Memorandum

To: San Francisco Technical Working Group (SF Environment, SFMTA, SFPUC)
From: Logan Pierce, Peter Slowik, International Council on Clean Transportation
Date: October 18, 2023
Re: Cost-benefit analysis by EV charging typology (final memo)

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INTRODUCTION

San Francisco is on the leading edge of the transition to electric vehicles (EVs). The city's Climate Action Plan has outlined ambitious goals to reach 100% new EV sales by 2030, five years ahead of when the state of California has committed to reaching the same goal per the Advanced Clean Cars II (ACCII) regulation.[1] By 2040, San Francisco's goal is to have all trips originating in, ending in, or passing through the city be emission-free. In 2022, zero-emission vehicles (ZEVs), which include EVs (battery electric vehicles (BEVs) and plug-in electric vehicles (PHEVs)) and fuel cell electric vehicles (FCEVs), accounted for over 28% of new cars registered in San Francisco, despite supply chain disruptions, suggesting that the city is building momentum towards meeting its goals.[2] To support continued growth in EV sales, the city will need to build out a charging infrastructure network to meet increasing charging demand.

ICCT's 2020 San Francisco charging gap analysis report found that achieving the city's 100% EV sales goal in 2030 means that more than 170,000 EVs could be on city roads in 2030, and that a local network of over 5,000 publicly accessible (i.e., public Level 2, DC fast, and workplace chargers) and 80,000 home chargers will be needed to support the EV transition.[3] Policy interventions such as mode-shift from personal vehicles to more sustainable modes (i.e., transit and pedestrian), congestion pricing, and the deployment of residential curbside chargers[4] were shown to reduce public charging needs significantly.

Constructing a citywide network of several thousand public chargers and tens of thousands of home chargers necessitates substantial financial investment. Through 2022, charging

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[1] City & County of San Francisco, "San Francisco's Climate Action Plan 2021" (2021), https://sfenvironment.org/sites/default/files/events/cap_fulldocument_wappendix_web_220124.pdf and "California moves to accelerate to 100% new zero-emission vehicles sales by 2035", California Air Resources Board, updated August 25, 2022, https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035.

[2] California Energy Commission ZEV and Infrastructure Stats Dashboard (California ZEV sales shares accessed February 2023), https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data?sort=desc&order=Name.

[3] Chih-Wei Hsu, Peter Slowik, Nic Lutsey, *City charging infrastructure needs to reach 100% electric vehicle sales: The case of San Francisco*, (ICCT, Washington, DC: 2020), https://theicct.org/publication/city-charging-infrastructure-needs-to-reach-100-electric-vehicles-the-case-of-san-francisco/.

[4] In this briefing, residential curbside chargers refer to Level 2 charging stations deployed on curbsides in and around residential neighborhoods. The curbside is considered a public good and is not owned by any resident, so chargers would be deployed and maintained by city agencies for use by residents who lack at-home charging access.

infrastructure deployment has been financially supported by a mix of public, private, and utility sector investments. Increased investments and utilization of policy actions are needed to accelerate infrastructure expansion that is aligned with San Francisco's bold EV goals. It is unlikely that private and utility sector investments alone will be sufficient for charging infrastructure growth to keep pace with rapidly accelerating EV sales and stock. Therefore, identifying the most cost-effective way to increase EV charging infrastructure given the limited public sector resources is critically important. At the same time, better understanding of the environmental and social benefits associated with transitioning to 100% EVs in San Francisco, the implications of different charging options on consumer energy costs and charging convenience, and new financing models and revenue streams from owning and operating charging stations can help illustrate the benefits of various infrastructure investment and deployment strategies. These policy and market developments lead to questions of where to prioritize investing public resources in charging infrastructure that will be increasingly utilized, convenient to access, and minimize electricity costs for consumer EV charging in San Francisco.

This memo establishes a methodology to conduct a citywide EV charging cost-benefit analysis that will help identify the costs and benefits of EV charging by typology and the most effective return on investment for each type of charger through 2030. It first summarizes the most recent data and literature regarding the total capital, operation and maintenance, and grid upgrade costs on a per-charger basis for each charger type in this analysis, which include Level 1 and Level 2 single- and multi-family home chargers, residential Level 2 curbside chargers, workplace, public Level 2, and DC fast. Building on the individual per-charger cost analysis, the work examines the total citywide charging infrastructure costs for transitioning to all-electric vehicles in San Francisco. The total citywide costs are assessed first for a "central case" that is based on the findings from the 2020 charging gap analysis, followed by an "intervention case" in which residential curbside chargers are deployed and the number of public Level 2 and DC fast chargers needed are reduced. A discussion of policy opportunities to minimize city outlays follows the quantitative cost-benefit findings.

Data sources and methodology

This section summarizes the cost modeling approach, assumptions, and data sources used for this cost-benefit analysis. Metrics considered in the analysis include all charging infrastructure monetary costs (i.e., capital, operation and maintenance, and grid upgrade costs) borne by various stakeholders and both non-monetary and monetary benefits such as greenhouse gas (GHG) emissions reductions and consumer's charging costs savings. We first discuss the assumptions and resources used to develop cost estimates on an individual, per-charger basis. Then, we discuss how per-charger costs are applied to assess charging infrastructure costs on a citywide basis for the City of San Francisco, both in a central case and in an intervention case. Following the discussion of our cost modeling approach we briefly discuss the benefits considered and the assumptions for how they are applied.

Per-charger costs

Table 1 summarizes the per-charger cost parameters and model inputs considered in this analysis and their values for chargers deployed in 2023. The costs parameters are broadly categorized into three different categories: capital costs, operation and maintenance costs, and grid upgrade costs, and are represented in 2022 dollars. A fourth category for other costs is included to illustrate some site-specific costs in San Francisco, however these costs are not considered in the cost-benefit analysis. The costs are shown for single- and multi-family home Level 1 (SFH and MFH L1), single- and multi-family home Level 2, residential Level 2 curbside, public level 2, workplace, and DC fast chargers of 50 kW, 150 kW, and 350 kW. Single-time fixed costs and recurring operational costs are converted into cashflows considering the useful lifespan of chargers, which we assume to be 10 years based on a forthcoming 2023 ICCT white paper.[5] The bottom row of the table shows the total capital, operation and maintenance, and grid upgrade costs for each charger type over a 10-year period. As shown, Level 1 chargers tend to be the lowest cost chargers, at around $1,200 to $1,300, followed by Level 2 chargers which tend to range from $4,600 to $20,000. DC fast chargers are the most expensive and range from about $135,000 to $490,000 over a 10-year lifespan.

Table 1. Summary of parameters and input values to cost-benefit analysis for chargers installed in 2023.

Category	Component	SFH L1	SFH L2	MFH L1	MFH L2	Residential curbside	Public L2	Workplace	DC fast (50 kW)	DC fast (150 kW)	DC fast (350 kW)	Notes and references
Capital	Hardware & installation	$444	$1,276	$559	$2,774	$8,452	$8,452	$5,471	$80,877	$130,708	$217,421	Numbers from M. Nicholas (2019); hardware costs decrease by 3% annually, see Table A1
Operation & maintenance (Annual costs)	Power (kW)	1.4	6.6	1.4	6.6	6.6	6.6	6.6	50 (42.5)	150 (97.5)	350 (192.5)	Costs scale based on power; average power for DCFC shown in parentheses
	Demand charges ($/yr)	$0					$125	$125	$945	$2,836	$6,618	Based on PG&E EV rate structure and charger power; costs increase by 3.34% annually, see Table A2 and footnote 13
	Network fees ($/yr)	$0			$286	$286	$286	$0	$286	$286	$286	From Avista EVSE pilot program
	Planned maintenance ($/yr)	$0			$0	$0	$0	$0	$458	$458	$458	From Avista EVSE pilot program
	Unplanned maintenance ($/yr)	$6			$80	$114	$114	$40	$572	$572	$572	From Avista EVSE pilot program
	Connection restoration ($/yr)	$0			$57	$57	$57	$57	$57	$57	$57	From Avista EVSE pilot program
	Testing ($/yr)	$0			$0	$114	$114	$57	$229	$229	$229	From Avista EVSE pilot program

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[5] Anh Bui, Logan Pierce, Pierre Louis-Ragon, Arijit Sen, and Stephanie Searle, *Charging up America: The growth of United States electric vehicle charging infrastructure jobs in a just transition,* (ICCT: Washington, DC, 2023), forthcoming.

	Site maintenance ($/yr)	$0			$0	$114	$114	$114	$172	$172	$172	From Avista EVSE pilot program
	Land acquisition ($/yr)	$0										No cost; assume city owns land
Grid upgrades	Primary	$675	$3,184	$675	$3,184	$3,184	$3,184	$3,184	$24,125	$72,375	$168,875	Based on E3 (2021); primary upgrades cost $483/kW, secondary upgrades cost $18/kW
	Secondary	$25	$120	$25	$120	$120	$120	$120	$907	$2,722	$6,352	
Other costs (Not part of the analysis)	Primary service switchgear upgrade (per site)	$500,000										WDT customers only; city in litigation against PG&E to contest these costs
	Fire code upgrade (per site)											Reliable cost estimates currently unavailable
10-year TCO	**($2022)**	**$1,203**	**$4,638**	**$1,317**	**$10,314**	**$18,625**	**$20,126**	**$12,395**	**$135,030**	**$257,679**	**$490,027**	

Capital costs include the hardware costs for the charger itself and the costs to install a charger, which consist of labor, permitting, and material costs, and taxes. We adopt values from a 2019 ICCT study on charging infrastructure costs in the United States.[6] Following the assumptions from that study, hardware costs are assumed to decrease by 3% annually.[7] Capital costs for residential curbside and public level 2 chargers are the same and reflect a charger mounted on a pedestal, which we assume is the most common format. A curbside charging pilot program by Burbank Water and Power found that equipment costs for level 2 chargers at the curbside versus other public locations do not vary much, but noted that more research is required as to whether the installation costs to bring power to curbside sites differs from other public sites.[8] Some cities have deployed residential curbside chargers in an alternative format as pole-mounted chargers on streetlights and utility poles. This format can save on installation costs, as much as 55% when compared to chargers on pedestals, through avoided labor and construction costs[9] Savings are reduced but can remain in cases where streetlights or utility poles require utility upgrades to have the necessary capacity. Due to regulatory limitations that would require new metering, rewiring, and costly electrical upgrades of streetlights to support pole-mounted chargers, they are not a viable option for curbside chargers in San Francisco and are not considered in this [10] If pole-mounted chargers were feasible, the costs of residential curbside chargers could be reduced significantly.

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[6] Mike Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*, (ICCT: Washington, DC, 2019), https://theicct.org/publication/estimating-electric-vehicle-charging-infrastructure-costs-across-major-u-s-metropolitan-areas/.

[7] For capital costs for chargers installed in future years refer to Table A1 in the appendix.

