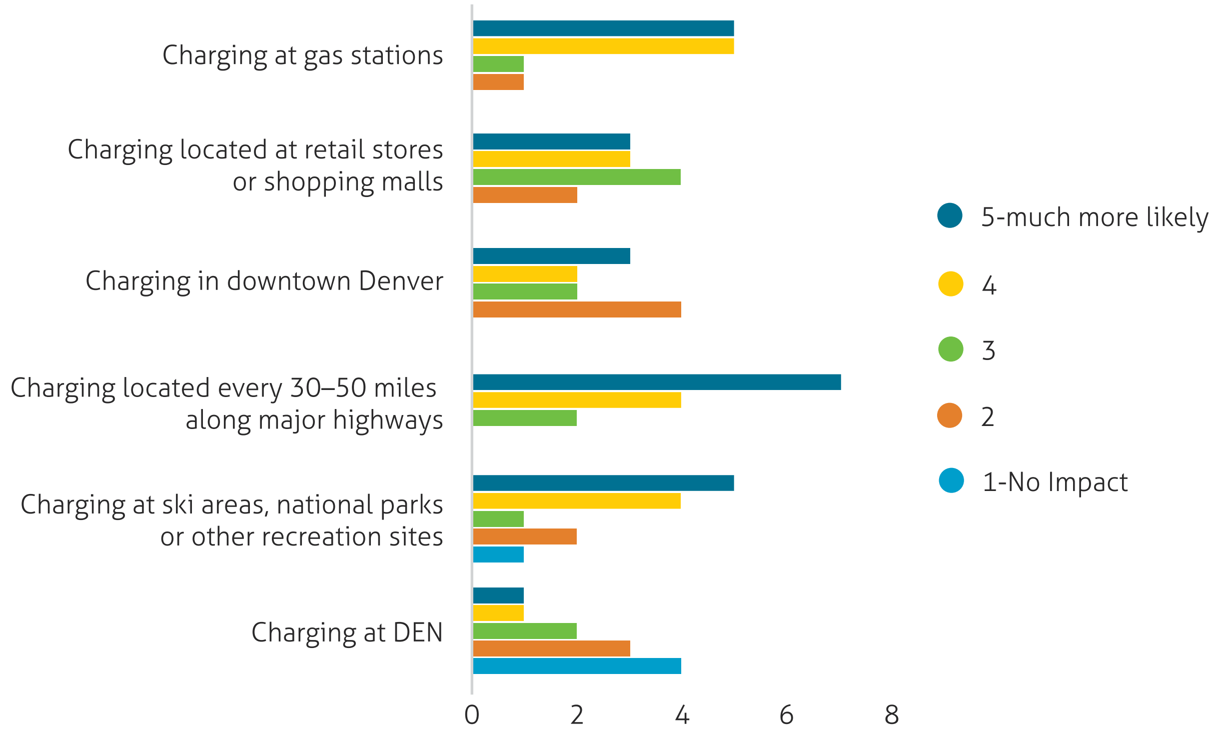

Figure B-26. Public agencies are considering investing in high powered fast charging in a variety of locations. These are stations that would allow you to fully charge your vehicle in about 20 minutes. Can you rate each of these location types on how widespread fast charging at these locations would affect your likelihood to buy an EV? (from 1 no impact to 5 much more likely)

Another way to compare the data in this question is to add up all times that a destination was named as the most likely to be used.

