BRIEFING

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Home charging access and the implications for charging infrastructure costs in the United States

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INTRODUCTION

About 6.5 million new plug-in electric vehicles (EVs) were sold worldwide in 2021, representing about 8.5% of light-duty vehicle sales and an increase from 3.1 million in 2020.[1] The United States is the third largest EV market, with about 667,000 new sales in 2021, representing about 4.5% of light-duty vehicle sales. This growth coincides with commitments from automakers and governments to rapidly expand their EV investments, model offerings, and supporting policies. In particular, the Biden Administration outlined a target of achieving a 50% EV sales share in 2030 along with a goal of deploying an accompanying network of 500,000 public chargers.[2]

Limited charging infrastructure has been one of the key barriers to EV market growth. Deploying sufficient charging infrastructure in tandem with market growth is needed to ensure that owning and operating EVs is as convenient and practical as their combustion counterparts. A recent ICCT analysis found that a total of 2.4 million non-home chargers, associated with a $28 billion infrastructure investment between 2021 and 2030, would need to be deployed to support an estimated 26

1 EV-Volumes, EV Data Center, (2021), http://www.ev-volumes.com/data/center/.

2 The White House, "Statements on the Biden Administration's Steps to Strengthen American Leadership on Clean Cars and Trucks," (August 5, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/05/statements-on-the-biden-administrations-steps-to-strengthen-american-leadership-on-clean-cars-and-trucks/ and The White House, "Fact sheet: The Biden-Harris Electric Vehicle Charging Action Plan," (December 13, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/13/fact-sheet-the-biden-harris-electric-vehicle-charging-action-plan/.

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million EVs on U.S. roads.[3] The Bipartisan Infrastructure Investment and Jobs Act, which President Biden signed into law in November 2021, allocates $7.5 billion towards public charging infrastructure nationwide, which is a little over 25% of the estimated investment needed.[4] While additional investments will need to be made, including from non-governmental stakeholders such as utilities and private charging companies, this political reality nevertheless invites deeper analysis into the most cost-effective ways to meet charging needs.

Around 80% of EV adopters live in detached homes where it is relatively easy to install a home charger, and have relied on low-cost, overnight, at-home charging for their primary charging needs.[5] This share is over-representative of the U.S. general population, where 63% of households live in detached homes.[6] As the EV market expands, more people who do not have access to home charging will purchase EVs. This includes renters who cannot unilaterally install home chargers, and residents of attached homes (6%) and multi-family homes (26%) which are less likely to have access to parking options where charging infrastructure is easily installed. Drivers without home charging access will rely on alternative charging options to meet their needs. Additionally, others who could choose to install a home charger but require significant or expensive electrical upgrades beforehand may instead choose to charge at public or workplace locations.

This briefing builds on a previous ICCT analysis of U.S. charging infrastructure needs through 2030 to assess how increased investment in home charging availability nationwide may lower the overall charging infrastructure investment costs needed to support the growing market.[7] We develop six hypothetical scenarios for charging infrastructure growth in the United States based on distinct ratios of home, workplace, and public charging deployment to assess the cost-effectiveness of alternative charging deployment strategies. By doing so, this briefing identifies potential trade-offs associated with different approaches to charging infrastructure planning and reveals the long-term importance of home charging access. A discussion of best practices for public policy to facilitate the proliferation of home charging access follows the quantitative findings.

MODIFIED CHARGING BEHAVIOR AND HOME CHARGING ACCESS

This section briefly summarizes the methodology behind ICCT's 2021 U.S. charging gap analysis and discusses new data additions in this briefing. Following this discussion, we define the six hypothetical scenarios considered for charging infrastructure growth in the United States, as well as the assumed policy and market contexts that exist in each.

3 Gordon Bauer, Chih-Wei Hsu, Mike Nicholas, and Nic Lutsey, "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030," (Washington, DC: ICCT, 2021), https://theicct.org/publications/charging-up-america-jul2021.

4 The White House, "Fact Sheet: The Bipartisan Infrastructure Deal," (November 6, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisan-infrastructure-deal/.

5 Jae Hyun Lee, Debapriya Chakraborty, Scott J. Hardman, and Gil Tal, "Exploring electric vehicle charging patterns: Mixed usage of charging infrastructure," (Transportation Research Part D, Transport and Environment, 2020).

6 United States Census Bureau (American Community Survey 2015-2019 5-year estimates, accessed June 2021), https://data.census.gov/mdat/#/.

7 Gordon Bauer, Chih-Wei Hsu, Mike Nicholas, and Nic Lutsey, "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030," (Washington, DC: ICCT, 2021), https://theicct.org/publications/charging-up-america-jul2021.

The 2021 ICCT U.S. charging gap analysis conducted a comprehensive assessment of the energy demand of EVs and the existing supply of charging infrastructure in the U.S. in 2020 to determine the amount and type of chargers needed for the growing EV fleet.[8] Data on regional market trends in EV sales, household characteristics, and charging behavior were used to project future charger counts, year-over-year until 2030. Figure 1 shows the analytical framework of the work, including data inputs (blue icons), analysis steps (yellow), and intermediate and final outputs (green and purple, respectively). Aspects of the original analysis that were altered for the purposes of this briefing are circled in red.

