Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings:
A Westside Cities Case Study

UCLA Luskin School *of* Public Affairs
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ABSTRACT

The transportation sector is a major source of greenhouse gas emissions in California. To address this issue, Governor Edmund G. Brown Jr. signed an executive order calling for 1.5 million zero-emission vehicles (ZEV) on California's roads by 2025. To achieve this ambitious goal, significant barriers must be overcome to expand and accelerate plug-in electric vehicle (PEV) adoption, including the need to build the necessary refueling infrastructure. Currently, residents of multi-unit dwellings (MUDs) such as apartments and condominiums are unlikely to have access to home charging (electric vehicle supply equipment or EVSE).

The purpose of this report is to explore barriers to PEV adoption for residents of MUDs within the Westside Cities subregion of Los Angeles County and then identify MUDs within the study region that may exhibit high latent PEV demand and subsequent demand for low-cost EVSE installation. These MUDs should be a priority for targeted outreach for programs that assist with EVSE installation, since they are most likely to host PEV drivers in the near future. We find that the MUDs with greatest demand for PEVs and charging infrastructure within the study region are located in West Los Angeles, followed in descending order by Beverly Hills, Santa Monica, West Hollywood, Culver City, and unincorporated portions of Los Angeles County.

This report also reviews the costs associated with EVSE installation at MUD sites, which are highly variable across properties. To keep charging installation costs as low as possible, property owners should consider Level 1 charging opportunities and group investments for EVSE installations. The report closes with a discussion of policy tools for scaling up charging infrastructure at MUD sites across the Westside cities subregion, concluding that targeted outreach to promote the PEV, PEV rebates, and PEV-ready new construction codes are likely required to ease the MUD-related barriers to PEV adoption.

Keywords: Plug-in electric vehicle, PEV, multi-unit dwelling, MUD, PEV charging, EVSE, Westside Cities, California Energy Commission, demand, installation costs

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CHAPTER 1: Introduction

The transportation sector represents the largest source of California's greenhouse gas (GHG) emissions, comprising 39% of all GHG emissions in 2015.[1] To reduce emissions from the transportation sector, the state is making a concerted effort to promote the adoption of advanced clean vehicles. The transition to more fuel-efficient and zero-emission vehicles (ZEVs) is critical to achieving the state's ambitious climate goals and air quality requirements. In 2012, Governor Edmund G. Brown Jr. signed an executive order setting a target of 1.5 million ZEVs on California's roads by 2025.[2]

To achieve the goals laid out by the Governor's executive order, a number of adoption barriers must be overcome. A key challenge addressed in the Governor's 2016 ZEV Action Plan is the need to build the necessary refueling infrastructure in apartment buildings and condominiums, also known as multi-family housing, or as the California Energy Commission (CEC) refers to them, multi-unit dwellings (MUDs).[3] ZEVs, and specifically plug-in electric vehicles (PEVs), require an entirely new set of refueling behavior and equipment. In place of a 15-minute detour to a gas station, most PEV owners refuel overnight when they are at home. While this is generally a straightforward proposition for single-family homeowners, MUD residents face a number of obstacles to installing electric vehicle service equipment (EVSE). Foremost is the variable and often high cost of EVSE installation at a MUD site. Additionally, the renter or owner exhibits a low to nonexistent investment motivation: renters are unlikely to invest in a piece of immobile equipment that they may move away from in the future, and owners do not yet see home PEV charging as an amenity by which to increase property value and attract tenants. Overcoming these financial and motivational challenges is critical to charting the path toward a low-carbon future.

1.1. Purpose of the Report

The goal of this report is to explore MUD-related barriers to greater PEV adoption within the Westside Cities subregion, as well as to prioritize policy tools and targeted outreach for MUD sites that exhibit relatively high latent PEV demand and a low cost of EVSE installation. This report represents the final report for Task 2 of Agreement Number Agreement M-004-16 with the South California Association of Governments (SCAG).

The formal boundary of the Westside Cities subregion encompasses the cities of Beverly Hills, Culver City, Santa Monica, West Hollywood, and parts of unincorporated Los Angeles County. For the purposes of this study, the western portions of the City of Los Angeles are also included in the boundary of analysis, and are referred to as West Los Angeles. All aggregated numbers that are reported for the Westside Cities subregion throughout this study reflect results from the jurisdictions within the formal boundary of the Westside Cities subregion, and results from West Los Angeles. See **Figure 1.1** for an overlay of the formal Westside Cities boundary and the boundary of analysis adopted for this study.