[8] Kapil Kulkami, JR DeShazo Ph.D., Alex Turek. (2022). *Burbank Charge 'N' Go Project*. Retrieved from the California Energy Commission https://www.energy.ca.gov/sites/default/files/2022-01/CEC-600-2022-019.pdf.

[9] Emmett Werthmann and Vishant Kothari, *Pole-mounted electric vehicle charging : preliminary guidance for a low-cost and more accessible public charging solution for U.S. cities*, (World Resources Institute: Washington, DC, 2021), https://wrirosscities.org/sites/default/files/pole-mounted-electric-vehicle-charging-preliminary-guidance.pdf.

[10] Conversation with contacts at the San Francisco Public Utilities Commission.

Trenching costs, along with any other installation costs, are accounted for within the capital costs category. The installation costs for curbside chargers were based on the average costs of public charger installations across the US at sites with varying levels and associated costs for trenching, boring, signage, repaving, permitting, etc. While these costs categories contribute to the installation costs reported, they are not individually examined within this analysis. Trenching costs at a site ultimately depend on how far the charger is from the electrical service and what material you must go through to reach it. Site selection and site design for where wiring will go can mean the difference between a reasonably priced project and a cost-prohibitive project. To minimize trenching costs, it is important to choose the location of chargers within the site carefully and to be aware of the distance between the chargers and the nearest utility interconnection point.[11]

Operation and maintenance costs refer to the recurring costs to ensure the function and upkeep of the chargers. These costs are incurred annually for the assumed 10-year lifespan of the chargers. The operation and maintenance costs shown in Table 1 represent expenses for a single year and must be multiplied by 10 to calculate the exact contribution to the 10-year total cost of ownership. We adopt values for the operation and maintenance costs from a 2019 electric vehicle supply equipment (EVSE) (i.e., charger) pilot program done by Avista Utilities.[12] Network fees refer to the costs of having the internet connection, energy monitoring, and billing services that come with a networked charger (which can be either Level 2 or DCFC). All public chargers except for workplace chargers are assumed to have network fees. Network fees are not applied for workplace chargers because we assume that employers will provide charging as a no-cost benefit to employees. Multi-family home Level 2 chargers are assumed to be networked, increasing their costs, whereas single-family home Level 2 chargers are not. Multi-family home chargers are often networked to accurately bill EV drivers for electricity usage because chargers are typically wired to the house meter instead of a tenant's unit meter. If chargers are wired directly to tenant's units, non-networked chargers can be used which reduces costs and allows tenants to take advantage of time-of-use (TOU) rates. The EV Charging for All Coalition has identified chargers being directly wired to tenant's units as a core tenet of equity-focused building codes for multi-family homes.[13]

Other operation costs include both planned and unplanned maintenance (e.g., cleaning and repairs), site maintenance (e.g., clearing trash, leaves, or other debris), connection restoration such as when a circuit breaker is switched, and testing to ensure the charging station is fully functional. Another common operational expense are land acquisition costs such as leasing or renting land for a charging station. We assume for this analysis that the city owns the land where they would install chargers and would not incur these costs. Additionally, this analysis does not consider potential lost revenue from parking meters or garage fees if they are not passed along to drivers or are not recouped through rental fees, nor does the analysis evaluate these costs if they are passed along.

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[11] Chris Nelder and Emily Rogers, Reducing EV Charging Infrastructure Costs, Rocky Mountain Institute, 2019, https://rmi.org/ev-charging-costs.

[12] Rendall Farley, P.E., Mike Vervair, Jon Czerniak, "Electric Vehicle Supply Equipment Pilot Final Report" (Avista Utilities, October 18, 2019), https://www.myavista.com/-/media/myavista/content-documents/energy-savings/electricvehiclesupplyequipmentpilotfinalreport.pdf

[13] "EV Charging Access for All", slide deck overview of the EV Charging for All Coalition's work to-date, EV Charging for All Coalition, accessed April 21, 2023, https://docs.google.com/presentation/d/e/2PACX-1vTk3F738fzVXYx8M7n7ZiR0gI7O0wrw2ZnPF3K_ZOCGx3L2LQhvy9wHalZgPW3kpYc87v9ByUVYs5Ql/pub?start=false&loop=false&delayms=3000&slide=id.ge4ca826347_0_62.

Costs associated with the electricity use of EV chargers are typically the largest operational costs. We assume that these costs are entirely passed onto consumers and therefore do not include them in the 10-year lifespan total cost accounting for chargers analyzed. We do, however, include demand charges which vary with the peak power draw of each charger in any given month. Demand charges shown reflect the highest costs as we assume there is at least one charging session per month at the nominal (max) power rating of each charger. Demand charges are also assumed to increase by 3.34% annually, in line with historical trends for electrical price increases in California.[14] Home and residential curbside chargers are assumed to be on residential EV rate structures which do not include demand charges. Pricing structures for curbside chargers vary across the United States. In Burbank, CA EV drivers are charged \$0.1753/kWh (\$0.3069/kWh during peak hours from 4-7pm), in New York City EV drivers are charged \$2.50/hour during the day (6am-9pm) and \$1.00/hour overnight, and in Portland users are charged a \$3.00 flat fee per session and an additional \$0.19/kWh during peak hours.[15] Prices are determined in part by the cost of electricity in a region which varies widely and there is often uncertainty as to what electricity rate structures would be applicable to non-home chargers as many utilities do not yet have dedicated non-residential/retail EV charging rate structures. Having a residential curbside charging pricing structure that is similar to pricing for home chargers would align with San Francisco's goals for equitable access to zero-emission vehicles.

Grid upgrade costs refer to electrical distribution upgrade costs to supply additional load. These include all the costs associated with "utility-side make-ready infrastructure" as opposed to "customer-side make-ready infrastructure;" Figure 1 illustrates the kinds of electrical infrastructure that are grouped into these two categories. Utility-side make-ready infrastructure costs are broken down further into primary and secondary costs which relate to the costs for every additional kW of coincident peak load and costs for every kW of new connected load, respectively. Customer-side make-ready infrastructure costs are accounted for in the capital costs in this analysis. The upfront costs to perform grid upgrades are normally borne by the utilities themselves and recovered through new tariffs (i.e., rate setting) for utility customers based on calculated primary and secondary grid upgrade costs.

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[14] "How much electricity prices increase per year in the U.S.", updated March, 23, 2023, https://www.solarreviews.com/blog/average-electricity-cost-increase-per-year; see Table A2 for demand charges in future years. To calculate the 10-year TCO contribution of demand charges sum the values for the 10 years following a charger's installation (e.g. for a charger installed in 2023 the 10-year TCO includes demand charges from 2024-2033)

[15] Information of EV public charging stations in Burbank, CA, Burbank Water and Power, accessed April 24, 2023, https://www.burbankwaterandpower.com/electric-vehicles/public-charging, "Curbside Level 2 Charging Project FAQ", New York City Government, accessed April 24, 2023, https://www.nyc.gov/html/dot/downloads/pdf/curbside-level-2-charging-pilot-faq.pdf, and "Schedule 50 Retail Electric Vehicle (EV) Charging", Portland General Electric Company, accessed April 24, 2023, https://assets.ctfassets.net/416ywc1laqmd/2hNjMQ203TEcCmZttyKCTt/17ad2b74fce656f4ccd4b516c18e3862/Sched_050.pdf.

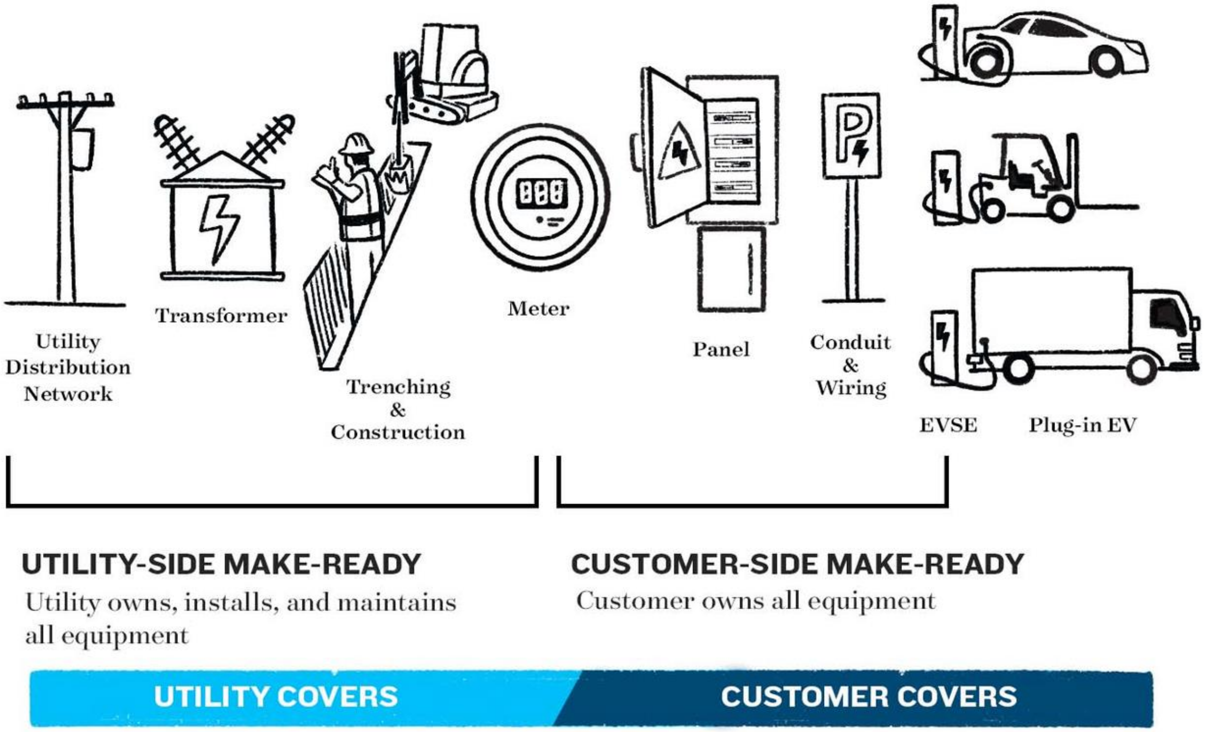

Figure 1. Electrical infrastructure for EVs and their classification as utility-side or customer-side make-ready infrastructure.[16]

In 2021, the California legislature passed Assembly Bill 841 establishing Rule 29 which requires utilities to set new tariffs to pay for grid upgrades costs related to anticipated demand from EVs, rather than waiting to assess projects on a case-by-case basis, thereby streamlining the process of building the necessary infrastructure to support transportation electrification.[17] Rule 29 however, does not apply to wholesale distribution tariff (WDT) customers, that is customers whose energy comes from a third-party provider who purchases access to grid transmission lines rather than the energy produced by the grid operator, as is the case with the San Francisco Public Utilities Commission (SFPUC) which pays PG&E for access to the San Francisco grid. Absent Rule 29, this means that SFPUC customers served under the WDT may be required by PG&E to pay for all infrastructure costs needed to bring electricity to a charging site on a per-project basis. We adopt values for primary and secondary grid upgrade costs from PG&E's 2017 rate case that was shared in a 2021 report by E3.[18] Because we do not know whether a charger will be installed at a site without available capacity or will be utilized during peak hours, we conservatively assume the nominal power rating of chargers contributes directly to both coincident peak loads and connected loads, incurring the highest potential grid upgrade costs. In practice, depending on the load available at a site and charger utilization, these costs may be reduced or zero.