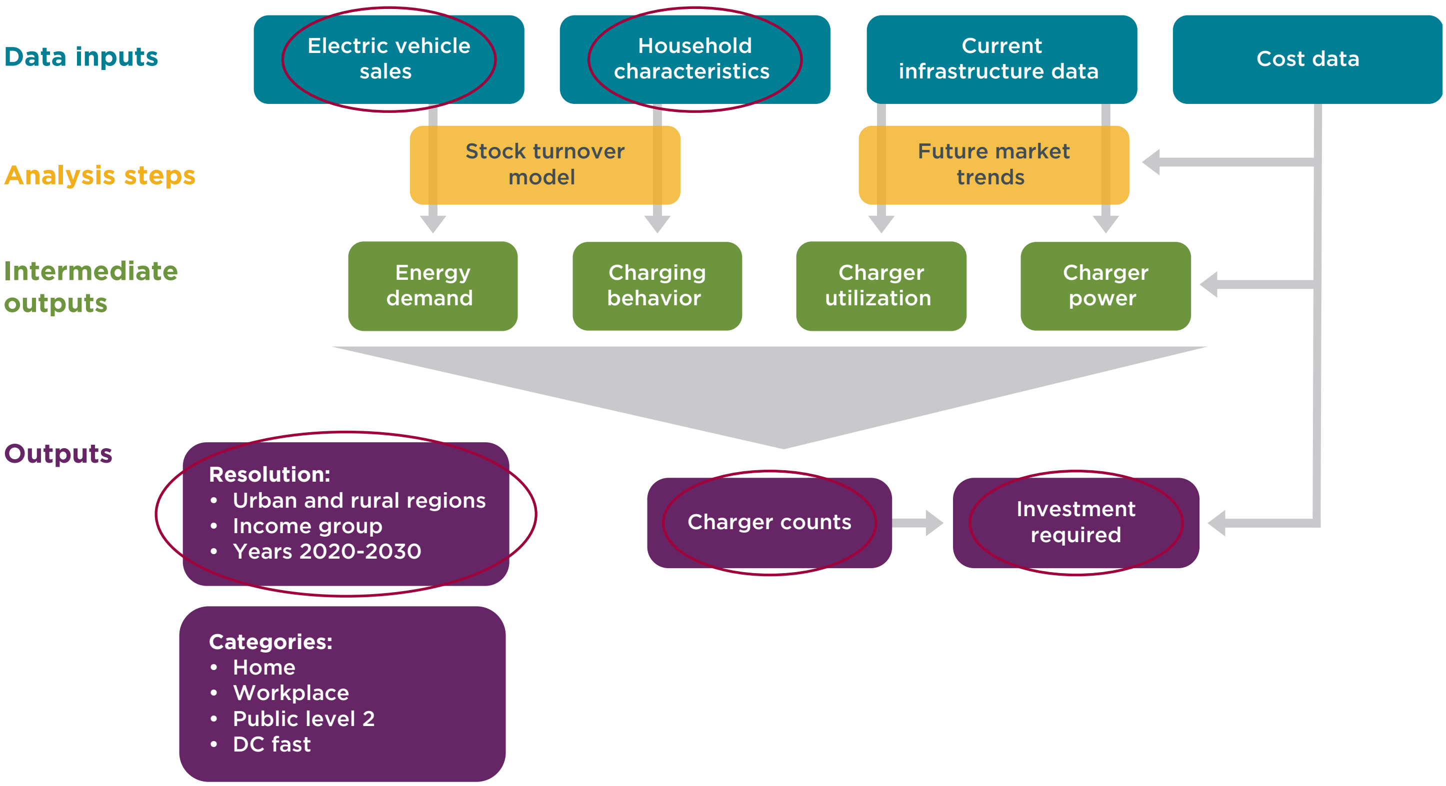

Figure 1. Flowchart depicting charging gap analysis process with changes circled.

Based on the most recent research from the National Renewable Energy Laboratory (NREL) and the U.S. Census Bureau, we apply updated national-survey data on household characteristics, including home parking options, electrical access, vehicle ownership, and housing tenure.[9] The NREL data provide a more detailed picture of potential home charging access by asking respondents if they park near existing electrical installations or, if not, whether they could change where they park or install electrical wiring such that they could charge where they park. This goes beyond previous survey data used, which only asked the former question, and provides a better understanding of home charging access among the general population. Additionally, we apply data from the U.S. Census on the share of homes that are

8 Bauer, Hsu, Nicholas, and Lutsey, "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030."

9 Yanbo Ge, Christina Simeone, Andrew Duvall, and Eric Wood, "There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure," (Technical report, National Renewable Energy Laboratory, October 2021), https://www.nrel.gov/docs/fy22osti/81065.pdf.

rented, by housing type, to isolate home charging proliferation among rented and owned homes in specific scenarios we consider.[10]

The scope of this analysis focuses on national charger counts and costs, so regional differences in EV sales and charger deployment examined in the 2021 ICCT analysis have been subsumed by aggregate national-level data. The projected size and growth of the U.S. EV stock was based on market and policy developments through 2020, such that annual U.S. EV sales increase to 5.9 million new sales in 2030, representing 36% of all new vehicle sales. Because new public and private sector goals to reach 50% ZEV sales in 2030 have been announced since the 2021 analysis, the pace and scale of EV market growth and the need for charging infrastructure quantified here may be an underestimate.

HOME CHARGING SCENARIOS

This briefing defines six different charging infrastructure deployment scenarios to assess how increased investment in home charging availability nationwide may lower the overall charging infrastructure investment costs. The first scenario is the original projection from the 2021 analysis, and the five other scenarios modify the assumptions regarding home charging access based on potential market and policy outcomes. The six scenarios are defined as follows:

Scenario 1: Projected home charging access. This scenario is the original projection from the 2021 ICCT U.S. charging gap analysis, which is based on survey data of early EV adopter home charging access and charging behavior.[11] Survey data from 2020 showed that most early adopters had access to home charging,[12] but that only about half of the U.S. general population would have access if all cars were EVs today.[13] As the EV market expands, more people who do not have access to home charging will purchase EVs, and so the percentage of EV owners with home charging will decline. At the same time, people will install chargers at their homes and will change their parking behavior, causing home charging access to increase. We assume home charging access slowly declines, converging to the average of the data representing early adopters and the general population by 2030. We estimate a lower bound that 53% of homes in the United States have home charging access, which results in the share of EV owners with home charging access gradually declining from 88% in 2020 to 70% in 2030.