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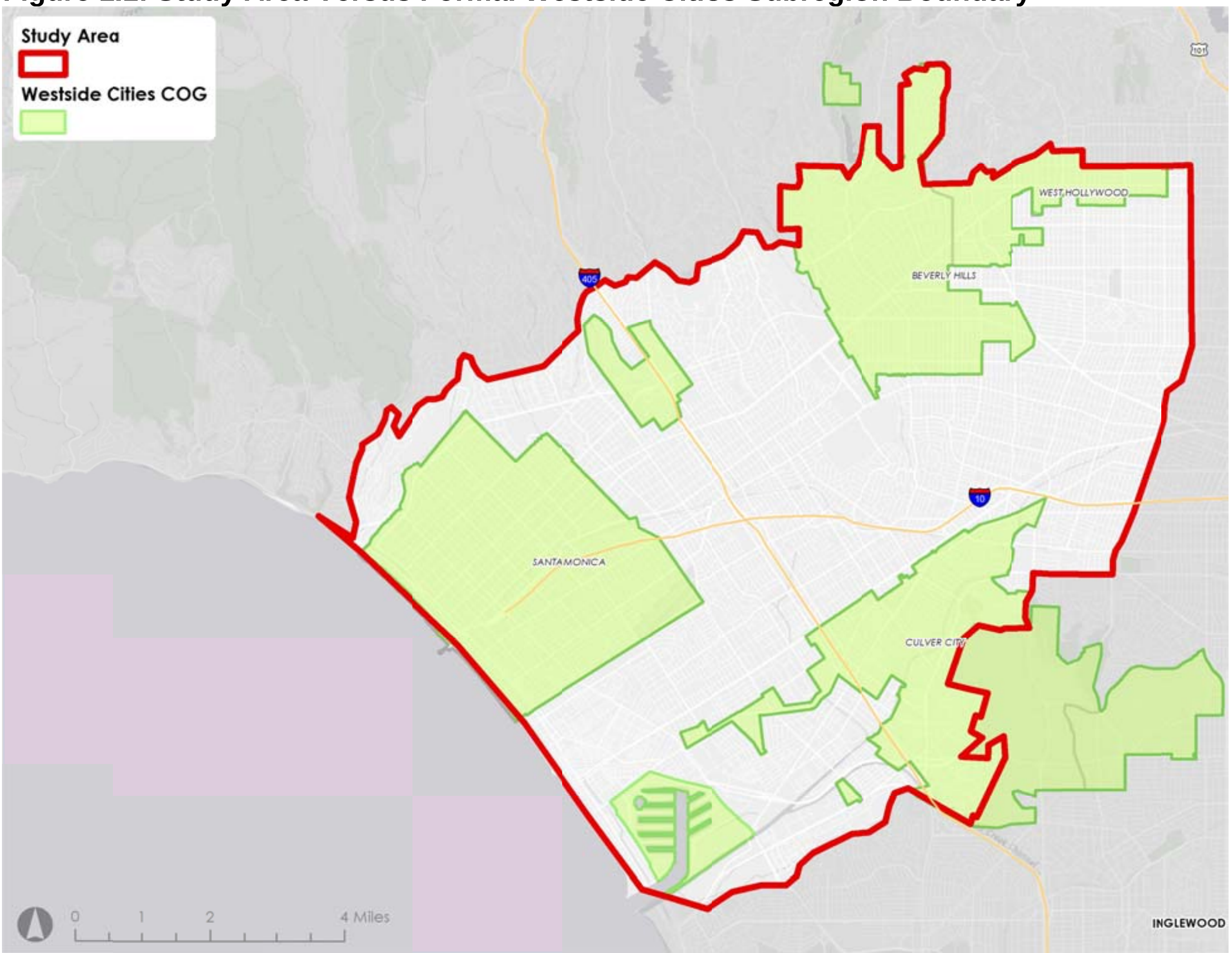
[1] California Air Resources Board. 2017. "California Greenhouse Gas Emission Inventory - 2017 Edition" Accessed August 2017 from https://www.arb.ca.gov/cc/inventory/data/data.htm

[2] California Office of the Governor. 2012. "Governor Brown Announces $120 Million Settlement to Fund Electric Car Charging Stations Across California" Accessed August 2017 from https://www.gov.ca.gov/news.php?id=17463

[3] Governor's Interagency Working Group on Zero-Emission Vehicles. 2016. *ZEV Action Plan.* Accessed August 2017 from https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf

Figure 1.1: Study Area Versus Formal Westside Cities Subregion Boundary



The Westside Cities subregion is a leader in the adoption of PEVs with 10,419 total registrations between December 2010 and September 2016.[4] Yet it is likely that the full adoption potential of the subregion is constrained by its mix of residential land uses, specifically the significant number of MUDs. There are 30,590 MUDs across the study area, which are home to 253,876 housing units, comprising 30.1% of the residential land use mix.[5] As such, the subregion provides a quality study area to evaluate MUD-related barriers to PEV adoption, as well as to implement policies or programs aimed at overcoming this barrier. The report is organized as follows:

Chapter 2 provides an overview of the MUD portfolio in the Westside Cities subregion. Researchers analyzed the Los Angeles County Office of the Assessor's Secured Basic File Abstract to identify MUD characteristics that may influence PEV demand such as size, per unit value, vintage, and ownership type. This chapter concludes with a review of the subregion's 16,495 MUD units located within disadvantaged communities. These may be appropriate targets for investments from Greenhouse Gas Reduction Fund revenues.