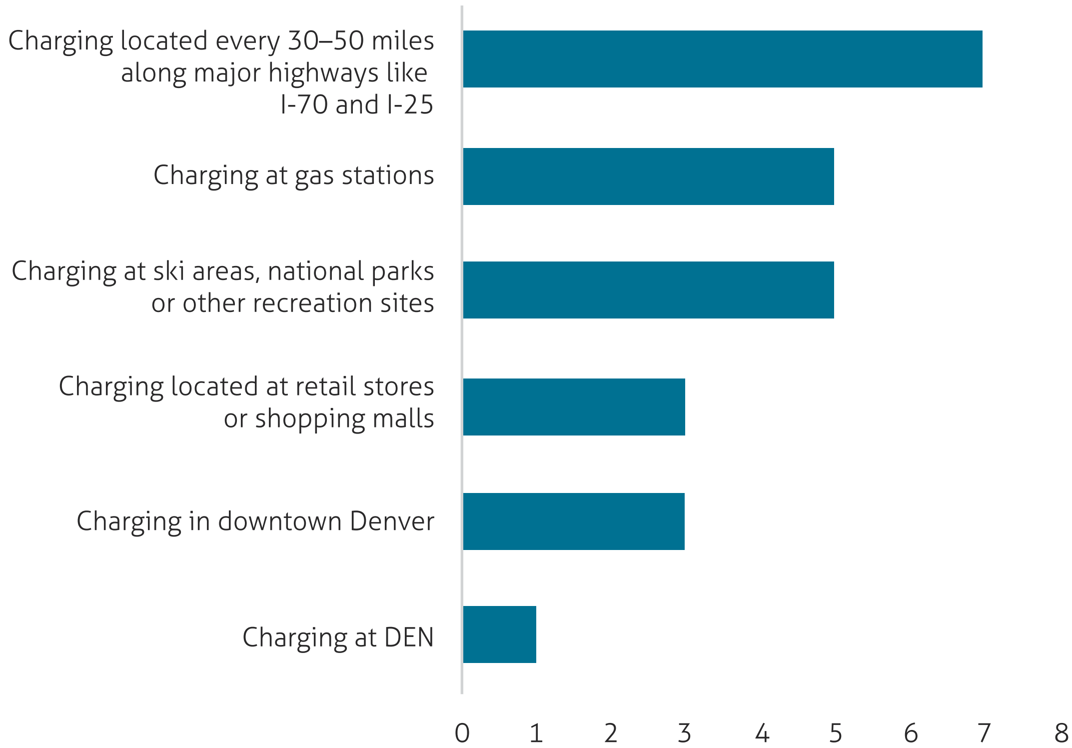

Figure B-27. Number of Times Each Destination was Ranked as "Most Likely to Use"

One interesting result is that in comparing the responses of non-owners to PEV owners there were different results. While both owners and non-owners valued charging along the interstates the most they differed in the importance of charging at gas stations. Owners rated gas stations as the destination they would be least likely to use while non-owners rated charging at gas stations as the second most likely location to influence them to buy a PEV.

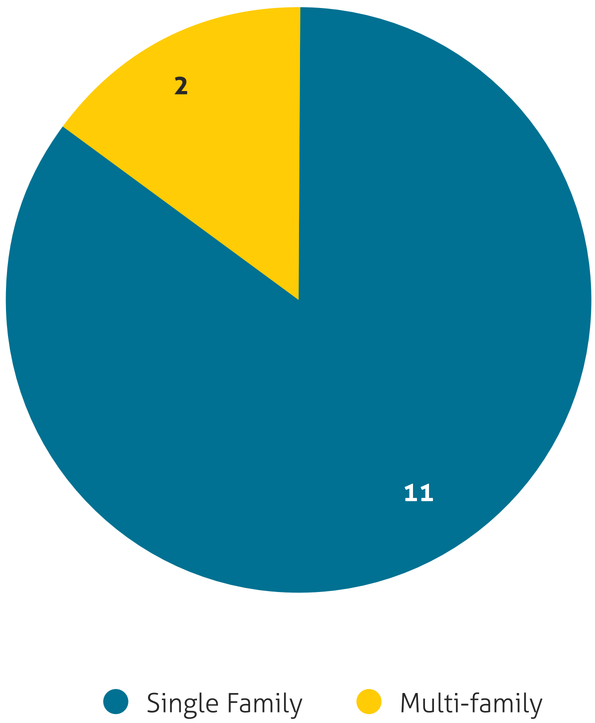

Figure B-28. Do you live in a single family home, or in multi-family housing like an apartment?