Scenario 2: Lower rental home charging access. A key uncertainty in all charging infrastructure modeling analyses is the extent to which landlords choose not to invest in home charging access for their tenants. Data from the U.S. Census Bureau's American Community Survey suggests that about a quarter of the U.S. passenger vehicle stock is owned by rentees.[14] If most of these individuals are unable to charge at home, more investment would be required to build sufficient public charging infrastructure. To understand these implications, Scenario 2 assumes that the share of rented homes with charging access does not grow over the next decade, staying at

10 United States Census Bureau (American Community Survey 2015-2019 5-year estimates, accessed June 2021), https://data.census.gov/mdat/#/.

11 "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030."

12 Lee, Chakraborty, Hardman, and Tal, "Exploring electric vehicle charging patterns: Mixed usage of charging infrastructure."

13 U.S. Energy Information Administration 2015 Residential Energy Consumption Survey microdata, updated December 2018, https://www.eia.gov/consumption/residential/data/2015/index.php?view=microdata.

14 United States Census Bureau (American Community Survey 2015-2019 5-year estimates, accessed June 2021), https://data.census.gov/mdat/#/.

around 30%.[15] In Scenario 1, the share of rented homes with charging access grows to 36% by 2040, when we assume a 100% EV market share.

Scenario 3: Potential home charging access. In 2020, NREL conducted a survey of U.S. vehicle owners and their potential to charge at home. The survey results indicated that 75% of all U.S. light-duty vehicles park (or could park) in locations where there would be access to home charging.[16] However, because many families own more than one vehicle, a slightly lower share of homes would have access. Scenario 3 assumes a lower bound of 66% of U.S. homes having charging access.[17]

Ideally every driver would have access to affordable and reliable charging access at their daily, overnight parking location—which may not necessarily be in a garage or driveway. In this analysis, we broadly define home charging access to include both what is traditionally thought of as home charging (i.e. a wall outlet or dedicated charger in a garage or driveway), as well as chargers installed in residential parking lots and garages, or on-street at multi-family homes (MFHs) and single-family homes without garages or driveways.

To determine the households with home charging access, we examine overnight parking options at each housing type. Table 1 shows the shares of overnight parking locations for each housing type synthesized from NREL's survey, assuming that people will park where they have the best opportunity to charge when they go home. The different parking options considered, and the hierarchy from most optimal for charging to least is as follows: personal garages, driveways or carports, parking garages or parking lots, and on-street parking.

Table 1. Assumed distribution of overnight parking options by housing type in the United States maximized for home charging access.

Housing type	Personal garage	Driveway/ carport	Parking garage/lot	On-street
Single-family detached	70%	18%	8%	4%
Single-family attached	58%	2%	28%	12%
Low-rise MFH	6%	18%	57%	19%
Mid-rise MFH	5%	7%	78%	10%
High-rise MFH	6%	0%	93%	1%

For single-family homes, personal garages and driveways with electrical access are the most common parking options, which makes expanding home charging access relatively easy. For MFHs however, personal garages are not very common, and as the size of the building increases from low-rise (2–4 units) buildings, to mid-rise (5–19), to high-rise (20+), we see a decrease in the share of homes with driveways and carports, in favor of more parking lots and parking garages. This of course makes expanding home charging access at MFHs more difficult. According to NREL's data, however,

15 Value estimated from share of homes with charging access reported in the 2015 RECS (footnote 6) and distribution of housing options by tenure from the ACS (footnote 7).

16 Yanbo Ge, Christina Simeone, Andrew Duvall, and Eric Wood, "There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure," (Technical report, National Renewable Energy Laboratory, October 2021), https://www.nrel.gov/docs/fy22osti/81065.pdf.

17 Value estimated from potential share of homes with charging access from NREL (footnote 9) and distribution of housing options by tenure from the ACS.

most people with single-family homes have already identified their personal garages and driveways as likely locations to have home charging access. Therefore, further expanding home charging access beyond the most suitable parking locations at single-family homes requires building infrastructure at residential parking lots and garages, just as with MFHs.

Scenario 4: Potential home charging access with additional MFH. Scenario 4 applies the same share of home charging access as Scenario 3, plus additional home charging access for MFHs where parking garages or lots are the best available overnight parking option, as identified by Table 1. NREL's survey data indicates that about 94% of personal garages at single-family homes are already, or could potentially be, electrified,[18] and Scenario 4 models comparable home charging access for MFHs. At low-rise MFHs, for example, we assume that of the 57% of these homes with parking garage/lot spaces for tenants, 94% have charging access at each of these spots. Based on these assumptions, Scenario 4 explores the implications of making home charging as easy for MFH tenants as it is for single-family homeowners, and overall assumes a lower bound that 77% of U.S. homes have charging access.

Scenario 5: Potential home charging access with additional private home. Scenario 5 applies the same share of the home charging access as Scenario 3, plus expanded home charging access to all single-family homes that have a personal garage, driveway, or parking lot. According to Table 1, this accounts for 96% and 88% of U.S., single-family detached and attached homes, respectively. In total, Scenario 5 assumes a lower bound that 71% of homes have charging access.

Scenario 6: Limited home charging access. Scenario 6 assumes that EV adoption increases even if insufficient investments are made to expand home charging access. This scenario assumes that the consumer barriers of model availability, cost, and consumer awareness are overcome, and that the transition to EVs continues despite relatively limited home charging access. Based on expectations for the timing of EV cost parity along with government and automaker commitments to reach 50% EV sales shares in 2030,[19] this scenario explores the charging infrastructure needs based on market growth that is independent of greater home charging access.