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[4] IHS Automotive New Vehicle Registration Data.

[5] Los Angeles County Office of the Assessor Secured Basic File Abstract. Accessed October, 2015.

Chapter 3 identifies MUDs in the Westside Cities subregion that may exhibit high latent PEV demand. Our PEV demand analysis provides parcel level information: We calculated a propensity-to-purchase score using the historical adoption rate of PEVs in each census tract, as well as the PEV adoption rate of individuals living in households of a certain value. Those MUD parcels that result in a higher propensity-to-purchase score should be targets for outreach efforts or other policy interventions.

Chapter 4 presents the costs associated with Level 1 and Level 2 EVSE installation at MUD sites. Using empirical evidence from visiting MUD sites and obtaining installation cost estimates from a qualified electrician, this chapter investigates how installation costs vary based on the electrical, structural, and parking configuration of the MUD building, and highlights potential low-cost installation solutions.

Chapter 5 offers policy tools that help alleviate the MUD-related barriers to PEV adoption. Potential policy solutions include designing rebates to reduce the cost of EVSE installation, implementing PEV-ready new construction codes, siting public charge programs to benefit MUD residents, and prioritizing outreach and education to increase PEV adoption.

1.2 Intended Audience

This report is intended for a wide audience of decision makers and advocates seeking to advance PEV adoption in MUDs, with emphasis on those in the Westside Cities subregion. Those who may find the report most useful include regional, subregional, and municipal planners; state agencies; utility representatives; MUD property owners; members of homeowner associations; as well as current and potential PEV drivers.

Regional, subregional, and municipal planners should use this report to facilitate PEV adoption where latent demand is greatest and installation solutions are needed. By outlining the subregion's MUD portfolio, this report empowers planners to strategically conduct targeted outreach and prioritize MUD sites for policy interventions.

State agencies should use this report to understand the MUD-related barriers to PEV adoption and consider policy tools, such as rebates, that reduce the cost of installing EVSE at MUD sites.

Utility representatives should use this report to identify and plan for where PEV demand and related electrical load may grow most rapidly in the subregion. Southern California Edison (SCE), the predominant electric utility in the Westside Cities subregion, recently received approval for Phase 1 of its Charge Ready program to install charging infrastructure at long dwell-time sites, including MUDs, where PEV drivers will be parked for at least four hours. SCE should use this report to help identify census tracts and specific parcels to prioritize outreach for this and other PEV programs.

Property managers and members of homeowner associations (HOAs) should use this report to understand the elements of their building's electrical systems and to better predict the cost of installing PEV home charging options.

PEV and prospective PEV drivers should use this report to better understand the challenges and costs of installing PEV charging infrastructure at home.

1.3 Methodology

The guiding objective of UCLA Luskin Center researchers was to prioritize outreach by 1) understanding the MUD portfolio of the Westside Cities subregion, 2) identifying high latent demand for residents of MUDs in the Westside Cities subregion, and 3) identifying MUD types with a low cost of EVSE installation. The MUD parcels that exhibited high latent demand and low-cost installation opportunities represent the low-hanging fruit for outreach or other policy interventions. The following presents the methodology conducted to achieve the goals of the research.

1) Understanding the multi-unit dwelling portfolio of the Westside Cities subregion

Researchers analyzed Los Angeles County Office of Assessor Secured Basic File Abstract data across a number of parcel specific variables. Most importantly, the data provided researchers with the assessor identification number, number of units, land and improvement value ("total value"), year built ("vintage"), and ownership type (i.e., rental or condominium). Researchers assessed the spatial distribution of MUDs in the Westside Cities subregion using geographic information systems (GIS).

2) Estimating plug-in electric vehicle demand for multi-unit dwelling residents

To identify high latent PEV demand at the parcel level in the Westside Cities subregion, researchers constructed a propensity-to-purchase model. The model works by assigning a score to an MUD unit based on the likelihood that the unit will be occupied by a PEV driver, if there are no barriers to charging. The score is based on three key variables: the forecasted number of PEV purchases per census tract, the PEV adoption rate among different income groups, and the percentage of income groups living in homes of certain values. From these three variables, the model builds a relationship between the value of an MUD unit and the occupants' propensity-to-purchase a PEV. That relationship can then be spatialized at the parcel level based on the MUD's per unit value. See **Appendix 1** for more for information on how the propensity-to-purchase model was constructed, including a summary of the data sources that underpin the model.