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[16] Jessica Russo, National Resources Defense Council, retrieved from https://www.nrdc.org/experts/miles-muller/ca-approves-new-rules-support-ev-charging-infrastructure

[17] Miles Muller and Max Baumhefner, "CA Approves New Rules to Support EV Charging Infrastructure," *National Resources Defense Council*, October 8, 2021, https://www.nrdc.org/experts/miles-muller/ca-approves-new-rules-support-ev-charging-infrastructure.

[18] Eric Cutter, Emily Rogers, Amparo Nieto, John Leana, Jessica Kersey, Nikit Abhyankar, and Taylor McNair. "Distribution Grid Cost Impacts Driven by Transportation Electrification" (E3, 2021), https://www.ethree.com/wp-content/uploads/2021/06/GridLab_2035-Transportation-Dist-Cost.pdf.

The cost results presented in this analysis are conservative (i.e., representing higher cost alternatives) and average (i.e., do not consider specific site dynamics that would affect costs). More research into site-specific costs parameters such as available grid capacity or site characteristics that allow for less expensive deployment formats for chargers (e.g., wall-mounted chargers, pole-mounted chargers, or outlets) is outside of the scope of this analysis.

San Francisco has some unique site-specific costs that should be considered when assessing charging projects for the city. In particular, the city has been in dispute with PG&E over the provision of electricity distribution service via the WDT. PG&E has required municipal sites requesting additional load to upgrade to primary service even when not technically necessary. The cost to fulfill these requirements and install primary switchgear is estimated at around $500,000, making not only EV charging projects, but all projects that require additional load prohibitively expensive, without dedicated strategic planning.[19] In December 2022, the Federal Energy Regulation Commission (FERC) issued settlement proceedings for the dispute indicating that PG&E would have to clearly lay out its requirements for WDT customers upgrading to primary service and potentially aligning with their requirements for retail customers.[20] FERC held settlement hearings in March 2023 on a revised WDT (WDT3) which would include the issue of and availability of secondary service. A settlement to that end could see the removal of these challenges for WDT customers making public charging projects more feasible; an Initial Decision is expected on August 31, 2023, however a Final Decision will not come until early 2024.

Another cost for certain EV charging projects in San Francisco comes as a result of an administrative bulletin passed by the San Francisco Fire Department at the beginning of 2023. This administrative bulletin requires upgrades to the sprinkler system in enclosed garages to prevent against the potential higher fire risk of EVs combusting while charging.[21] There are not yet any reliable estimates for what these upgrades would cost, but they should be a consideration when budgeting for charging projects in enclosed garages.

Citywide charging infrastructure costs

Building on the per-charger costs above, the analysis quantifies the total citywide costs to construct the needed charging infrastructure to meet San Francisco’s goals of transitioning entirely to ZEVs. The per-charger costs above are multiplied by the charging gap findings of the number of new chargers needed by type for each year from 2023 through 2030. The citywide infrastructure cost analysis is conducted for a “central case” that includes home, workplace, public Level 2, and public DC fast chargers, and an “intervention case”, in which residential curbside chargers are deployed and reduce the number of public Level 2 and DC fast chargers needed. The cost findings of the central case and intervention case are compared to determine the effect of deploying curbside chargers on overall infrastructure costs and overall cost-effectiveness.

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[19] Discussions with SFPUC staff.

[20] Robert Mullin. “Settlement Hearing Ordered for PG&E, SF Distribution Dispute.” RTO Insider Volume 2022, Issue 51 (2022): 23.

[21] 4.29 Sprinkler protection requirements for parking spaces associated with Electric Vehicles (EV) charging stations, San Francisco Department Bureau of Fire Prevention & Investigation, 2022, https://sf-fire.org/files/2022-11/4.29%20%20Sprinkler%20Protections%20Requirements%20for%20Parking%20Spaces%20Associated%20with%20Electric%20Vehicles%20%28EV%29%20Charging%20Stations%202022.pdf.

The central case for this cost-benefit analysis modifies a few assumptions from the 2020 San Francisco charging gap analysis.[22] The 2020 charging gap analysis considered five charger types: home Level 1, home Level 2, public Level 2, workplace, and DCFC. Because home charger costs differ between single- and multi-family homes, we estimate the share of Level 1 and 2 MFH chargers to apply the costs from Table 1 based on the share and number of vehicles with access to home charging that are in apartments in San Francisco divided by the number of vehicles per vehicle-owning household. Around 13% of home Level 1 chargers are in MFHs and 6% of home Level 2 chargers are in MFHs in 2023; these shares grow to 19% and 9%, respectively, by 2030. Similarly, to apply DCFC costs we make assumptions for the shares of 50 kW, 150 kW, and 350 kW that align with the average power output of DCFC modeled in the charging gap analysis. In 2023, 54% of new DC fast chargers are 50 kW, 43% are 150 kW and 3% are 350 kW; by 2030, 5% of new DC fast chargers are 50 kW, 72% are 150 kW, and 23% are 350 kW.

The 2020 charging gap analysis considered idealized public charger usage of 8 hours per day yet notes that there is little evidence that chargers in 2020 met such high average utilization. Recent data from charge point operators (CPOs) suggests that public charger utilization has increased at a relatively slower rate than what was assumed in the ICCT charging gap analysis. EVGo reported that it's chargers in San Francisco measured around two hours of daily utilization during Q4 2021.[23] Similarly, Electrify America and EVGo, in California and in Colorado, found utilization in the range of 1-3 hours per day currently, and the companies target increasing utilization to about five hours per day.[24] Based on the recent EVGo and Electrify America data and announced utilization targets, we modify the assumptions in the ICCT charging gap analysis by reducing the utilization of public Level 2 and DC fast chargers down from eight hours per day to five hours per day. By decreasing the utilization, the number of public chargers needed is increased.

The intervention case for our analysis maintains the above assumptions from the central case, while also considering the policy intervention of the city installing residential curbside chargers at 10% of parking spaces, about 1,945 spaces, near multi-family homes by 2050. Deployment of residential curbside chargers reduces the number of public Level 2 and DCFC needed. We assume residential curbside chargers serve as proxies for home charging for multiple drivers without off-street parking and therefore are highly utilized, as many EV drivers are likely to leverage the convenience of near-home chargers and plug-in for longer periods of time, including overnight. This analysis assumes that curbside chargers are utilized for around 9.5 hours per day, an increase from around 4.5 hours per day in the charging gap analysis. This assumption is consistent with recent data about the average charger utilization of street chargers (curbside chargers) during the overnight hours in Stockholm, Sweden. In fact, the data

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[22] Chih-Wei Hsu, Peter Slowik, Nic Lutsey, *City charging infrastructure needs to reach 100% electric vehicle sales: The case of San Francisco*, (ICCT, Washington, DC: 2020), https://theicct.org/publication/city-charging-infrastructure-needs-to-reach-100-electric-vehicles-the-case-of-san-francisco/

[23] EVGo, European investor's meeting presentation, April 2022, https://s27.q4cdn.com/370825096/files/doc_presentations/2022/EVgo-European-Investor-Meetings_April2022.pdf.

[24] "New Report: Electrifying America California Corridor/Urban Q3 2021EV Charging Utilization Averages 4.8% Per Port (Charger)", *EVAdoption*, January 30, 2022, https://evadoption.com/new-report-electrify-america-california-corridor-urban-q3-2021-ev-charging-utilization/#:~:text=January%2030%2C%202022-,New%20Report%3A%20Electrify%20America%20California%20Corridor%2FUrban%20Q3%202021%20EV,4.8%25%20Per%20Port%20(Charger) and EVGo, Investor relations presentation, (no date), https://a.storyblok.com/f/78437/x/0517471944/evgo-investor-relations-presentation-final.pdf.

suggests our assumptions may be conservative as there is an increasing share of street charger charging sessions of 12-16 hours.[25]

Assessment of benefits

Following the analysis of monetary charging infrastructure costs, we quantitatively assess and discuss several potential benefits that are associated with the transition to EVs and deploying the associated charging infrastructure in San Francisco. First, we quantify the greenhouse gas mitigation potential of transitioning to 100% new ZEV sales by 2030 and 100% renewable electricity generation in San Francisco. Second, we discuss the potential for charging infrastructure to unlock new revenue streams and the price of electricity that charging operations would need to charge to achieve a positive return on investment. Third, we discuss the consumer energy savings associated with switching to EVs and assess the potential for increased residential curbside charging infrastructure deployment to reduce consumer energy costs relative to the central case where no curbside chargers are deployed. Fourth, we discuss the equity and access implications of residential curbside charging and the demographics that may especially benefit from its deployment.

Results

This section summarizes the analytical findings of this work. First, the 10-year total cost of ownership results are presented on a per-charger basis for each type of charger introduced above. After the per-charger costs, the total citywide costs are shown for 2023 through 2030. The citywide infrastructure costs are shown for the central case without residential curbside charging and the intervention case where residential curbside chargers are deployed.

Per-charger costs

Figure 2 illustrates the total cost of ownership in 2022 dollars of all capital costs, operation and maintenance costs (i.e., demand charges, network fees, planned and unplanned maintenance, connection restoration, testing, and site maintenance), and primary and secondary grid upgrade costs, over a 10-year lifespan, for single- and multi-family home Level 1 and Level 2 chargers (SFH and MFH), and Level 2 workplace, public, and curbside chargers. Level 1 charger costs range from $1,200 to $1,300 per-charger while Level 2 chargers range in costs from $4,600 to $20,000 per charger. Multi-family home level 2 chargers cost more than twice as much as single-family home Level 2 chargers do because of increased capital costs for the additional trenching and conduit work that multi-family homes often require during installation, and the hardware costs of a networked charger compared to a non-networked charger, as well as additional operation and maintenance costs for a networked charger. Workplace chargers are about $7,000 cheaper than public level 2 and $6,000 cheaper than curbside chargers due to lesser capital costs and the absence of network fees for a non-networked charger. Curbside and public Level 2 chargers have identical costs except for about $1,300 in lifetime demand charges for public Level 2 chargers, which curbside chargers do not incur as they are on residential EV rate plans without demand charges.

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[25] Elin Lindblad, Erik von Essen, and Anton Sjögren, “Evaluation of public charging for electric cars in the city of Stockholm in 2021” (Sweco, October 2022), https://miljobarometern.stockholm.se/content/docs/tema/trafik/miljobilar/2022%20-%20Utv%C3%A4rd%20publik%20ladd%20elbil.pdf; translated using Google translate.