RESULTS

Table 2 summarizes the charger results in 2030 for the six scenarios defined above. The rows in the table are the variables analyzed, broadly categorized into electric vehicle market development, electric vehicle ownership characteristics, number of chargers, and electric vehicle charger dynamics. The columns in the table are the six scenarios. The findings based on the new scenarios introduced in this briefing (Scenario 2 through Scenario 6) are compared to the findings from the original ICCT 2021 charging gap analysis (Scenario 1). Values in green indicate a relative increase compared to the same variable in Scenario 1, whereas red values indicate a decrease and black values indicate no change. As discussed above, the pace and scale of EV market growth

18 Ge, Simeone, Duvall, and Wood, "There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure.".

19 Nic Lutsey and Mike Nicholas, "Update on electric vehicle costs in the United States through 2030," (Washington, DC: ICCT, 2019), https://theicct.org/publication/update-on-electric-vehicle-costs-in-the-united-states-through-2030/ and Anh Bui, Peter Slowik, Nic Lutsey, "Power play: Evaluating the U.S. position in the global electric vehicle transition," (Washington, DC: ICCT, 2021), https://theicct.org/publications/us-position-global-ev-jun2021.

applied in the analysis is identical across all scenarios to isolate the impact of home charging access on public charging infrastructure needs.

Table 2. Summary of analysis results in 2030 for each scenario.

Category	Variable	2030					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
		Projected home charging access	Lower rental home charging access	Potential home charging access	Potential with additional MFH	Potential with additional private home	Limited home charging access
Electric vehicle market development	Total EV population (millions)	25.8	25.8	25.8	25.8	25.8	25.8
	EV share of new light-duty vehicle sales	36%	36%	36%	36%	36%	36%
	EV share of US light-duty vehicle population	9%	9%	9%	9%	9%	9%
Electric vehicle ownership characteristics	Detached home share of EV owners	68%	68%	68%	68%	68%	68%
	Commuter share of EV owners	58%	58%	58%	58%	58%	58%
	Home charging access share	70%	67%	78%	81%	82%	53%
	Home charging share of energy demand	59%	57%	66%	68%	69%	45%
Number of chargers	Private home chargers (thousands)	16,997	16,459	19,083	19,083	20,170	13,257
	Multi-family home chargers (thousands)	997	871	1,001	1,778	1,001	486
	Workplace chargers (thousands)	1,310	1,345	1,162	1,122	1,089	1,572
	Public Level 2 chargers (thousands)	883	925	723	624	653	1,175
	DC fast chargers (thousands)	177	185	144	135	126	237
Electric vehicle charger dynamics	EVs per public charger	24	23	30	34	33	18
	EVs per non-home charger	10.9	10.5	12.7	13.7	13.8	8.6
	Non-home charger annual growth rate (2021-2030)	27%	28%	25%	24%	24%	30%

The results in Table 2 show that in Scenarios 3, 4, and 5, where home charging access is increased relative to the projected scenario, we see a substantial rise in the number of home chargers and a smaller, but still significant, decrease in the number of non-home chargers needed to support adoption. For example, in Scenario 3 – potential home charging access, home chargers increase in number by about 2.1 million, while non-home chargers decrease by around 340,000. Similarly, in Scenario 4 (potential home charging access with additional MFH) home chargers increase by about 2.9 million and non-home chargers decrease by about 490,000. Overall, Table 2 also shows how a higher share of home charging access corresponds with a lower annual growth rate of non-home chargers, and vice versa.

Increased home charging access also increases the ratio of EVs per public charger, as a greater share of EVs charge at public locations less frequently. The EV-to-public charger ratio would increase to 30, or an additional six vehicles per charger, by 2030 if home charging access was expanded to the most suitable homes (Scenario 3). The ratio would increase to 34 by 2030, an additional ten vehicles per charger, under Scenario 4 with additional charging at multi-family homes.

In Scenarios 2 and 6, where home charging access growth is limited, we see the reverse of all these trends. Because EV drivers with access to home charging will still occasionally use non-home chargers, there is not a one-to-one ratio in the increase in home chargers and the decrease of non-home chargers, or vice versa. Which types of non-home chargers make up that decrease (or increase) is largely dictated by EV drivers' charging behavior.

This analysis finds that the number of DC fast chargers are most sensitive to increased home charging access at private homes, closely followed by public Level 2 chargers, and then workplace chargers. As an example, in Scenario 3 – potential home charging access, an increase from 18 million to 20 million home chargers (mostly at private, single-family homes) reduces the number of non-home chargers from around 2.4 to 2 million. Of that around 400,000 decrease in chargers, 33,000 are DC fast chargers, accounting for an 19% reduction in DC fast chargers relative to the projected scenario. In comparison, public Level 2 and workplace chargers see a 18% and 11% reduction, respectively. This finding can be explained by charging behaviors and the convenience that home charging access provides, whereby an EV can be more regularly charged overnight, effectively removing the need for EV owners to stop at public chargers to top off their batteries during daily travel.

Public Level 2 charging needs are slightly more impacted by home charging access at MFHs. Comparing Scenario 4 – potential home charging access with additional MFH with Scenario 3, MFH chargers increase by 78% from 1 million units to around 1,780,000 units, requiring 260,000 fewer public Level 2 chargers, a 29% decrease. DC fast chargers are a close second, with 42,000 fewer chargers, a 24% decrease, followed by workplace chargers at 188,000 fewer chargers, a 14% decrease. While shared chargers at MFHs may not provide the same reliability as a private charger at a single-family home, they are highly desirable because of their convenience and have a higher utilization rate when serving multiple tenants' EVs. Additionally, from a user cost perspective, MFH chargers can offer relatively lower refueling costs compared to public Level 2 chargers, which often have higher per-kilowatt-hour electricity costs in addition to membership fees, idle fees, and possibly other charges.

Workplace chargers comprise the majority of non-home chargers in all scenarios and are the least sensitive to increasing levels of home charging. Furthermore, when home charging access levels are reduced, workplace chargers make up a significant portion of additional chargers. Workplace chargers can be extremely desirable to EV owners who commute to work because they are located where drivers leave their cars parked for extended periods of time and tend to be low-cost or free to use. However, it is unlikely that free-to-use charging will be a sustainable long-term option for businesses.