3) Identifying multi-unit dwelling types with low-cost EVSE installation

This chapter reviews findings from the report *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study,* in which cost estimates were developed for the installation of charging infrastructure at sample sites within the South Bay Cities Subregion.[6] With the South Bay Cities Council of Governments, researchers released a Request for Information for qualified electricians in Los Angeles County with experience installing EVSE in MUDs. Researchers requested 30 MUD site visits to assess Level 1 and Level 2 charge readiness and to estimate the cost of installing a single Level 2 EVSE unit. From those site visits, 15 complete cost estimates were obtained, the results of which are discussed in this chapter.

[6] UCLA Luskin Center for Innovation. 2016. *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study.*

CHAPTER 2: MUDs of the Westside Cities Subregion

The Westside Cities is home to approximately 250,000 MUD households, making up 30% of the subregion's residential land use.[7] Although the Westside Cities subregion is driving PEV adoption for Southern California, this land use mix may very well be constraining the full potential of the area's PEV uptake. The MUDs present a series of hurdles to installing charging infrastructure (electric vehicle supply equipment or EVSE) at home — the preferred refueling choice for early adopters of PEVs — including the variable and often high costs of installation.

This chapter provides an overview of the Westside Cities' MUD portfolio, including MUD characteristics that can influence the cost of EVSE installation and the investment motivation such as building size (i.e., number of units), per unit value, vintage, ownership type, and locational attributes such as MUDs located in disadvantaged communities. Subregional and city planners and other interested parties can review this chapter to understand the MUD composition of the subregion at large and where the MUD might be significantly constraining PEV adoption.

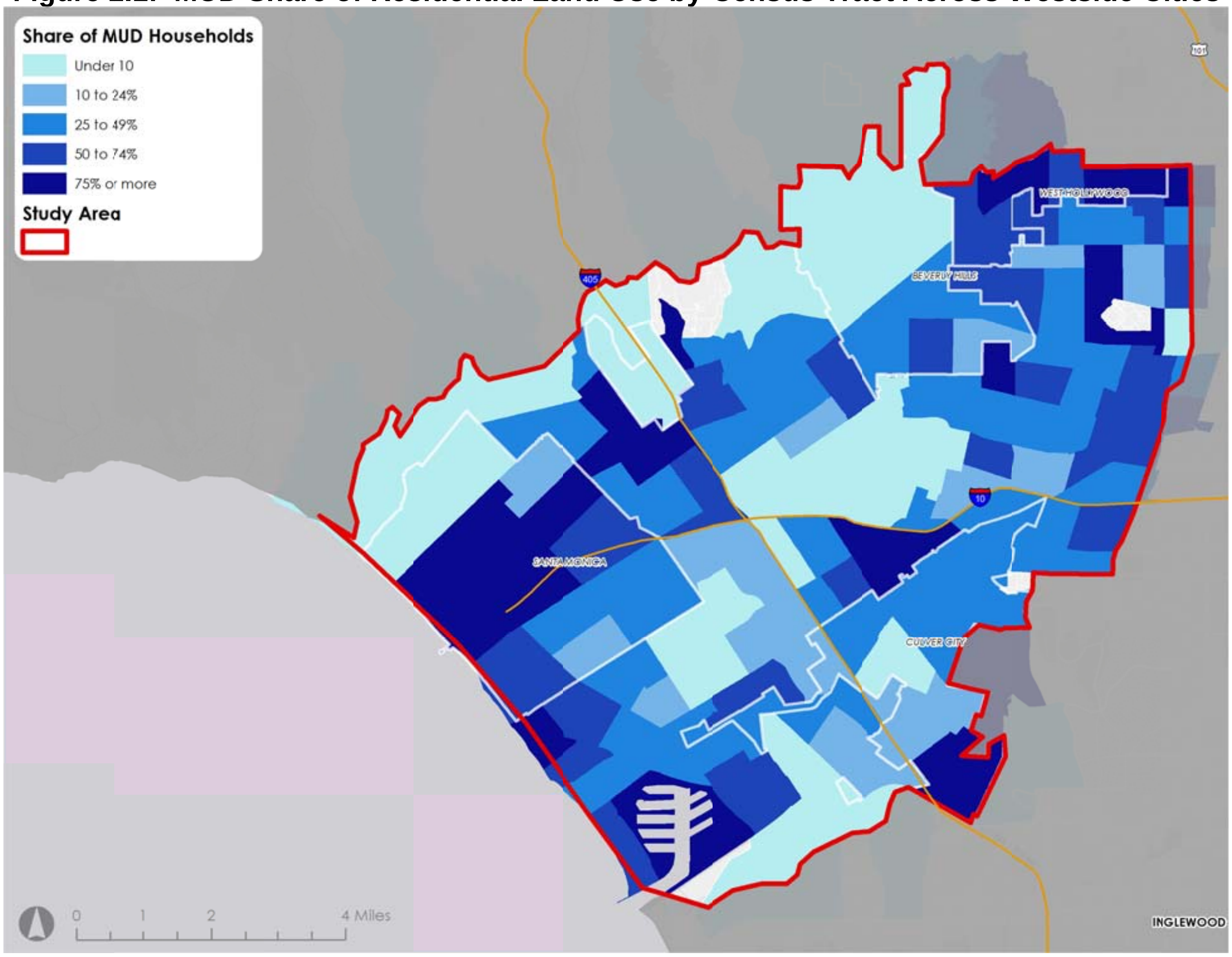
Apartment buildings in downtown Santa Monica (Photo Credit: iStock by Getty Images).