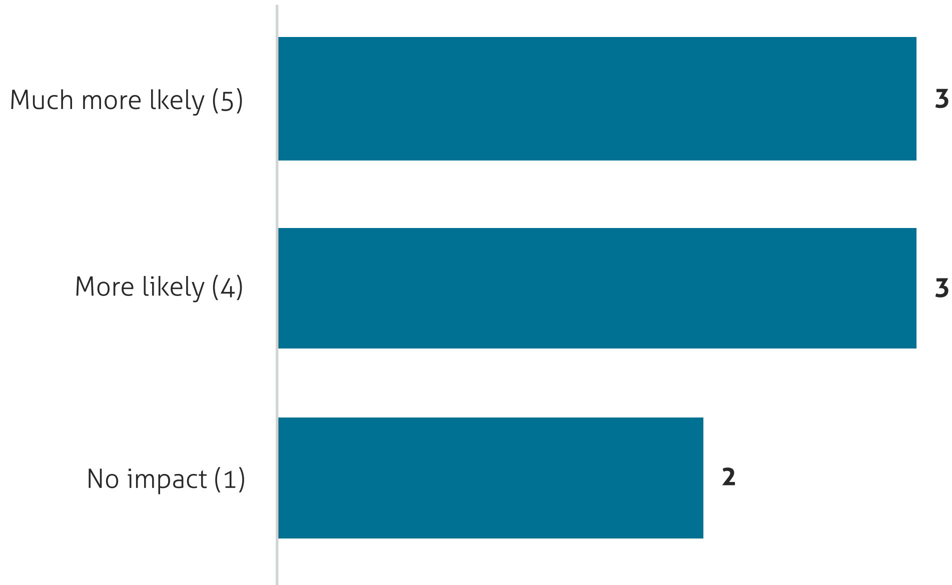

Figure B-29. How much would the availability of charging at work affect your likelihood to buy an EV? (from 1 no impact to 5 much more likely)

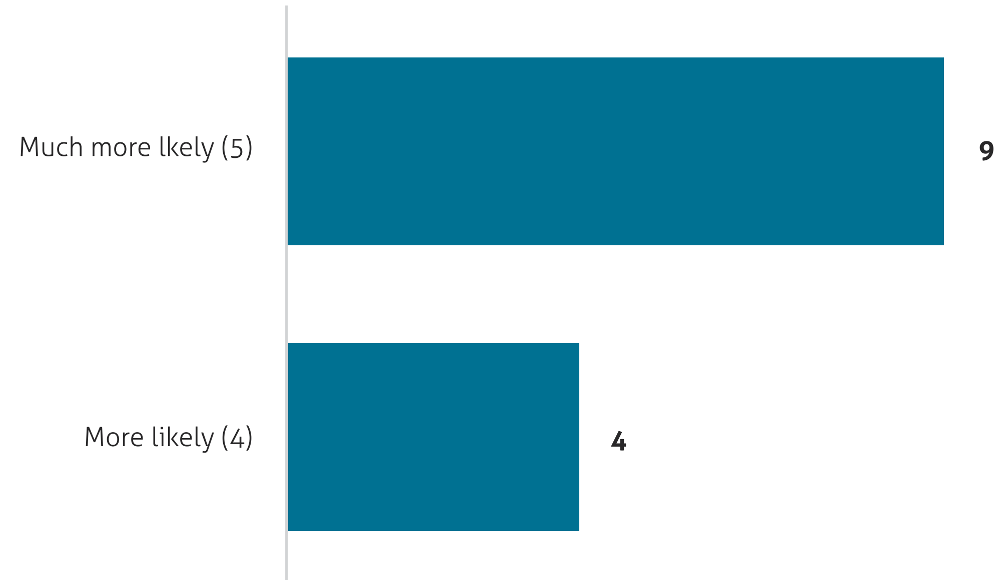

Figure B-30. In the next year, affordable longer range electric vehicles will begin to be available in Colorado (200-250 mile range instead of 100 mile). On a scale from 1-5, how much more likely are you to buy a PEV when ranges of over 200 miles are available?