If usage costs are made low enough to entice those without home charging access, but high enough to discourage those that already or could have home charging access, there can be confidence that workplace chargers will remain highly utilized and will be key to ensuring equitable charging access as the U.S. EV market develops.[20]

The rate at which the share of EV drivers with home charging access declines in the United States is inversely related to how fast public charging infrastructure must be deployed to support adoption. If home charging access is more widespread, public charging infrastructure deployment can grow at a relatively slower rate. Figure 2 shows the percent of EV owners with home charging access from 2020 to 2030 for the six scenarios. In 2020, 88% of electric vehicle owners have home charging access, and access decreases to between 53% and 82% in 2030 depending on the scenario.

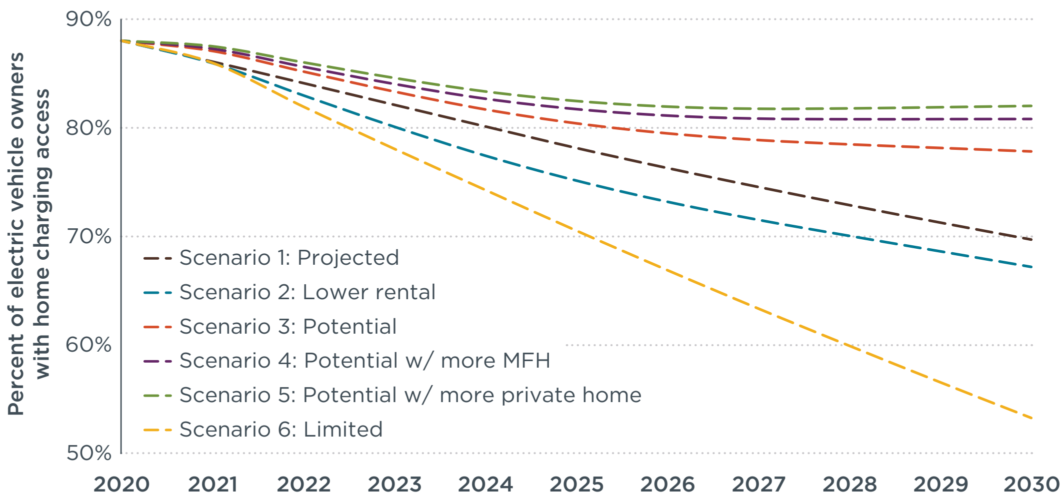

Figure 2. Share of electric vehicle owners with home charging access in the U.S from 2021 through 2030.

Because home charging access is so prevalent among the early market through 2021, we anticipate that even in the most optimistic scenarios the share of EV drivers with home charging access will decline over time. Based on Scenario 1, the share of U.S. EV owners with home charging access declines from 86% in 2021 to 70% in 2030. However, different market and policy contexts could drastically shift this trend, either tempering the decline or accelerating it. For example, based on the potential home charging access scenario (Scenario 3; red trendline), expanding home charging access to additional homes that are most suited for home chargers could cut this reduction by half, leaving 78% of U.S. EV drivers with home charging access in 2030. Alternatively, if there is a significant resistance to home charger installations at rental properties (blue trendline), the decline in home charging access could accelerate such that about 67% of U.S. EV drivers have home charging access in 2030.

20 "Workplace Charging for Plug-In Electric Vehicles", U.S. Department of Energy Alternative Fuels Data Center, accessed October 7, 2021, https://afdc.energy.gov/fuels/electricity_charging_workplace.html.

IMPLICATIONS FOR CHARGING INFRASTRUCTURE PLANNING AND COSTS

This section builds on the above findings to examine the impact of relatively greater and lesser home charging access on overall charging infrastructure costs in the United States. The economic case to increase home charging access depends on whether this reduction provides sufficient overall savings to offset increased spending on home charging.

Figure 3 shows the cumulative investment required to support charging infrastructure deployment between 2021 and 2030 for the six scenarios. Investment costs include labor and materials for installation, charger hardware, and permitting and tax expenses. The total costs are split by charger type to clearly illustrate where the relative cost changes occur between each scenario. The left side of the figure shows how Scenario 1, the projected scenario from the 2021 ICCT charging gap analysis, estimates a need of $48.4 billion to be invested by 2030.[21] Approximately $28 billion, or 58%, of those costs is expected to come from non-home chargers, with DC fast chargers representing about 66%, followed by workplace (19%), and public Level 2 (15%). Of the $20.5 billion in home charging costs, about 75% is for private home charging and 25% is for MFHs. The findings for the other five scenarios flow to the right. Total infrastructure costs in these scenarios were developed by applying annual costs per charger from the 2021 analysis to the annual charger counts modeled for each scenario.