[7] Reflects modified study area for this report. See **Figure 1.1** for an overlay of the formal Westside Cities boundary and the boundary of analysis adopted for this study.

2.1 Density

The density of MUDs ranges greatly across the Westside Cities region. **Figure 2.1** shows the MUD share of residential land use per census tract. Santa Monica, West Hollywood, West Los Angeles, and portions of unincorporated Los Angeles County are each home to census tracts in which more than 75% of the residential land is occupied by MUDs. In contrast, Culver City does not have a single census tract in which more than 50% of the land area is occupied by MUDs. Similarly, most of Beverly Hills is occupied by census tracts with less than 50% of the land dedicated to MUDs, with the exception of one census tract in the southern boundary of the city with 50% to 75% of the residential land dedicated to MUDs.

Figure 2.1: MUD Share of Residential Land Use by Census Tract Across Westside Cities



Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 2.1 summarizes the number of MUDs and the number of MUD units in each city within the study area. The table also summarizes the percentage of residential land occupied by MUDs for each city. West Hollywood has the greatest density of MUDs on residential land, followed in descending order by unincorporated portions of Los Angeles County (explained by MUDs in Marina Del Rey), Santa Monica, Culver City, and Beverly Hills. In contrast, West Los Angeles has the greatest number of MUDs and MUD units, followed in descending order by Santa Monica, West Hollywood, Culver City, Beverly Hills, and unincorporated portions of Los Angeles County.

Table 2.1: MUD Unit Count and Share of Residential Land Use for Westside Cities

City	Number of MUDs	Number of MUD Units	MUD % of Residential Land Use
Beverly Hills	1,273	10,451	10.2%
Culver City	1,763	10,774	32.0%
Santa Monica	5,016	41,165	37.9%
West Hollywood	2,264	23,366	73.1%
West Los Angeles	20,267	167,698	30.3%
Unincorporated Los Angeles County	7	422	69.7%
Total	**30,590**	**253,876**	**30.7%**