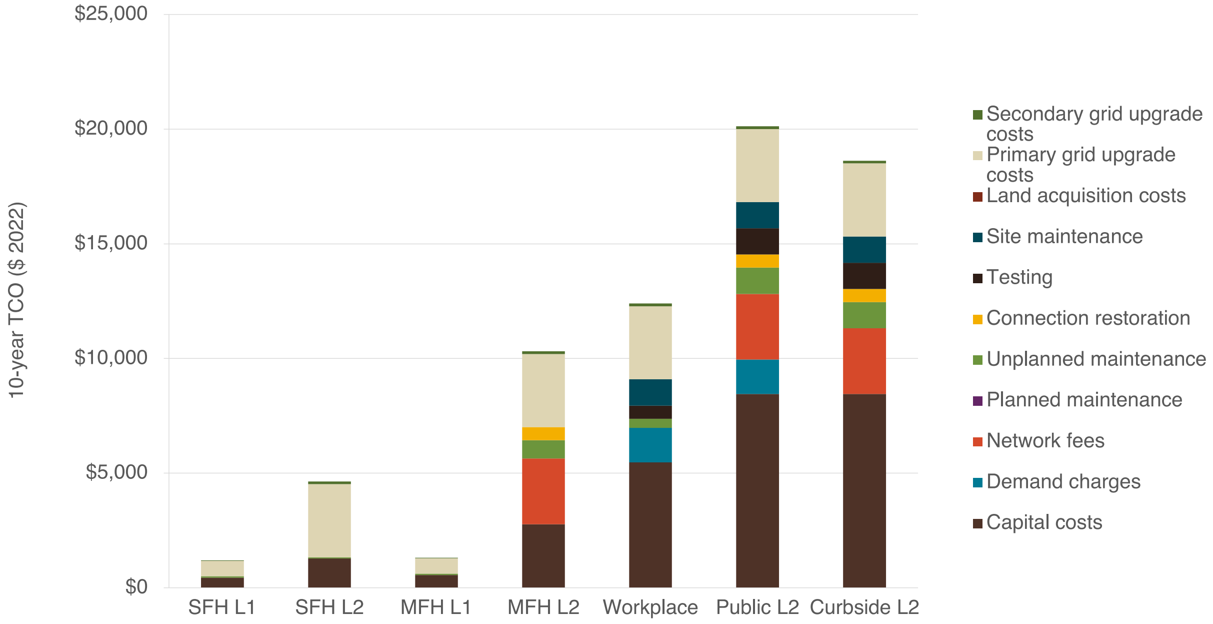

Figure 2. Total cost of ownership for EV chargers, by type, over a 10-year lifespan.

Figure 3 illustrates the total cost of ownership of all capital costs, operation and maintenance costs (i.e., network fees, planned and unplanned maintenance, connection restoration, testing, and site maintenance), and primary and secondary grid upgrade costs, over a 10-year lifespan for DC fast chargers of 50 kW, 150 kW, and 350 kW. As shown, the total cost of ownership for DC fast chargers ranges from about $135,000 (50 kW) to $490,000 (350 kW) per charger. Capital costs and grid upgrade costs scale with power and comprise a similar share of the total costs when comparing a 50 kW charger (79% of total costs), to a 150 kW charger (80% of total costs), to a 350 kW charger (80% of total costs). Excluding demand charges, operation and maintenance costs are identical for all DC fast chargers and are estimated at about $17,750 over a 10-year lifespan. Demand charges scale with power and represent an increasing share of total costs, starting at 8% for 50 kW chargers, 13% for 150 kW charges and 16% for 350 kW chargers.

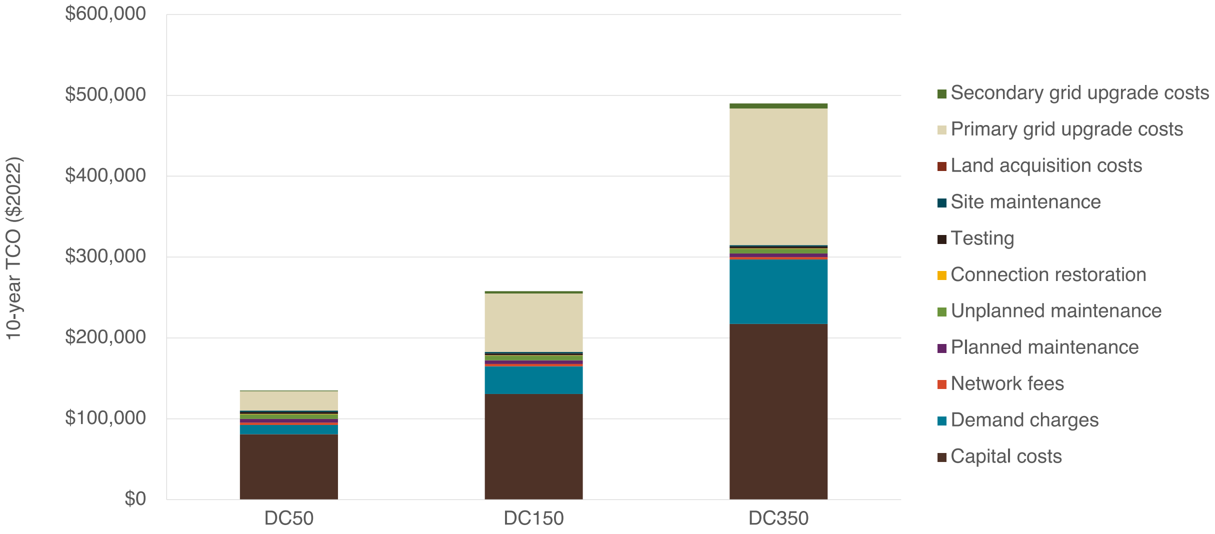

Figure 3. Total cost of ownership for EV chargers, by type, over a 10-year lifespan.

Citywide charging infrastructure costs

The per-charger cost findings from above are combined with projections of the number of chargers needed annually to assess citywide charging infrastructure costs. The projections of the number of annual chargers needed in San Francisco are based on the 2020 ICCT San Francisco charging infrastructure gap analysis with the methodological modifications discussed above. Table 2 summarizes the number of chargers needed by type across San Francisco in 2025 and in 2030 for the central case and the intervention case. As shown, the number of home Level 1, home Level 2, and workplace chargers are identical between the two cases. In the intervention case, where about 300 residential curbside chargers are deployed by 2025 and about 800 residential curbside chargers are deployed by 2030, the number of public Level 2 and DC fast chargers needed by 2030 are reduced by 284 and 70, respectively.

Table 2. Estimated charging infrastructure needed in San Francisco in 2025 and 2030

Year	Central case					Intervention case					
	Public Level 2	DC fast	Workplace	Home Level 1	Home Level 2	Public Level 2	DC fast	Workplace	Home Level 1	Home Level 2	Curbside
2025	712	197	1,462	14,735	17,238	598	163	1,462	14,735	17,238	301
2030	1,848	415	3,959	34,772	45,190	1,564	346	3,959	34,772	45,190	798

The per-charger cost assessment and the estimates of the number of each type of charger needed citywide through 2030 are combined to assess the total charging infrastructure costs citywide. Table 3 depicts the total cost of ownership of all costs (i.e., capital costs, operation and maintenance costs, and grid upgrade costs) by charger type associated with deploying charging infrastructure in San Francisco from 2023 through 2030 in the central case and in the intervention case. We assume the existing stock of chargers as of 2022 is aligned with the 2022 projections in the ICCT San Francisco charging gap analysis and consists of 8,091 home Level 1 chargers, 8,401 Level 2 chargers, 743 workplace chargers in both cases, 476 public Level 2 chargers and 180 DCFC in the central case, and 433 public Level 2 chargers, 163 DCFC, and 155 curbside chargers in the intervention case. If the number of chargers deployed through 2022 are different than these assumed values, then the additional number of chargers needed by 2025 and 2030 would be comparatively adjusted. The costs below correspond to the remaining chargers needed to be installed based on these assumptions of 2022 charger deployment: about 27,000 home Level 1 chargers, 37,000 home Level 2 chargers, and 3,200 workplace chargers in both cases, 1,400 public Level 2 chargers and 240 DCFC in the central case, and 1,100 public Level 2 chargers, 190 DCFC, and 640 curbside chargers in the intervention case.

Table 3. Comparison of the total cost of ownership of San Francisco's charging network from 2023-2030 in the central case and the intervention case.

	Central case (no curbside chargers)	Intervention case (with curbside chargers)	Change from Central case
Home Level 1	$32 million	$32 million	--
Home Level 2	$185 million	$185 million	--
Workplace	$40 million	$40 million	--
Curbside	--	$12 million	**+ $12 million**
Public Level 2	$27 million	$23 million	**- $4 million**
DC fast	$63 million	$50 million	**- $13 million**
Total	$348 million	$342 million	**- $6 million**

Numbers in table are rounded

The left-hand side of Table 3 shows the infrastructure costs by charger type for the central case, which total about $348 million for chargers installed in 2023 through 2030 (this includes operation and maintenance costs through 2040 as chargers installed in 2030 are assumed to remain functional through the end of the next decade). The middle column shows the results for the intervention case, where about 650 residential curbside chargers are deployed by 2030 and the number of public Level 2 and DC fast chargers deployed are reduced by about 300 and 50, respectively. The right-most column shows the change in costs for the intervention case relative to the central case. As shown, there is an additional $12 million in residential curbside costs, along with a $4 million reduction in public Level 2 charger costs and a $13 million reduction in DC fast charger costs. Overall, the charging infrastructure costs for the intervention case are about $6 million less than that of the central case. This finding underscores the opportunity for residential curbside charging deployment to reduce overall infrastructure system costs which is consistent with the findings in a 2023 ICCT analysis of U.S. charging infrastructure costs.[26]

Figure 4 shows the annual charging infrastructure costs by charger type each year from 2023 through 2030, which is different than the 10-year total costs of ownership. The annual costs are shown for both the central case and the intervention case. Operation and maintenance costs after 2030 are excluded. Costs for the same charger type in each scenario are shown in the same color but different shades and are further differentiated in the legend by "I" and "(I)" which stand for central case and intervention case, respectively. Curbside chargers are only applicable in the intervention case and are not differentiated further. Annual costs shown include the summation of capital costs and grid upgrades costs for chargers installed in any given year and all operation and maintenance costs for previously installed chargers from 2023 on; existing chargers currently installed in the city as of 2022 are not analyzed.

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[26] Logan Pierce and Peter Slowik, *Home charging access and the implications for charging infrastructure costs in the United States*, (ICCT: Washington, DC, 2023), https://theicct.org/publication/home-charging-infrastructure-costs-mar23/.