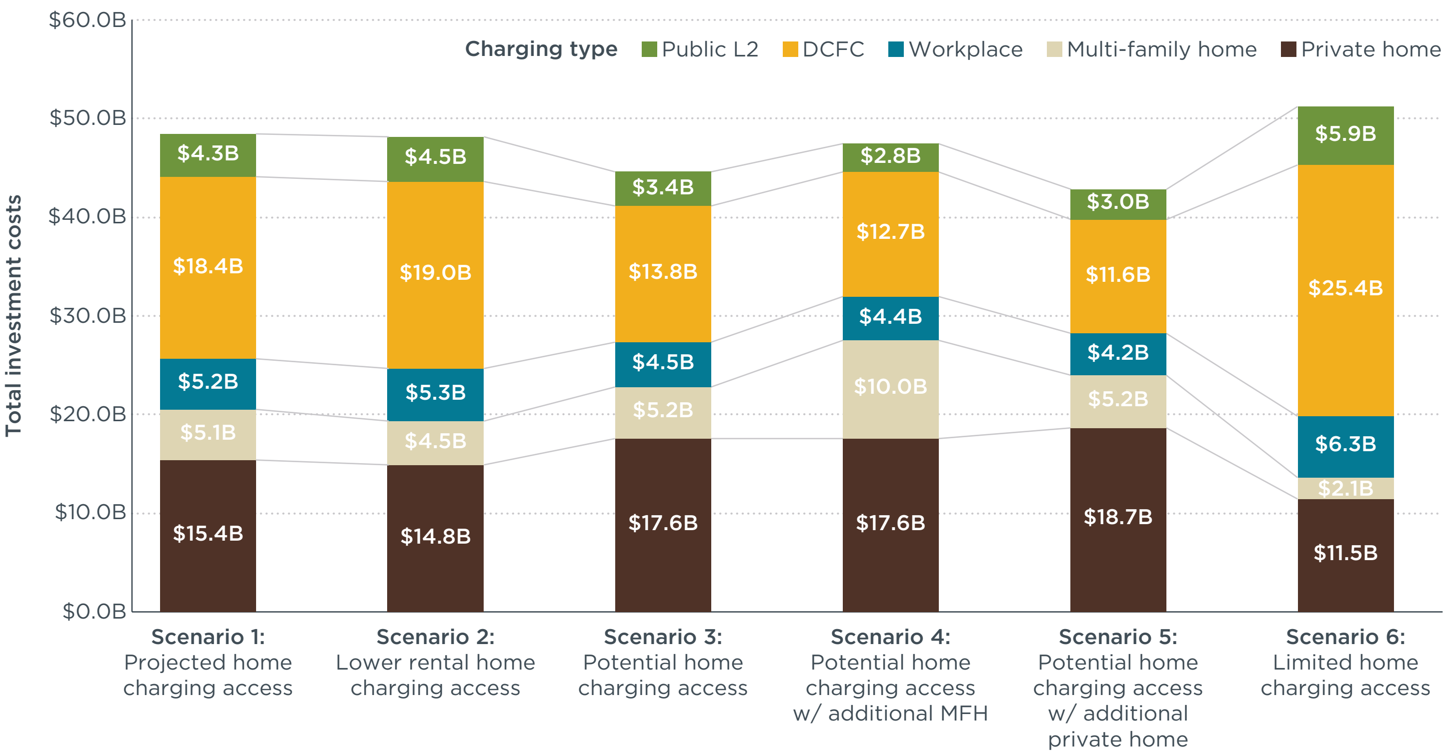

Figure 3. Cumulative charging infrastructure investment cost scenarios for 2021-2030, broken down by charger type.

21 "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030."

Figure 3 shows that in the three scenarios where home charging access is expanded, the overall infrastructure costs are reduced. For example, in Scenario 3 – potential home charging access, total charging infrastructure investment costs are estimated to be around $44.6 billion, which amounts to $3.8 billion in savings compared to Scenario 1. Most of these cost savings would come from expanded home charging access and the subsequent reduction in the number of DC fast chargers. Our analysis suggests that an additional $2.2 billion put towards expanding home charging access only at the most suitable private homes would yield $4.6 billion in savings on DC fast chargers—about $2.10 in savings per additional $1.00 spent on home charging. Including workplace and public Level 2 chargers, every dollar spent on private home chargers saves $2.81 on non-home chargers.

Scenario 5 – potential home charging access with additional private home, shows how investing in home charging for all single-family homes that have either a private garage, driveway/carport, or parking lot would result in the lowest overall charging infrastructure costs. In this scenario, the cumulative investment over this decade would total around $42.8 billion. This analysis finds that spending an additional $1.1 billion at private homes, in addition to the potential scenario's $2.2 billion, could yield an additional $1.8 billion in savings on non-home chargers, bringing the total savings to around $5.6 billion when compared to Scenario 1.

The opportunity to offset additional public charging needs by expanding home charging access at private homes is largely what drives charging infrastructure cost savings. In Scenario 4 – potential home plug access with additional MFH, expanding MFH charging access would cost an additional $4.7 billion and would reduce the costs for non-home chargers by $1.9 billion compared to Scenario 3, saving about $0.40 for every dollar spent on MFH charging. However, when combined with expansion of charging access at suitable private homes, overall infrastructure costs in Scenario 4 amount to $47.4 billion, about $1 billion in total savings compared to Scenario 1.

The main challenge with expanding charging access at MFHs in a cost-effective way is that most parking locations available do not already have an outlet available, thus requiring significant and costly construction work to retrofit with a charging station.[22] Beyond the economic impact, the equity case for MFH charging expansion is straightforward. Public charging usage costs are often much higher than the cost of residential electricity at private homes.[23] Those who live in MFHs, who are more likely to be lower income, would likely be subject to a greater economic burden to charge than those living in private homes. As Figure 3 indicates, growing both MFH and private home charging access within the existing U.S. housing stock together is a viable solution that can yield cost savings overall.

Figure 3 also shows the cost estimates for Scenario 2 and Scenario 6, where home charging access was comparatively limited. The total infrastructure costs in both of these scenarios is found to be greater than the total infrastructure costs in all of the scenarios where home charging access was increased (Scenario 3, Scenario 4, and Scenario 5). In the lower rental and limited charging access scenarios, reduced home charging access led to savings on MFH and private home chargers, while the

22 J.R. Deshazo, Norman Wong, and Jason Karpman, "Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings," (UCLA Luskin Center for Innovation, Los Angeles, CA: 2017), https://innovation.luskin.ucla.edu/sites/default/files/Overcoming%20Barriers%20to%20EV%20Charging%20in%20Multi-unit%20Dwellings%20-%20A%20Westside%20Cities%20Case%20Study.pdf.