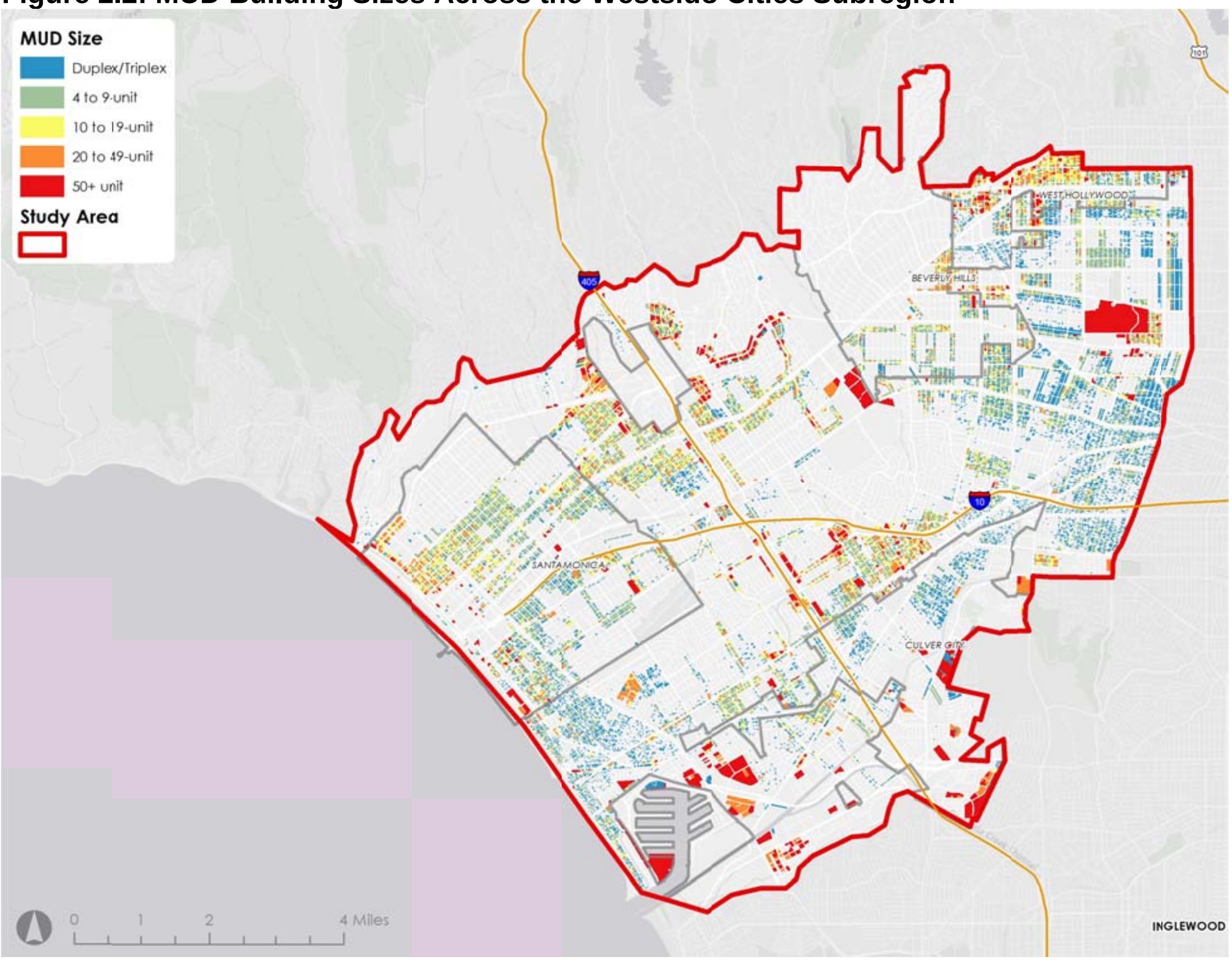
Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

2.2 Building Size

Mapping the precise location of MUDs and knowing the density of units on a site are helpful for utility planning. Utilities can use such maps to anticipate where upgrades may be needed for transformers and distribution stations to accommodate PEV charging at MUDs. As PEVs become increasingly adopted by residents, the electricity load capacity at large MUDs (e.g., 50-unit-plus buildings) will likely need to be upgraded.

MUDs within the Westside Cities subregion range in size from duplexes to 770-unit buildings. **Figure 2.2** presents MUD sizes and their spatial distribution across the Westside Cities subregion. Each city within the study region is home to a wide range of MUD sizes. Duplexes and triplexes can be found within each jurisdiction, as well as buildings with more than 50 units.

Figure 2.2: MUD Building Sizes Across the Westside Cities Subregion



Source: Los Angeles County Office of the Assessor Secured Basic Abstract FIle

Table 2.2 provides a count of MUDs by building size for each city in the Westside Cities subregion. Most of the region's MUDs are four- to nine-unit buildings, followed by duplexes and triplexes (i.e., two- and three-unit buildings, respectively), 10- to 19-unit buildings, 20- to 49-unit buildings, and 50+-unit buildings. This distribution is fairly consistent from city to city, except in Culver City (where duplexes and triplexes comprise most of the MUD housing stock), and in unincorporated portions of Los Angeles County (where there are only seven MUDs in total).

Table 2.2: MUDs by Building Size for the Westside Cities

City	Duplex/ Triplex	4 to 9 units	10 to 19 units	20 to 49 units	50+ units	Total
Beverly Hills	298	686	181	103	5	1,273
Culver City	1,159	489	39	44	32	1,763
Santa Monica	1,128	2,725	831	293	39	5,016
West Hollywood	741	744	513	215	51	2,264
West Los Angeles	8,775	7,784	2,309	1,055	344	20,267
Unincorporated	1	3	0	0	3	7
Total	**12,102**	**12,431**	**3,873**	**1,710**	**474**	**30,590**
% of Total	**39.6%**	**40.6%**	**12.7%**	**5.6%**	**1.5%**	**100%**