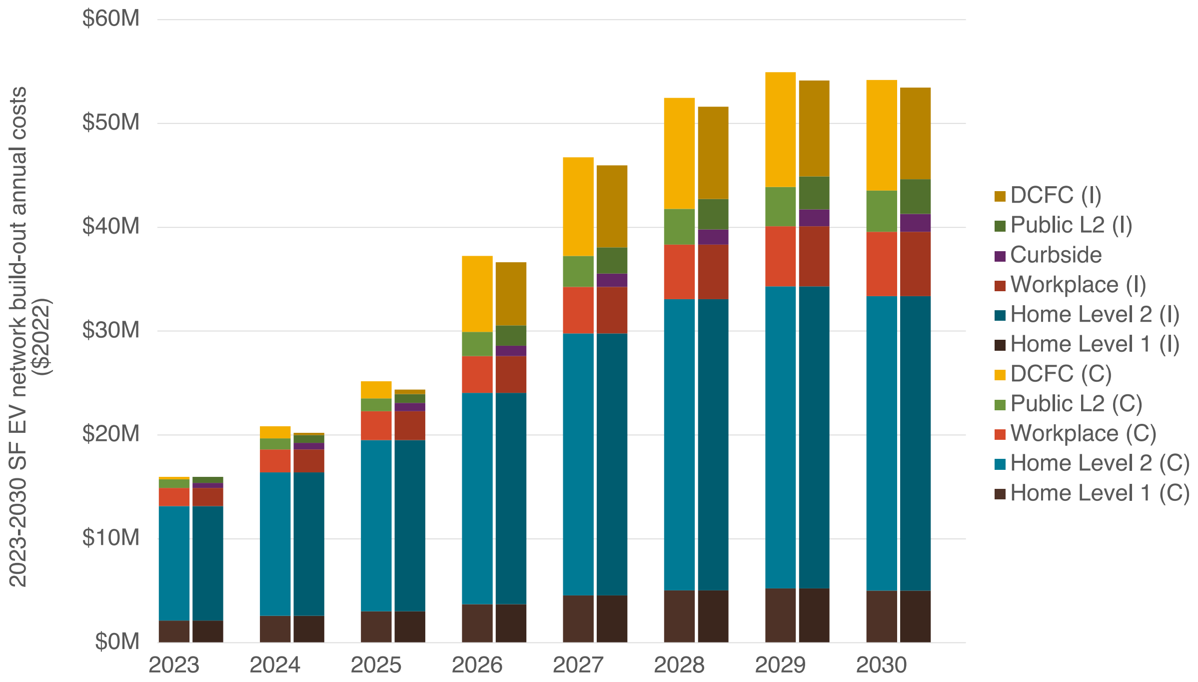

Figure 4. Comparison of annual costs to build-out and maintain San Francisco's charging network from 2023-2030 in the central case and the intervention case.

Annual costs grow from around $16 million in 2023 for both cases to about $54.4 million and $53.6 million in the central case and the intervention case, respectively. From 2024-2030 annual costs in the intervention case are between $600,000 and $840,000 less than in the central case and are on average $740,000 less than in the central case. Home chargers account for the greatest share of costs, and in 2023 represent 83% of costs in both cases. However, over time non-home charger costs grow to become an increasing share, driven mostly by DCFC costs which grow from 1% of costs in 2023 to 19% of costs in 2030 in the central case, and from 0% of costs in 2023 to 16% of costs in 2030 in the intervention case. This growth is driven primarily by the increasing share of higher power DCFCs as the market shifts away from 50 kW chargers towards 150 kW and 350 kW chargers which have two to four times the costs.

The analytical findings are sensitive to assumptions about utilization. The above analysis assumed that public Level 2 and DC fast chargers are used an average of 5 hours per day, while residential curbside chargers are used an average of 9.5 hours per day. Changes in utilization affects the number of chargers needed by type and thus the overall citywide infrastructure costs, and the value proposition for investing in different charging types may change depending on typical usage. The relationships between infrastructure cost and utilization are further explored below.

Figure 5 shows the average 10-year infrastructure cost per kilowatt-hour for different charging typologies with changes in utilization. The 10-year total cost of ownership for each charger type are from the bottom-most row in Table 1 and the kilowatt-hours are based on the average power (kW) of each charger (second row in Table 1) multiplied by the assumed number of hours of daily utilization over a 10-year period. The assumed average power for residential curbside chargers and public Level 2 chargers is 6.6 kW and for DC fast chargers the average power output is assumed to be 42.5 kW for DC50, 97.5 kW for DC150, and 192.5 kW for DC350, reflecting the fact that the average charging speed is substantially lower than the maximum charging speed due to vehicle-side technological limitations and slower charging speeds outside of the typical 20% to 80% battery state-of-charge range. As shown, when utilization is increased the average 10-year levelized cost per kilowatt-hour is dramatically reduced.[27] For example, the blue line shows how curbside chargers that are used 1 hour per day have a levelized cost of about $0.77 / kWh over a 10-year lifespan, compared to about $0.09 / kWh for curbside chargers that are used 9 hours per day.

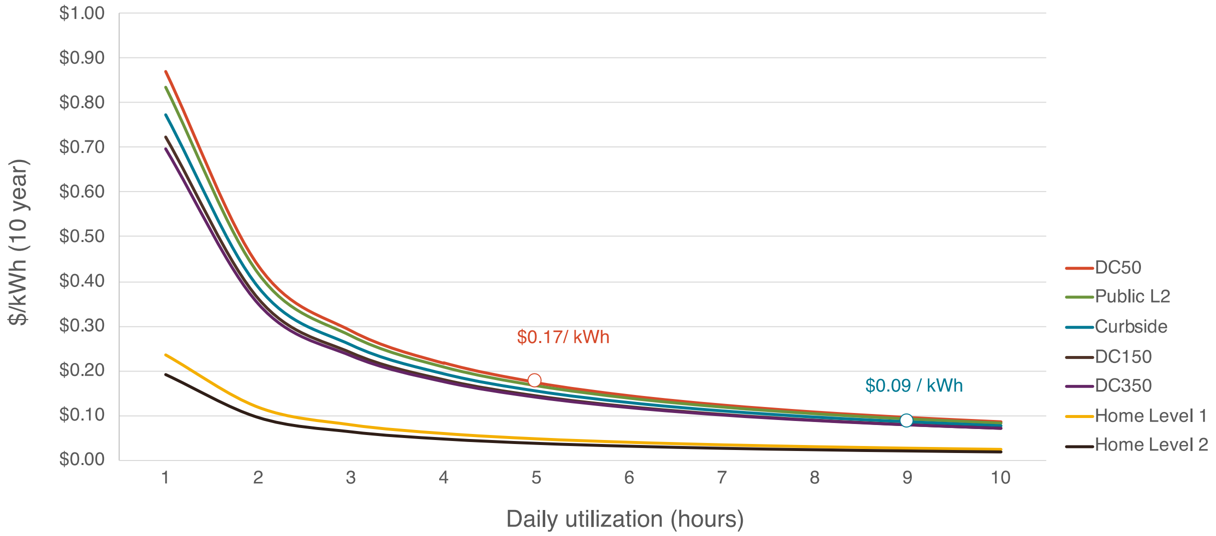

Figure 5. Levelized 10-year infrastructure cost per kilowatt-hour by utilization for different charging typologies

The figure also shows how, for a given utilization, home chargers have the lowest levelized cost per kilowatt-hour of the typologies shown. This means that home chargers provide energy at the lowest costs when utilization is the same. The charger type with the highest levelized cost per kilowatt-hour are 50 kW DC fast. Higher-powered 350 kW fast chargers have lower levelized costs per kWh compared to lower-powered fast 50 kW chargers for a given utilization. This means that 350 kW DC fast chargers can provide energy for lower cost than 50 kW DC fast chargers for the same utilization, despite their higher capital and grid upgrade costs. For curbside chargers, Figure 5 shows how for a given utilization, the levelized infrastructure cost per kWh are less than those of 50 kW DC fast chargers but greater than those of 350 kW DC fast chargers (e.g., at five hours of utilization, DC50 have levelized costs of $0.17/kWh compared to $0.15/kWh for curbside chargers and $0.14/kWh for DC350).

However, utilization varies significantly across the different chargers. Because of their location, lower energy cost, and convenience, it is likely that residential curbside chargers have higher average daily utilization than many DC fast chargers. Based on the utilization assumptions in our analysis of 9.5 hours/day for residential curbside and 5 hours/day for DC fast chargers, the levelized 10-year infrastructure cost is about $0.08/kWh for residential curbside and about $0.17/kWh for 50 kW DC fast chargers, an increase by a factor of greater than two. For 150 kW and 350 kW DC fast chargers, the levelized cost per-kilowatt-hour with 5 hours/day of utilization is $0.14/kWh, which is about 75% greater than residential curbside. This underscores the opportunity for high-usage residential curbside chargers to supply electricity more cost-effectively than typical DC fast chargers. However, if residential curbside chargers have much

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[27] Table A3 lists values for the levelized cost per kilowatt-hour by utilization for several typologies shown in Figure 5. Changes in utilization do not impact the per-charger 10-year cost of ownership values from Table 1

lower utilization and DC fast chargers have much higher utilization than these values, the value proposition for residential curbside chargers relative to DC fast chargers is reduced.

Case-study: comparing charging costs at private vs. public parking lots

The citywide charging infrastructure cost results quantify all the costs to build-out and operate San Francisco's charging network. These costs will be borne by various stakeholders including, but not limited to, homeowners, utilities, CPOs, and the city government. As the city determines where to invest public resources to build its own chargers, there is a need for more clarity as to what site-specific costs the city may face. A point of uncertainty is the additional costs PG&E has levied to provide distribution service to WDT customers, which have already presented obstacles to EV charger deployment in city garages. As discussed earlier, Rule 29 in California dictates that grid upgrade costs to support EV chargers are covered by the utility and recovered through rate increases on all customers of the utility, rather than being assessed as part of a project's costs. However, this is not the case when the electricity service provider is a WDT customer rather than the utility/grid owner itself; in these instances, the utility will require grid upgrade costs be paid upfront as part of the project's cost. SFPUC is a WDT customer of PG&E at many municipal sites, and so charging projects on these sites will bear grid upgrade costs in addition to costs to procure, install, and operate chargers. Similarly, PG&E has imposed requirements for WDT customers to upgrade to expensive, high-voltage primary service at sites requesting additional load based on a separate criterion than it has for its retail customers. These costs are not specific to EV charging, but nevertheless should be considered at municipal sites. The city has disputed these costs as unnecessary to FERC, which ruled in the city's favor in December 2022 for settlement proceedings and held hearings in March 2023. The result of these proceedings is yet to be seen and may well remove these expensive requirements. A Final Decision is expected in early 2024, but until then the situation is unresolved and it should be assumed that primary service will continue to be required at municipal sites for the time being. To illustrate how similar charging projects can have different costs to the city depending on the project site, we compare a project at a privately-owned parking lot serviced by PG&E to projects at publicly owned parking lots serviced by SFPUC – one with an upgrade to primary service and the other without.