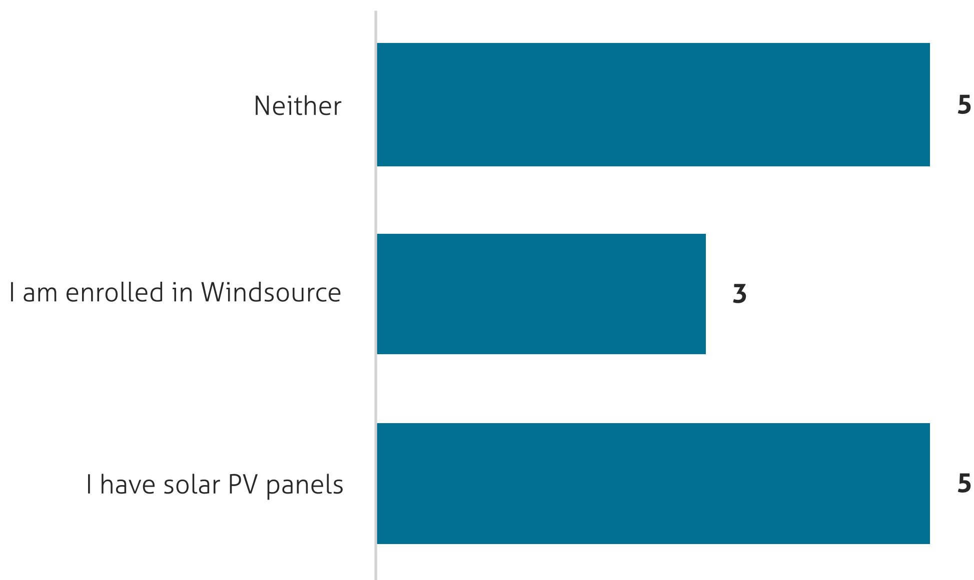

Figure B-31. Do you have rooftop solar PV panels or are you enrolled in Xcel's Windsource program?

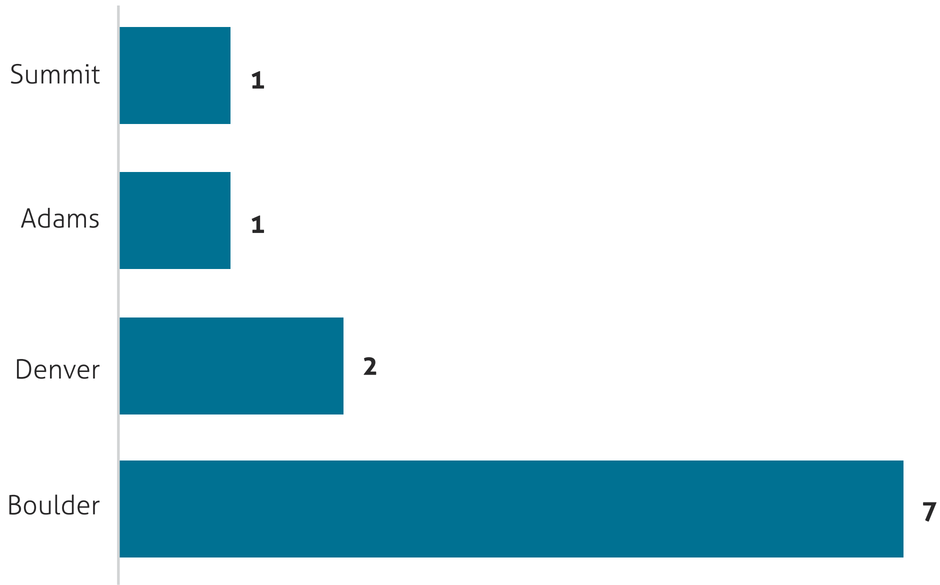

Figure B-32. Please let us know what County you live in.

Appendix C.

Example PEV Ready Building Codes

California Statewide CalGreen Code[123]

The raceway termination location shall be permanently and visibly marked as "EV CAPABLE".

4.106.4.2. New multi-family dwellings. Where 17 or more multi-family dwelling units are constructed on a building site, 3 percent of the total number of parking spaces provided for all types of parking facilities, but in case less than one, shall be electric vehicle charging spaces (EV spaces) capable of supporting future EVSE. Calculations for the required number of EV spaces shall be rounded up to the nearest whole number.