23 Bonney, "The Pros and Cons of Public vs. At-Home EV Charging Stations", updated March 11, 2022, https://www.bonney.com/2022/03/the-pros-and-cons-of-public-vs-at-home-ev-charging-stations/.

resulting increased need for non-home chargers led to greater costs for non-home chargers. The total charging infrastructure costs in the scenarios where home charging access was limited are about 1%–20% more expensive than for the scenarios where home charging access was increased. This indicates that greater efforts to expand both private home and MFH chargers can lead to a more cost-effective charging infrastructure network relative to curtailed home charging access.

Several additional points provide context to Figure 3 and the overall findings of cost-effectiveness. Table 3 illustrates the evolution of charging infrastructure costs for each charger type in 2021 and in 2030. As shown, the charger costs increase from 2021 to 2030. This is for two primary reasons: increased labor and material costs as fewer low-cost installation sites are available and increased power output, such that Level 1 home chargers are replaced by Level 2 chargers and 50 kW DC fast chargers are replaced by 150 kW or greater fast chargers.

Table 3. Average charger cost by type in 2021 and 2030 including all direct and indirect costs.

Charger type	Average charger cost	
	2021	2030
DCFC	$79,199	$157,354
Public L2	$3,715	$6,017
Workplace	$4,118	$4,231
MFH	$3,081	$7,084
Private home	$635	$1,143

Note: Average costs determined from Bauer, Hsu, Nicholas, and Lutsey, "Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030."

Table 3 shows how in 2021, DC fast chargers are about 125 times more expensive than a private home charger. This means that a DC fast charger would have to supply the same amount of energy to 125 EVs as a home charger supplies to a single EV to be as cost-effective in supplying that energy, notwithstanding who might pay for which type of charger (e.g. government or industry for DC fast chargers and home owners for home chargers). More affordable Public Level 2 and workplace chargers are about 6 to 6.5 times more expensive than private home chargers and would have to supply the same amount of energy to about six EVs as each home charger supplies for the chargers to be equally as cost effective. These limitations highlight why home charging is so cost-effective and why sufficient investment and policies to support growth in home charging access alongside EV adoption are worthwhile. Although not considered in this analysis, including grid connection and planning costs, which are often greater for non-home chargers than home chargers, would likely make home charging more cost-effective than shown here.[24]

BEST PRACTICES TO FACILITATE HOME CHARGING

This analysis finds that the most cost-effective charging infrastructure deployment scenarios are those where home charging access is maximized at private homes and MFHs. Guaranteeing widespread home charging access among future EV adopters

24 Mike Nicholas and Sandra Wappelhorst, "Preparing Italy's charging infrastructure for rapid vehicle electrification," (Washington, DC: ICCT, 2022), https://theicct.org/publication/europe-ldv-preparing-italys-charging-infrastructure-rapid-vehicle-electrification-mar22/.

will require several policies that address cost barriers to installing home charging, misaligned incentives between tenants and owners at MFHs and rental properties, and consumer knowledge deficits around EV charging. This section will discuss the effective policy solutions to address these challenges and ensure home charging access at viable locations.

Until EVs reach cost parity with conventional vehicles, purchasing one will represent a significant upfront expense, not to mention the additional costs of installing a home charger. The federal Alternative Fuel Infrastructure Tax Credit, now the Alternative Fuel Vehicle Refueling Property Credit, was renewed by the passage of the Inflation Reduction Act and has incentivized many early adopters to invest in home charging stations.[25] Nevertheless, for lower income adopters who cannot take full advantage of the tax credits, state or local grants that cover the upfront cost of installing a charger would be a good substitute; the Clean Vehicle Assistance Program in California is one such example.[26] Improving these programs to additionally cover the cost of electrical inspections would help to encourage lower income EV adopters to seriously consider a home charger installation.

Proliferation of charging stations at MFHs and rental units comes with different difficulties than at private single-family homes. Rental agreements often stipulate that tenants cannot make modifications to a property and landlords have minimal motivation to install chargers themselves. To address this, several states have enacted "right-to-charge" laws that give tenants the right to install a charger so long as they follow building codes for new electrical installations.[27] However, these laws do not address how cost-prohibitive it can be for tenants to install a home charger, particularly at MFHs.

Utilities have a financial incentive to facilitate home charging access expansion and can offer rebates to help cover the cost of installing home charging stations at MFHs or rental properties, such as those offered by Austin Energy.[28] The federal government can also contract charger manufacturers to provide charging stations at no cost to MFHs, such as what was initiated by the U.S. Department of Energy (DOE) for commercial and residential EV charger installations in 2010.[29] Scenario 4 in our analysis, which has the greatest number of MFH chargers, projects the annual cost to procure about 1.7 million new MFH chargers would grow from $76 million in 2021 to about $3.1 billion in 2030, representing 0.16% and 6.4% of the DOE's Fiscal Year 2023 budget request of $48.2 billion, respectively.[30] State and local governments can also pass "EV-ready" building codes for new MFH construction or renovations, which require some amount of parking spaces to have an outlet or EV charging station

25 U.S. Department of Energy Alternative Fuels Data Center, "Alternative Fuel Infrastructure Tax Credit," accessed September 22, 2021, https://afdc.energy.gov/laws/10513 and Alternative fuel vehicle refueling property credit, Office of the Law Revision Counsel, 26 U.S.C. § 30C, August 15, 2022, https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title26-section30C&num=0&edition=prelim.

26 Clean Vehicle Assistance Program, "Charging Stations," accessed October 22, 2021, https://cleanvehiclegrants.org/charging-stations/.

27 1947.6, California Civil Code, 2019, https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=CIV&sectionNum=1947.6.# and 38-12-601. Unreasonable restrictions on electric vehicle charging systems – definitions., Colorado Revised Statutes, 2013, https://advance.lexis.com/documentprint/documentprintclick/?pdmfid=1000516&crid=0ab3bf3c-f0bd-4832-b49c-c14562959ecd&ecomp=pghckkk&prid=fa101450-117c-4078-bd35-1922745b9b96.