Figure 6 illustrates the total costs of ownership for three identical charging projects in 2023 at a private parking lot, at a public parking lot, and at a public parking lot where primary service has been required by PG&E. Each lot has 10 public Level 2 chargers. We assume there is no excess electrical capacity at any site and that the distribution network must be upgraded to support an additional 66 kW for simultaneous charging at full power for each charger (66 kW = 10 chargers * 6.6 kW). The costs in Table 1 are applied for each charger, however per-charger capital costs are reduced by about 20% due to economies of scale for a site with more than six chargers.[28] Land acquisition costs to rent space for chargers are estimated for the private lot but excluded for the public lots on city-owned land. Electricity costs have been estimated using rates schedules from PG&E for the private lot and from SFPUC for the public lots.[29] Utilization is the same at all sites and increases gradually over time reaching five hours per day per charger.

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[28] Mike Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*, (ICCT: Washington, DC, 2019), https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_Charging_Cost_20190813.pdf; Demand charges also increase by 3.34% annually as mentioned previously.

[29] San Francisco Public Utilities Commission, "Rates Schedules & Fees for Hetch Hetchy Power and CleanPower SF," (July 2022), https://sfpuc.org/sites/default/files/accounts-and-services/2022_23_Rates_Schedule_HHP_CleanPowerSF.pdf and "Electric Rates," current and historical electric rates, Pacific Gas & Electric, accessed November 1, 2023, https://www.pge.com/tariffs/electric.shtml#COMMBEV.

Costs to install primary service switchgear to upgrade to primary service is included for one of the public lots.

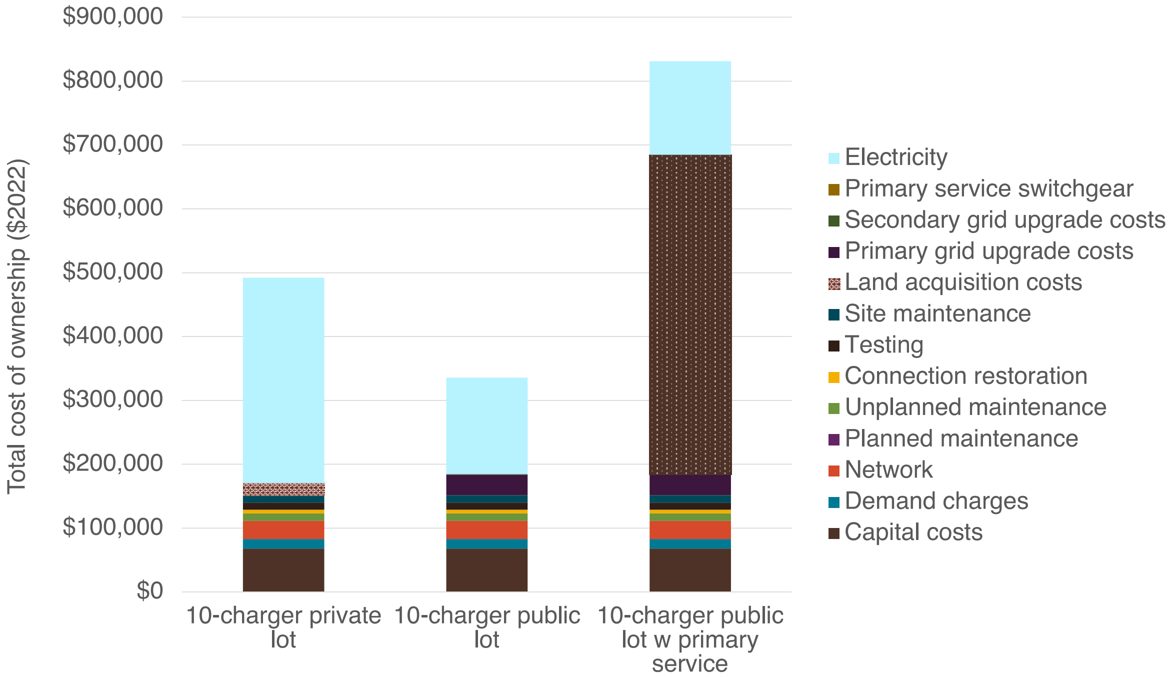

Figure 6. Comparison of charging project costs at privately-owned and publicly-owned parking lots.

The costs for most cost components in every context are the same, except for land acquisition costs, grid upgrade costs, electricity costs, and costs for primary service switchgear. Land acquisition and grid upgrade costs are marginal compared to electricity costs or the costs to upgrade to primary service. Land acquisition costs for the private lot are estimated to be about $19,000 based on an annual rent of $191 per charger which we calculate from the cumulative 20 square feet for the chargers' footprint at a cost of $3.8 million per acre.[30] DCFC are known to have associated land acquisition costs, but there is limited information on similar costs for lower power chargers or when they might apply; we shade these costs differently to indicate this uncertainty. In the public lots serviced by SFPUC, grid upgrades amount to around $33,000, assuming no excess electrical capacity, but these costs could be reduced if there is available electrical capacity for EV charging. In the private lot serviced by PG&E grid upgrade costs are excluded because Rule 29 in California dictates that grid upgrade costs to support EV chargers are covered by the utility. However, grid upgrade costs will eventually be recovered by PG&E through electricity rate increases over time for all its customers.

We base the electricity rate for the private lot on PG&E's EV rate schedules, and the electricity rates at the public lots on SFPUC's corresponding EV rate schedules. Because we cannot predict when EVs will be charged, we use a time-weighted average of the TOU rates. The electricity rate at the private lot is estimated at $0.22/kWh in 2023, more than twice that of the estimated $0.11/kWh and $0.10/kWh at the public lot and the public lot with primary service respectively; these rates increase by 3.34% annually. For the almost 1.2 million kWh of energy

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[30] Richard Florida, "The Staggering Value of Urban Land," *Bloomberg*, November 2, 2017, https://www.bloomberg.com/news/articles/2017-11-02/america-s-urban-land-is-worth-a-staggering-amount

supplied over 10 years at each site, electricity costs at the private lot amount to around $320,000 while these costs are only around $150,000 at the public lots. The higher total project costs at the private lot versus the public lot are almost entirely driven by this difference in electricity costs.

The public lot requiring primary service switchgear has the largest costs by far. In fact, the $500,000 in costs to upgrade to primary service alone exceed the entire project costs at either the private lot or the public lot that doesn't require these upgrades. Given the specific load requirements of the projects of 66 kW, primary service shouldn't be technically required (PG&E has a threshold of 3,000 kW before requiring primary service for its retail customers). Pending the resolution of the settlement proceedings ordered by FERC, it's unclear how these costs will apply going forward and we shade them differently to indicate this uncertainty. If it's determined primary service should only be required when technically necessary, WDT customers will find costs more comparable to retail customers, but still will need to factor in grid upgrades not covered by PG&E. Under that new regulatory context, comparing the total cost of ownership of the private lot and the public lot without primary service, the figure shows how greater electricity costs at the private lot outweigh PG&E's grid upgrade costs for WDT customers at the public lot. The total costs for the public lot are about $156,000 less than that of the private lot due to less expensive electricity, and the levelized cost of energy is $0.28/kWh at the public lot compared to $0.41/kWh at the private lot, making it easier to recover the investment. This highlights the importance of considering electricity rates when assessing the value proposition of a particular site. Cross-agency collaboration between SFPUC, SFMTA, SFE, and other relevant departments will be important to identify sites where chargers can be most cost-effectively deployed.

Benefits

Greenhouse gas mitigation. The greenhouse gas reduction potential from transitioning to 100% ZEVs in San Francisco is significant. Figure 7 shows the estimated annual greenhouse gas emissions in San Francisco from light-duty vehicle transportation activity in 2020 through 2050. The approximately 450,000 light-duty vehicles on San Francisco roads emit about 2.5 million tons of CO2/year in 2020. As electric vehicle sales increase and more older polluting vehicles leave the fleet, GHG emissions are greatly reduced. The green line represents San Francisco's 100% EV by 2030 transition along with 100% renewable energy generation by 2030. Annual GHG emissions are reduced to about 1 million tons of CO2/year in 2030 and less than 0.15 million tons of CO2/year by 2050. This represents a reduction of about 95% from 2020. The grey line represents the EPA 2021 revised GHG standard where about 17% of new light-duty vehicle sales are electric in 2026.

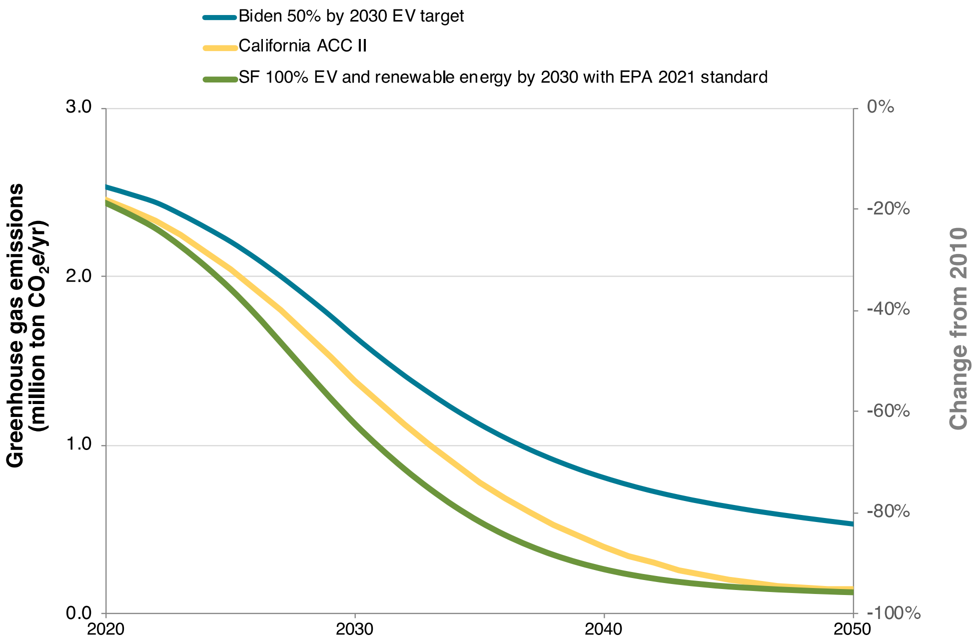

Figure 7. Greenhouse gas reduction potential from transitioning to 100% EV sales by 2030 in San Francisco

Revenue. Electric vehicle charging infrastructure has the potential to enable new business models and revenue sources. Based on the infrastructure cost analysis above and our assumptions regarding charger utilization, we calculate the price of electricity that corresponds with a return on investment for residential curbside chargers.

The estimated 10-year capital and operational cost of a new 2023 residential Level 2 curbside charger is about $18,625 (see Table 1). Based on 9.5 hours of daily utilization, the estimated annual energy supplied is about 22,885 kWh (6.6 kW * 9.5 hours/day * 365). Dividing the 10-year costs by the energy supplied over 10 years equals the levelized cost of electricity, which is about $0.081 per kilowatt-hour. This means that infrastructure owners and operators would need to charge customers a premium of at least 8.1 cents per kilowatt-hour on top of the wholesale electricity rate to achieve a positive return on investment over a 10-year timeframe. For example: if residential curbside chargers are on an EV overnight electric rate plan at $0.24 per kWh, charging providers would need to charge at least $0.32/kWh to recoup their investment. If charging providers have access to lower electricity rates than $0.24/kWh for their EVSE, they could charge less than $0.32/kWh and still recoup their initial investment.