> **Note:** Construction documents are intended to demonstrate the project's capability and capacity for facilitating future EV charging. There is no requirement for EV spaces to be constructed or available until EV chargers are installed for use.
>
> 4.106.4.2.1. Electric vehicle charging space (EV space) locations. Construction documents shall indicate the location of proposed EV spaces. At least one EV space shall be located in common use areas and available for use by all residents.
>
> When EV chargers are installed, EV spaces required by Section 4.106.4.2.2, Item 3, shall comply with at least one of the following options:
>
> 1. The EV space shall be located adjacent to an accessible parking space meeting the requirements of the California Building Code, Chapter 11A to allow use of the EV charger from the accessible space.
> 2. The EV space shall be located on an accessible route, as defined in the California Building Code Chapter 2, to the building.
>
> 4.106.4.2.2 Electric vehicle charging space (EV Space) dimensions. The EV spaces shall be designed to comply with the following:
>
> 1. The minimum length of each EV space shall be 18 feet.
> 2. The minimum width of each EV space shall be 9 feet.
> 3. One in every 25 EV spaces, but not less than one, shall also have an 8-foot wide minimum aisle. A 5-foot wide minimum aisle shall be permitted provided the minimum width of the EV space is 12 feet.
>   a. Surface slope for this EV space and the aisle shall not exceed 1 unit vertical in 48 units horizontal (2.083 percent slope) in any direction.

[123] CalGreen. 2016. Residential Mandatory Measures. http://www.hcd.ca.gov/building-standards/calgreen/docs/HCDSHL605_2016.pdf

4.106.4.2.3 Single EV space required. Install a listed raceway to accommodate a dedicated 208/240-volt branch circuit. The raceway shall not be less than trade size 1 (nominal 1-inch inside diameter). The raceway shall originate at the main service or subpanel and shall terminate into a listed cabinet, box or other enclosure in close proximity to the proposed location of an EV charger. Construction documents shall identify the raceway termination point. The service panel and/or subpanel shall provide capacity to install a 40-ampere minimum dedicated branch circuit and space(s) reserved to permit installation of a branch circuit overcurrent protective device.

4.106.4.2.4 Multiple EV space required. Construction documents shall indicate the raceway termination point and proposed location of future EV spaces and EV chargers. Construction documents shall also provide information on amperage of future EVSE, raceway method(s), wiring schematics and electrical load calculations to verify that the electrical panel service capacity and electrical system, including any on-site distribution transformer(s), have sufficient capacity to simultaneously charge all EVs at all required EV spaces at the full rated amperage of the EVSE. Plan design shall be based upon 40-ampere minimum branch circuit. Raceways and related components that are planned to be installed underground, enclosed, inaccessible or in concealed areas and spaces shall be installed at the time of original construction.

4.106.4.2.5. Identification. The service panel or sub-panel circuit directory shall identify the overcurrent protective device space(s) reserved for future EV charging as “EV CAPABLE” in accordance with the California Electrical Code.

City of Boulder[124]

Subsection 210.52 (J), “Electric Vehicle Charging Requirements,” shall be added to read:

Electric Vehicle Charging Requirements. Every newly permitted multi-family dwelling with more than twenty-five parking spaces shall include the following:

(1) Ten percent of parking spaces shall have one 240-volt and one 120-volt dedicated charging receptacle outlet.

(a) Accessible Spaces. Ten percent of accessible parking spaces, but in no case less than one accessible parking space, shall have one 240-volt and one 120 volt dedicated charging receptacle outlet. Parking in accessible spaces where electric vehicle supply equipment is installed shall not be limited to electric vehicles when no other comparable accessible space is available.

(b) Designation. Fifty percent of the parking spaces with a required dedicated charging receptacle outlet for electric vehicles shall be designated for electric vehicle charging.

(2) At least two parking spaces shall have a Level 2 dual port electric vehicle charging station. These two parking spaces with a Level 2 dual port electric vehicle charging station shall be designated for electric vehicle charging.

[124] The building code language can be found under agenda item 5B. https://www-static.bouldercolorado.gov/docs/2017_02_21_Agenda_Packet_final-1-201702161617.pdf?_ga=1.83006550.1155664477.1487788003

Boulder County[125]

K111.4 Electric vehicle (EV) charging receptacle outlets. Level 2 (240-volt) electric vehicle (EV) charging re¬cepta-cle outlets are to be installed for all new commercial, industrial or multiple-family residential buildings or additions or alterations to existing such buildings that increase the existing total floor area of the building by either fifty percent or by 5,000 square feet in accordance with Table K111.4. Charging receptacle outlets shall be installed in accordance with the requirements of Article 625 of the Electrical Code.