28 Austin Energy, "Plug-In Austin Electric Vehicles," accessed October 22, 2021, https://austinenergy.com/ae/green-power/plug-in-austin/multifamily-charging.

29 Kumar Gogineni, "Recovery Act – Transportation Electrification Final Project Report," (Chargepoint, Inc., 2013), https://www.osti.gov/biblio/1165597.

30 U.S. Department of Energy, "Department of Energy FY 2023 Congressional Budget Request" (March 2022), https://www.energy.gov/sites/default/files/2022-04/doe-fy2023-budget-in-brief-v6.pdf.

available.[31] These policies would reduce future charger installation costs at MFHs because retrofitting an existing property for charging infrastructure is more costly than adding it at the time of construction.[32]

EV charging dynamics are not well understood by the general public, as demonstrated by NREL's survey data, which showed that 12% of vehicles would have home charging access if the owner knew they can charge using a standard 120V outlet. Cooperative advertising by government and automakers has been credited with promoting EV uptake in the United Kingdom.[33] In the United States, legislation governing public-private partnerships varies between jurisdictions so the viability of similar programs is unclear.[34] Nevertheless, federal agencies, state, and local governments should consider the possibility to form public-private partnerships with automakers and local dealerships to produce advertising to dispel misconceptions around EV charging at home and educate the public on the environmental and costs benefits of home charging and adopting EVs more generally. Dealerships and charger manufacturers can also partner to streamline the process of purchasing and installing home chargers by providing installations quotes near the time of purchase, as has been done by Ford and Best Buy, or more recently GM and Qmerit.[35]

CONCLUSION

Public and private sector developments suggest a significant expansion of the U.S. electric vehicle market through 2030 and beyond. As the market expands, substantial investment in home, workplace, and public charging infrastructure will be necessary. This analysis shows how additional efforts to expand home charging access can lead to overall reductions in the total costs required to deploy the necessary charging ecosystem. Our analysis leads us to the following conclusions.

The total private and public sector costs of deploying the necessary charging infrastructure through 2030 are reduced when the availability of home charging is increased. When the share of electric vehicle drivers with home charging access increases from 70% to about 82%, $5.6 billion worth of savings could be had on projected total charging infrastructure investments by 2030 by offsetting the need for additional public and workplace chargers. This translates to an overall savings of about $2.63 for every $1.00 put towards increasing home charging access at single- and multi-family homes. Such high levels of home charging access require the deployment of about 21 million private home and multi-family home chargers through 2030.

Charging expansion at multi-family homes (MFHs) is critical for equitable charging access. Existing MFHs are not well suited for home charging access without significant

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31 4.106.4 Electric vehicle (EV) charging for new construction and major alterations., San Francisco Green Building Code, 2019, https://codelibrary.amlegal.com/codes/san_francisco/latest/sf_building/0-0-0-87806.

32 Dale Hall and Nic Lutsey, "Electric vehicle charging guide for cities,) (Washington, DC: ICCT, 2020), https://theicct.org/publication/electric-vehicle-charging-guide-for-cities/.

33 "Updated: Go Ultra Low campaign to close after funding cut," *FleetNews*, April 2, 2021, https://www.fleetnews.co.uk/news/latest-fleet-news/electric-fleet-news/2021/02/04/go-ultra-low-campaign-to-close-after-funding-cut.

34 Fernando J. Rodrigues Marin and Nicolai J. Sarad, "Public Private Partnerships: USA," *Bracewell*, October 1, 2021, https://bracewell.com/insights/public-private-partnerships-usa.

35 National Academy of Sciences, "Overcoming Barriers to Deployment of Plug-in Electric Vehicles," (2015), https://www.nap.edu/catalog/21725/overcoming-barriers-to-deployment-of-plug-in-electric-vehicles and "GM Partners with Qmerit to Create a More Accessible At-Home Charging Solution," General Motors, October 12, 2019, https://media.gm.com/media/us/en/gm/ev.detail.html/content/Pages/news/us/en/gm_green/2019/0812-gm-partners.html.

and costly construction work being done to retrofit them, and most EV owners who live in MFHs rely on public charging. Tenants of MFHs are more likely to be of lower socioeconomic status, so to have them disproportionately reliant on more costly public charging exacerbates existing economic inequalities. Although MFH chargers are more expensive than single-family home chargers, this analysis finds that expanding both private and MFH-home chargers can lead to total charging infrastructure network costs that are 1% to 20% less than one where home charging access is limited. To guarantee widespread MFH charging deployment, utilities can offer rebates that cover all or most of the cost of installing chargers, while state and federal governments can provide grants to charger manufacturers to install MFH charging stations at no cost. To help reduce future charging installation costs at MFHs, local and state government can implement EV-ready building codes for MFH renovations and new constructions.

Public charging infrastructure will always play an important role in establishing basic geographic coverage and capacity. Even in our most aggressive home charging access scenarios, around 2 million new non-home charger installations will be required over the next decade. DC fast chargers will need to be deployed alongside major highways at rest stops and eating exits throughout the United States to ensure that travelers can make long distance trips without the need to detour significantly from their routes and for charging stops not to feel like an inconvenience. Similarly, Public Level 2 chargers will be important to have at common destinations, so people can top off their batteries when leaving their cars parked for long periods, thereby easing range anxiety. Workplace chargers will be the largest part of the public charging equation and crucial for low-cost and convenient charging.

To support the EV market as adoption grows in the general population, charging infrastructure must be increasingly deployed in an equitable and cost-effective way. Home charging, which has been a staple of the early market, promises to offer low-cost and convenient charging access to many adopters. Our analysis shows that there is significant potential to provide a greater amount of the U.S. population with access to charging at home, and that doing so would be particularly cost-effective. Home charging offers more savings on fuel than public charging, which would benefit all EV adopters, but especially low and middle-income consumers. Policymakers would ideally consider supporting expansion of home charging access within their communities to encourage EV adoption and maximize limited public funds simultaneously.