A comprehensive charging infrastructure discounted cash flow analysis is beyond the scope of this memo. Researchers at the National Renewable Energy Laboratory published a charging infrastructure financial analysis scenario tool with detailed finance projections that include common financial metrics.[31] Intended users include governments, infrastructure operators, equity investors, strategic investors, and lenders. Such tools could help cities like San Francisco conduct more specific charging infrastructure financial analysis to assess return on investment for particular charging infrastructure deployment options and use-cases.

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[31] Penev, M., Wood, E., and Borlaug, B. *Electric vehicle infrastructure financial analysis scenario tool (EVI_FAST): spreadsheet tool user's manual.* (National Renewable Energy Laboratory, 2020), https://www.nrel.gov/transportation/assets/pdfs/evi-fast-user-manual-draft-nov-2020.pdf

Consumer energy savings. The citywide charging infrastructure cost results capture the costs associated with installing and maintaining the proper function and operation of chargers in San Francisco, but do not consider the electricity costs faced by consumers to charge their vehicles. In addition to the utilization-dependent variability in the costs per kilowatt hour, which dictates the premium over the wholesale electricity price that consumers may face, the wholesale electricity rate is typically less for slower chargers than for faster chargers. We estimate the consumer energy costs in the central and the intervention case using the average of current rate structures from EVGo for public chargers, the average of residential EV rate structures from PG&E for residential curbside chargers and the assumed utilization described above of 5 hours and 9.5, for public and curbside chargers, respectively.[32] The consumer energy savings from increased residential curbside charging and reduced DC fast and public Level 2 charging are significant. By switching from more DC fast and public Level 2 charging to more residential curbside, we calculate that consumers can save about $18.2 million in EV charging energy costs from 2023 and 2030.

Equity and access. Equity considerations remain at the forefront of planning for the transition to EVs. Access to convenient and low-cost charging is an important amenity to realize the full financial benefits of driving an EV, but is more readily available to higher income EV drivers with single-family homes and off-street parking than it is to lower income EV drivers living in multi-family homes or without off-street parking. Residential curbside chargers not only can offer savings on charging infrastructure costs as discussed above, but also can provide EV drivers without off-street parking or home charging a convenient charging experience, lower charging costs, and can help maintain the battery life of their EVs. Enabling these benefits by deploying curbside chargers is consistent with San Francisco's goals for equitable access to electric mobility options as laid out in the city's EV Roadmap.[33]

Opportunities to minimize city outlays

This section discusses potential opportunities to minimize city outlays for deploying electric vehicle charging infrastructure using examples from other cities in the U.S. and internationally.

Technological advancements and increased hardware production volumes are lowering capital costs of charging infrastructure and improving the business case for private sector operation. However, soft costs, such as permitting, easement, and code compliance remain high and have the greatest potential for further cost reductions.[34] Local agencies can reduce soft costs by simplifying and streamlining codes and permitting, facilitating easement processes, and providing informational materials for residential and charging provider stakeholders.[35] California has passed AB1236 and AB970 which provide requirements for streamlining permitting processes for EV charging projects. Additional best practices such as providing an online

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[32] We calculate an electricity rate of $0.54/kWh for DCFC and $0.32/kWh for curbside chargers in 2023 using a time-weighted average of EVGo's Pay As You Go rates in the Bay Area and PG&E's residential EV rate plans, respectively. Public Level 2 chargers receive a rate of $0.43/kWh in 2023 representing the midpoint of the rates for DCFC and curbside chargers. Rates increase by 3.34% annually.

[33] San Francisco Electric Vehicle Working Group, "Proposed Electric Vehicle Roadmap for San Francisco" (2019), https://sfenvironment.org/sites/default/files/fliers/files/sfe_tr_ev-roadmap.pdf.

[34] Rocky Mountain Institute, "Reducing EV charging infrastructure costs" (2019), https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf

[35] Chih-Wei Hsu, Peter Slowik, and Nic Lutsey, *City charging infrastructure needs to reach electric vehicle goals: The case of Seattle*, (ICCT: Washington, DC, 2021), https://theicct.org/wp-content/uploads/2021/06/Seattle-charging-infra-jan2021.pdf.

permitting process and allowing for concurrent reviews through separate departments can help reduce soft costs further and are outlined in the state's permitting guidebook.[36] Reducing soft costs will be of particular importance for charging installations in low-income communities which may have greater need for grid upgrades and require more comprehensive approval processes.[37]

EV-ready building codes can ensure home charging at single-family and multi-family homes for all San Franciscans. Building codes without EV-Ready requirements present obstacles to the cost-effective deployment of chargers as charging installations during retrofits can be up to five times greater than at the time of construction.[38] The most cost-effective way for charging to be installed is to install as many at once, either in comprehensive retrofits of all parking spaces where charging need is anticipated or during construction, rather than in incremental additions over time. Numerous Canadian jurisdictions have enacted bold building codes to avoid future costly retrofits for charging, which require 100% of parking spaces (or at minimum 1 space per unit) at new residential buildings to be EV-ready with at least a 240V outlet at each space and sufficient panel capacity. These codes represent an international best practice.[39]

To ensure that the deployment or supply of charging infrastructure is aligned with local demand, cities could consider developing an online portal for residents to submit requests or applications for where additional residential Level 2 curbside chargers are needed. Such programs are underway in Stockholm and Amsterdam.[40] Requirements and details vary. For example: in Stockholm, applicants are responsible for installation, operation, and maintenance; the chargers must be publicly accessible and placed between two parking spaces so that they can serve two vehicles; and the city has created a map illustrating potential suitable locations for new chargers. In Amsterdam, applicants can request the city install a publicly-accessible Level 2 charging station if they do not have off-street parking such as a garage or driveway and the city will review the application and examine whether and where the charging network will need to be expanded, considering existing charging, pending requested charge points, technical feasibility, visibility, safety, and other criteria. If approved, a charger will be installed in about 4 to 8 months at no cost to the applicant. Such programs can be very effective at ensuring optimal placement and that infrastructure supply is linked to demand thereby increasing the likelihood of high utilization and faster recovery of costs.

A request for proposals (RFP) issued by the City of Sacramento could serve as an example for cities that are exploring opening curbside locations or other city-owned property for companies to install electric vehicle charging infrastructure. Sacramento issued an RFP for companies to

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[36] Heather Hickerson and Hannah Goldsmith, "Electric Vehicle Charging Station Permitting Guidebook," (California Department of General Services Office of State Publishing, January 2023), https://business.ca.gov/wp-content/uploads/2019/12/GoBIZ-EVCharging-Guidebook.pdf.

[37] "*Curbside Charging in the Public Right-of-Way Stakeholder Meeting Summary*," City of Oakland, accessed March 30, 2023, https://cao-94612.s3.amazonaws.com/documents/Curbside-Charging-Meeting-Summary.pdf.

[38] Zealan Hoover, Florian Nägele, Evan Polymeneas, and Shivika Sahdev, "How charging in building can power up the electric-vehicle industry", (Mckinsey & Company, January 5, 2021), https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-charging-in-buildings-can-power-up-the-electric-vehicle-industry.

[39] Brendan McEwen, "Making Parking 'EV-Ready': Requirements for New Construction & Incentives for Existing Buildings", (AES Engineering, February 2022), https://emc-mec.ca/wp-content/uploads/EMC-Position-Paper-EV-Ready-Parking-2022.02.24-Formatted-EMC-Format.pdf.

[40] City of Stockholm. (2020). Apply to establish new charging points for electric cars. Retrieved from https://tillstand.stockholm/tillstand-regler-och-tillsyn/parkering/ansok-om-att-etablera-nya-laddplatser-for-elbil/ and Township Amsterdam. (n.d.). Request a charging point for electric cars. Retrieved from https://www.amsterdam.nl/veelgevraagd/?productid=%7b1f11ff96-a45d-4607-8275-6310816aff2f%7d#case_%7B34434E57-906C-4246-BAA5-FC04A7A409EE%7D

install, operate, and own chargers at no cost to the city in potential right-of-way locations as identified by the city.[41] The no-cost RFP allowed Sacramento to identify a vendor that was not reliant on public investment and could demonstrate a business case for public charging. Cities could provide additional incentives for operators by issuing RFPs with compensation in the form of grants, reduced taxes, streamlined permitting, or other financial or nonfinancial incentives. Non-profit organization, Forth, provides a good template to support cities in developing RFPs for vendors to install, own, and operate EV charging on city-owned property.[42]

Inclusive utility investment and on-bill financing (OBF) programs could potentially serve as a model for charging infrastructure deployment in San Francisco. Through these alternative financing models, the utility pays a significant portion of the upfront, customer-side capital costs for an energy efficiency or clean energy project and will recover the costs through a fixed fee on the electricity bill.[43] Inclusive utility investments are typically used for residential customers while OBF can be for residential and non-residential customers alike. Unlike OBF or other loan programs, inclusive utility investments are unique in that the cost recovery obligations are tied to the meter rather than the originating customer thereby negating the need for credit checks or income verification. These factors, including that there is no required upfront cost, make this a financing option suitable for low-income customers, renters, and those looking to avoid incurring debt.[44]

Inclusive utility investments have largely been used for building energy efficiency improvements but are being increasingly considered for transportation electrification. As an example, the Michigan Public Service Commission approved funding for a PAYS (Pay As You Save) pilot in Detroit which allows the utility, DTE Energy, to pay for the upfront costs of electric buses and supporting charging infrastructure and to recover costs through a service fee on the city’s electricity bill.[45] PG&E offers OBF of energy efficiency projects for its non-residential customers, and does not currently offer an inclusive utility investment program, also known as tariff on-bill (TOB). However, the California Public Utility Commission (CPUC) has ordered that utilities in the state put forth a joint TOB proposal outlining such a program for consideration by early 2024, in addition to expanding existing OBF programs.[46] CPUC has authorized these new and expanded programs to include eligibility for transportation electrification projects, but specific eligible projects/technologies have not yet been determined.

Cities can also leverage state and federal grants for charging infrastructure deployment. In March 2023, the Biden-Harris Administration opened applications for the first round of $2.5

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[41] City of Sacramento, “Curbside Charging,” (accessed October 1, 2021), http://www.cityofsacramento.org/Public-Works/Electric-Vehicle-Initiatives/Curbside-Charging

[42] Erin Galiger, “EV Charging and Public/Private Partnerships: RFP Template” (Forth, January 2021), https://forthmobility.org/storage/app/media/Reports/RFP%20Template%20EVSE%20In%20Cities_FINAL_20210119.pdf

[43] “Introduction to inclusive utility investments,” *CleanEnergyWorks*, January 1, 2023, https://www.cleanenergyworks.org/2023/01/01/introduction-to-inclusive-utility-investments/.