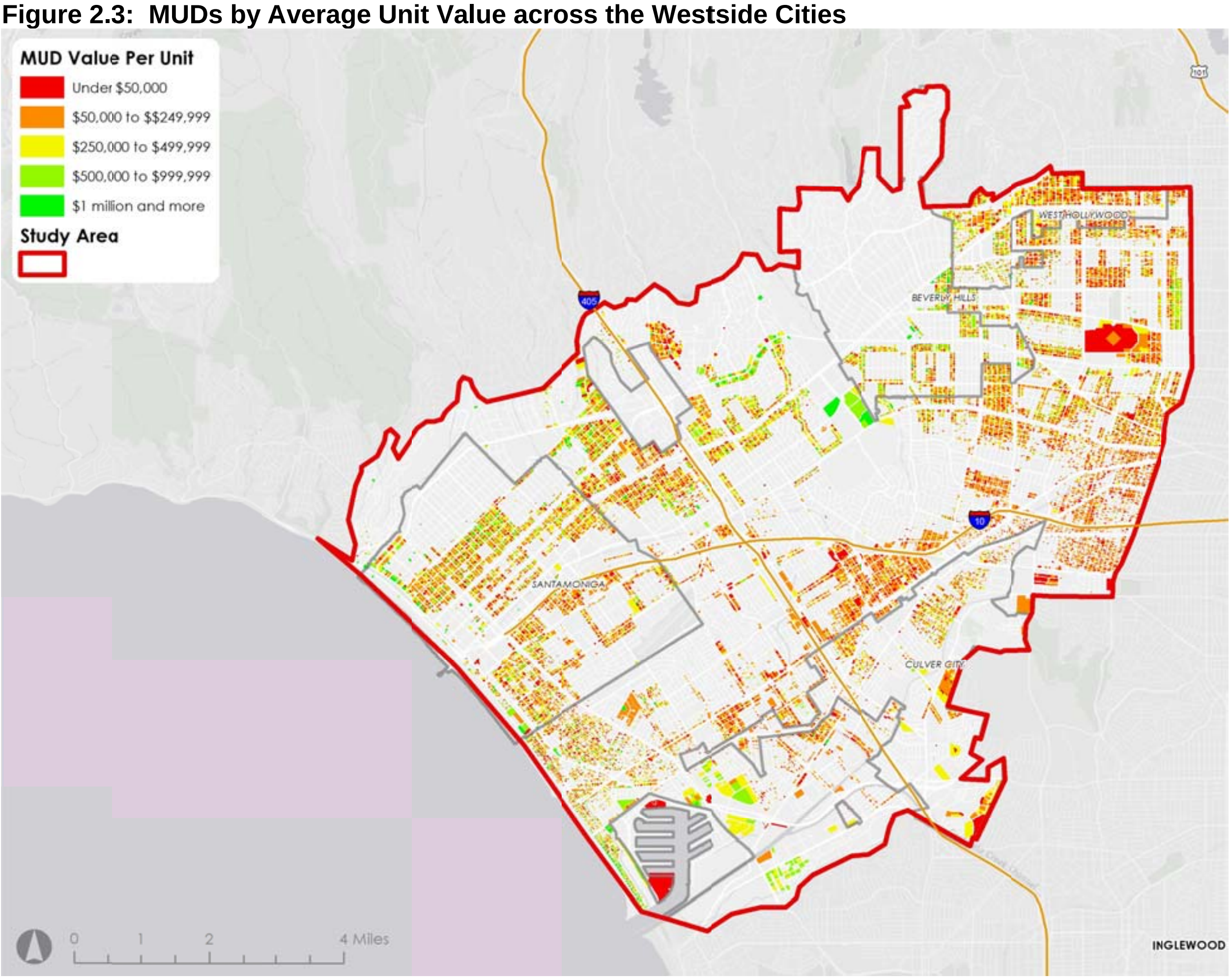
Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

2.3 Unit Values

Early PEV sales indicate that high-income households are purchasing PEVs at higher rates than middle- and low-income households.[8] High-income households tend to purchase new vehicles at faster rates in general and also have more disposable income to spend on new technologies such as PEVs. High-income earners can also afford to live in higher-value homes, making the MUD value per unit an indicator of latent PEV demand. This provides the basis for the propensity-to-purchase measure discussed in Chapter 3.

Figure 2.3 presents the spatial distribution of MUDs according to the average unit value across the Westside Cities subregion. The average unit value associated with each MUD was calculated by dividing the total property value of an MUD by the number of units at that MUD. Each city within the study region is home to a wide range of MUD unit values. MUDs with an average unit value over $1 million can be found in each city, as can MUDs with an average unit value less than $50,000.

Figure 2.3: MUDs by Average Unit Value across the Westside Cities



Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

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8 Sheldon, Tamara L., J.R. DeShazo, Richard T. Carson, and Samuel Krumholz. 2016. *Factors Affecting Plug-in Electric Vehicle Sales in California*. Accessed August 2017 from http://innovation.luskin.ucla.edu/content/factors-affecting-plug-electric-vehicle-sales-california

Table 2.3 provides the total number of MUDs according to the average unit for each city in the Westside Cities subregion. The most common average unit value for an MUD is between $50,000 and $249,999, with around 49% of the MUDs falling into this category. This is true among all cities within the region, except in unincorporated portions of Los Angeles County, where this is a very small sample of MUDs.