Table K111.4 Electric Vehicle (EV) Charging Receptacle Outlets

Total Parking Spaces Provided											
1-19	20-50	51-100	101-150	151-200	201-250	251-300	301-350	351-400	401-450	451-500	501+
Minimum Number of EV Charging Outlets											
0	1	2	3	4	5	6	7	8	9	10	2% of Total

Palo Alto, CA[126]

A4.106.8.1 Definitions. For the purposes of this section, the following definitions shall apply:

(a) Level 2 EVSE. "Level 2 EVSE" shall mean an EVSE capable of charging at 30 amperes or higher at 208 or 240 VAC. An EVSE capable of simultaneously charging at 30 amperes for each of two vehicles shall be counted as two Level 2 EVSE.

(b) Conduit Only. "Conduit Only" shall mean, at minimum: (1) a panel capable to accommodate a dedicated branch circuit and service capacity to install a 208/240V, 50 amperes grounded AC outlet; and (2) raceway or wiring with capacity to accommodate a 100 ampere circuit; terminating in (3) a listed cabinet, box, enclosure, or NEMA receptacle. The raceway shall be installed so that minimal removal of materials is necessary to complete the final installation.

(c) EVSE-Ready Outlet. "EVSE-Ready Outlet" shall mean, at minimum: (1) a panel capable to accommodate a dedicated branch circuit and service capacity to install a 208/240V, 50 amperes grounded AC outlet; (2) a two-pole circuit breaker; (3) raceway with capacity to accommodate 100-ampere circuit; (4) 50 ampere wiring; terminating in (5) a 50 ampere NEMA receptacle in a covered outlet box.

(d) EVSE Installed. "EVSE Installed" shall mean an installed Level 2 EVSE.

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[125] Boulder County. 2017. Boulder County Building Code Amendments. https://assets.bouldercounty.org/wp-content/uploads/2017/03/building-code-2015.pdf

[126] City of Palo Alto. 2014. Proposed Ordinance. https://www.cityofpaloalto.org/civicax/filebank/documents/43223

A4.106.8.3 Multi-Family Residential Structures. The following standards apply to newly constructed residences in a multi-family residential structure, except as provided in section A4.106.8.4.

(a) Resident parking. The property owner shall provide at least one EVSE-Ready Outlet or EVSE Installed for each residential unit in the structure.

(b) Guest parking. The property owner shall provide Conduit Only, EVSE-Ready Outlet, or EVSE Installed, for at least 25% of guest parking spaces, among which at least 5% (and no fewer than one) shall be EVSE Installed.

(c) Accessible spaces. Projects shall comply with the 2016 California Building Code requirements for accessible electric vehicle parking.

(d) Minimum total circuit capacity. The property owner shall ensure sufficient circuit capacity, as determined by the Chief Building Official, to support a Level 2 EVSE in every location where Circuit Only, EVSE-Ready Outlet or EVSE Installed is required.

(e) Location. The EVSE, receptacles, and/or raceway required by this section shall be placed in locations allowing convenient installation of and access to EVSE. In addition, if parking is deed-restricted to individual residential units, the EVSE or receptacles required by subsection (a) shall be located such that each unit has access to its own EVSE or receptacle. Location of EVSE or receptacles shall be consistent with all City guidelines, rules, and regulations.

A4.106.8.4 Exception - Multi-Family Residential Structures with Individual, Attached Parking. The property owner shall provide Conduit Only, EVSE-Ready Outlet, or EVSE Installed for each newly constructed residence in a multi-family residential structure featuring: (1) a parking space attached to the residence; and (2) a shared electrical panel between the residence and parking space (e.g., a multi-family structure with tuck-under garages).

Salt Lake City (Proposed Language)

1. **Electric Vehicle-Ready Parking:** The following standards shall only apply to multi-family uses. At least 20% of the minimum required parking spaces must have conduit to accommodate wiring for the future use of a minimum of 208 Volt (Level 2) electric vehicle charging equipment:

    a. The number of required minimum spaces is determined after applying any applicable reductions and exemptions.

    b. Electric vehicle-ready parking spaces shall count toward the required number of parking spaces.

    c. Sufficient electrical capacity shall be provided for the use of the above required electric vehicle charging equipment. Sufficient electrical capacity means that the electrical panel(s) and transformer have the capacity to accommodate the future use of a minimum of 208 Volt electric vehicle charging equipment.

    d. Where no minimum is required, calculations are based on provided parking.

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