[44] “Inclusive Utility Investments: Tariffed On-Bill Programs,” United States Environmental Protection Agency, accessed June 14, 2023, https://www.epa.gov/statelocalenergy/inclusive-utility-investments-tariffed-bill-programs.

[45] Margarita Parra, “Michigan Public Service Commission Approves DTE’s PAYS® Pilot for Electric Transit Buses,” *CleanEnergyWorks*, November 18, 2022, https://www.cleanenergyworks.org/2022/11/18/dte_transit_batteries_pilot/.

[46] Proposed Decision: Order Instituting Rulemaking to Investigate and Design Clean Energy Financing Options for Electricity and Natural Gas Customers, Public Utilities Commission of the State of California, R2008022, June 9, 2023, https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M511/K023/511023292.PDF.

billion in funding for EV charging infrastructure rollout in U.S. communities and neighborhoods.[47] The $1.25 billion "community" program provides funding to strategically deploy publicly accessible EV charging at public roads, parking facilities at public buildings, schools, parks, or other facilities, and city and county governments are eligible applicants.

A new 2023 C40 report on city charging infrastructure financing strategies offers guidance to cities that want to advance infrastructure planning in their jurisdictions, and provides case studies from cities around the world using innovative strategies and collaborating across government, private sector, and energy utility stakeholders to deploy charging infrastructure.[48] The purpose of the report is to share successful strategies and business models for charging deployment with other city governments to try and implement. Cities like San Francisco may find successful funding strategies within this resource for deploying charging in their own jurisdictions.

Key Findings

This memo assesses the average capital hardware and installation, operating and maintenance, and grid upgrade costs of deploying home, residential curbside, workplace, and public electric vehicle charging infrastructure in San Francisco through 2030. It compares the citywide infrastructure costs for two hypothetical cases with and without residential curbside charging and presents a case study of typical costs at representative locations in the city. The per-charger costs, their average power (kW), and assumptions about their utilization are used to identify the chargers that have potential to provide electricity at the lowest cost. We draw the following reflections from the analysis:

- **Lots more charging is needed to support SF's transition to ZEVs.** By 2030 there could be 170,000 EVs on San Francisco roads which could demand about 379 GWh of energy per year in 2030 and necessitate more than 86,000 chargers, which includes the charging infrastructure that exists today. The vast majority of EV charging and charging infrastructure is likely to continue to be at homes and near-home residential locations.

- **Deploying all these chargers necessitates significant financial investment**. This analysis finds between $348 million (central case) and $342 million (intervention case) dollars in cumulative annual costs are needed to deploy and operate over 68,000 new chargers from 2023 through 2030 over their expected lifetime. This includes more than 63,000 home chargers, 3,200 workplace chargers, 1,100-1,400 public L2 chargers, 190-240 DC fast, and 0-640 curbside chargers.

- **Shifts in the relative deployment of residential curbside vs. public charging has important implications for total costs and can increase consumer convenience and access to lower energy costs**. This analysis finds that deploying a stock of 800 curbside chargers by 2030 can offset the need for 70 DC fast and 284 public Level 2

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[47] Biden-Harris Administration opens applications for first round of $2.5 billion program to build EV charging in communities & neighborhoods nationwide. (U.S. Department of Transportation, 2023). https://highways.dot.gov/newsroom/biden-harris-administration-opens-applications-first-round-25-billion-program-build-ev

[48] Ana Terra, Claire Markgraf, Mariola Panzuela, Zoe Allen, Gustavo Jiménez, Jorge Suárez, Miriam Monterrubio, Josemaría Jiménez, Fabrício Pietrobelli, *EV charging infrastructure: Business models and city case studies*, (C40: London, UK, 2023), https://www.c40knowledgehub.org/s/article/EV-charging-infrastructure-Business-models-and-city-case-studies?language=en_US.

chargers, which can reduce the total infrastructure system costs by about $6 million. The associated consumer benefits to shifting from more expensive DC fast charging to more affordable overnight residential charging is substantial and sums up to over $18 million through 2030.

- **Utilization is key to increasing cost-effectiveness and enabling a return-on-investment.** Charging stations with relatively less utilization have longer payback periods. Lower utilization also means electricity would have to be priced higher for the same payback period compared to more utilization. Home chargers tend to have the lowest levelized cost of energy, even with relatively low utilization. Based on the utilization assumptions introduced in this memo (i.e., 5 hours/day for public Level 2 and DC fast, 9.5 hours/day for residential curbside), residential curbside chargers have the lowest levelized cost of energy of any non-home charger at $0.09/kWh, compared to $0.17 for public Level 2 and 50kW DC fast, and $0.14/kWh for 150kW and 350kw DC fast.

- **Careful planning can help maximize utilization**. Deploying charging where there is known demand can ensure that charging infrastructure is used more often. Programs like Amsterdam's and Stockholm's applicant-based programs can ensure that infrastructure supply is strategically placed where there is demand, increasing utilization. Such programs can address multiple city goals simultaneously, including stimulating electric vehicle adoption, expanding charging equity and access, lowering consumer energy costs, and maximizing infrastructure usage and cost-effectiveness.

- **Various actions can help minimize costs borne by city stakeholders.** Several policy actions can help reduce costs and shift them to the private sector. Examples include streamlining permitting processes to reduce soft costs and accelerate projects breaking ground, no-cost RFPs to encourage private sector investment in chargers, and on-bill financing or inclusive utility investment programs.

- **Cross-agency collaboration is important to deploy chargers in a timely and cost-effective manner.** Infrastructure planning and financing is complex. More detailed investigation of charging project costs at particular sites is needed. Continued dialogue and collaboration across city agencies will be key to identifying the optimal locations for charging infrastructure deployment and better understanding the costs, technical barriers, and policy opportunities that are key to facilitating deployment at the most cost-effective locations.

Appendix

Table A1. Charger capital costs 2023-2040 ($2022)

Charger	SFH L1	SFH L2	MFH L1	MFH L2	Workplace	Public L2	Curbside	DC50	DC150	DC350
2023	$444	$1,276	$559	$2,774	$5,471	$8,452	$8,452	$80,877	$130,708	$217,421
2024	$441	$1,269	$556	$2,766	$5,435	$8,357	$8,357	$80,014	$128,428	$213,164
2025	$438	$1,261	$553	$2,759	$5,400	$8,264	$8,264	$79,176	$126,216	$209,036
2026	$436	$1,254	$550	$2,751	$5,366	$8,175	$8,175	$78,364	$124,071	$205,031
2027	$433	$1,247	$547	$2,744	$5,333	$8,088	$8,088	$77,576	$121,990	$201,146
2028	$430	$1,240	$545	$2,737	$5,302	$8,004	$8,004	$76,811	$119,971	$197,377
2029	$428	$1,233	$542	$2,731	$5,271	$7,922	$7,922	$76,070	$118,013	$193,722
2030	$425	$1,227	$540	$2,724	$5,241	$7,843	$7,843	$75,351	$116,113	$190,177
2031	$423	$1,221	$537	$2,718	$5,212	$7,766	$7,766	$74,653	$114,271	$186,737
2032	$420	$1,214	$535	$2,712	$5,184	$7,692	$7,692	$73,976	$112,484	$183,401
2033	$418	$1,209	$532	$2,706	$5,156	$7,620	$7,620	$73,320	$110,750	$180,165
2034	$416	$1,203	$530	$2,700	$5,130	$7,549	$7,549	$72,683	$109,069	$177,027
2035	$414	$1,197	$528	$2,695	$5,104	$7,481	$7,481	$72,065	$107,437	$173,982
2036	$411	$1,192	$526	$2,689	$5,079	$7,416	$7,416	$71,466	$105,855	$171,029
2037	$409	$1,187	$524	$2,684	$5,055	$7,352	$7,352	$70,885	$104,321	$168,164
2038	$407	$1,182	$522	$2,679	$5,031	$7,289	$7,289	$70,321	$102,832	$165,385
2039	$405	$1,177	$520	$2,674	$5,009	$7,229	$7,229	$69,774	$101,388	$162,690
2040	$404	$1,172	$518	$2,669	$4,987	$7,171	$7,171	$69,244	$99,987	$160,075

Table A2. Demand charges 2023-2040 ($2022)

Charger	SFH L1	SFH L2	MFH L1	MFH L2	Workplace	Public L2	Curbside L2	DC50	DC150	DC350
2023	$0	$0	$0	$0	$125	$125	$0	$945	$2,836	$6,618
2024	$0	$0	$0	$0	$129	$129	$0	$977	$2,931	$6,839
2025	$0	$0	$0	$0	$133	$133	$0	$1,010	$3,029	$7,067
2026	$0	$0	$0	$0	$138	$138	$0	$1,043	$3,130	$7,303
2027	$0	$0	$0	$0	$142	$142	$0	$1,078	$3,234	$7,547
2028	$0	$0	$0	$0	$147	$147	$0	$1,114	$3,342	$7,799
2029	$0	$0	$0	$0	$152	$152	$0	$1,151	$3,454	$8,059
2030	$0	$0	$0	$0	$157	$157	$0	$1,190	$3,569	$8,329
2031	$0	$0	$0	$0	$162	$162	$0	$1,230	$3,689	$8,607
2032	$0	$0	$0	$0	$168	$168	$0	$1,271	$3,812	$8,894
2033	$0	$0	$0	$0	$173	$173	$0	$1,313	$3,939	$9,191
2034	$0	$0	$0	$0	$179	$179	$0	$1,357	$4,071	$9,498
2035	$0	$0	$0	$0	$185	$185	$0	$1,402	$4,207	$9,816
2036	$0	$0	$0	$0	$191	$191	$0	$1,449	$4,347	$10,143
2037	$0	$0	$0	$0	$198	$198	$0	$1,497	$4,492	$10,482
2038	$0	$0	$0	$0	$204	$204	$0	$1,547	$4,642	$10,832
2039	$0	$0	$0	$0	$211	$211	$0	$1,599	$4,797	$11,194
2040	$0	$0	$0	$0	$218	$218	$0	$1,653	$4,958	$11,568

Table A3. Levelized 10-year infrastructure cost per kilowatt-hour by utilization for different charging typologies

Utilization (hours)	1	2	3	4	5	6	7	8	9	10
Curbside	$0.77	$0.39	$0.26	$0.19	$0.15	$0.13	$0.11	$0.10	$0.09	$0.08
DC50	$0.87	$0.44	$0.29	$0.22	$0.17	$0.15	$0.12	$0.11	$0.10	$0.09
DC150	$0.72	$0.36	$0.24	$0.18	$0.14	$0.12	$0.10	$0.09	$0.08	$0.07
DC350	$0.70	$0.35	$0.23	$0.17	$0.14	$0.12	$0.10	$0.09	$0.08	$0.07
Public L2	$0.84	$0.42	$0.28	$0.21	$0.17	$0.14	$0.12	$0.10	$0.09	$0.08