Table 2.3: MUDs by Average Unit Value across the Westside Cities Subregion

City	Less Than $50,000	$50,000–$249,999	$250,000–$499,999	$500,000–$999,999	$1 million and more	Total
Beverly Hills	173	488	322	232	58	1,273
Culver City	285	808	525	141	4	1,763
Santa Monica	767	2,354	1,150	602	143	5,016
West Hollywood	471	1,064	467	228	34	2,264
West Los Angeles	3,698	10,161	4,052	1,998	358	20,267
Unincorporated	4	2	1	0	0	7
Total	**5,398**	**14,877**	**6,517**	**3,201**	**597**	**30,590**
% of Total	**17.6%**	**48.6%**	**21.3%**	**10.5%**	**2.0%**	**100%**

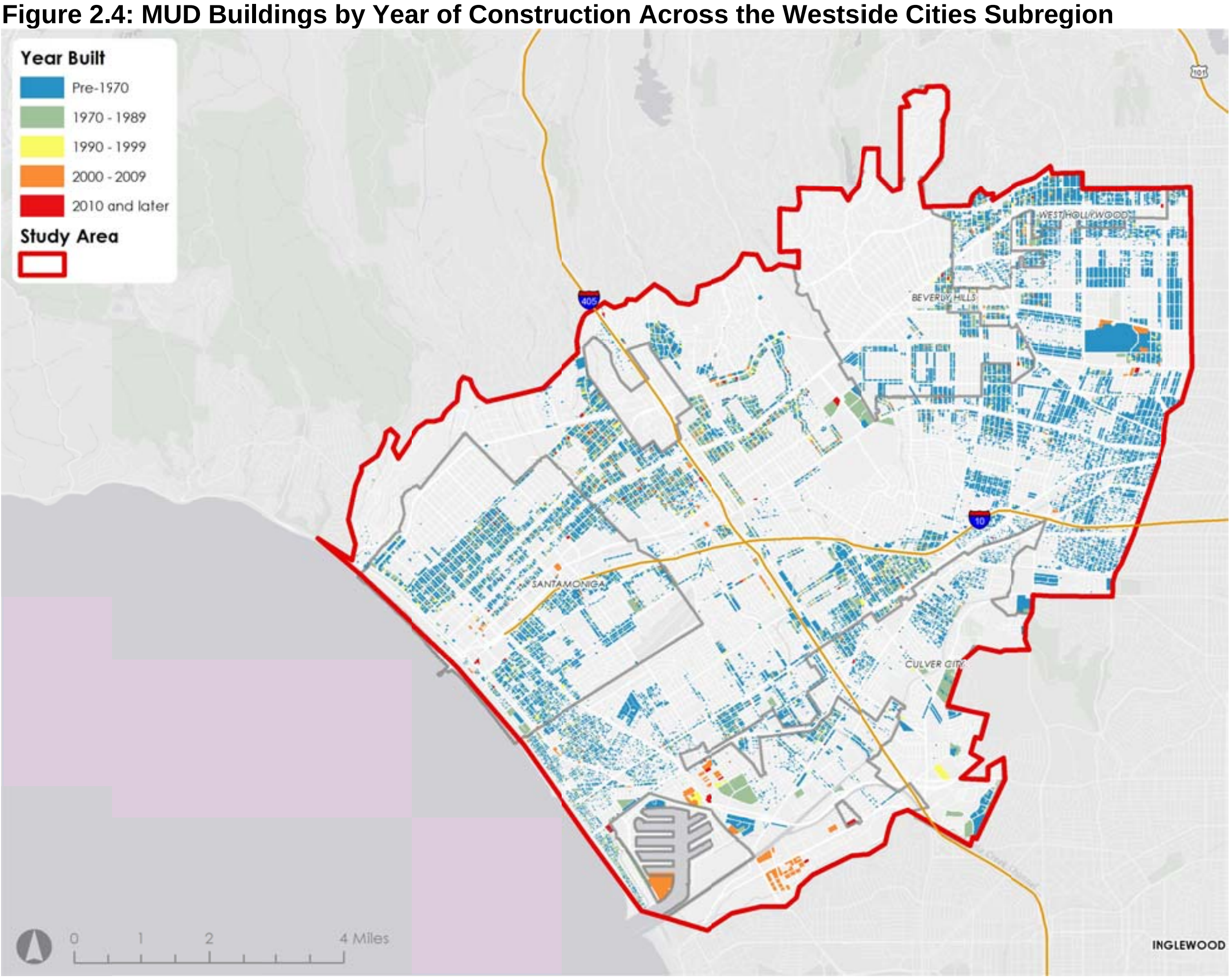
Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

2.4 Vintage

More recently constructed MUDs may provide advantages when installing EVSE on site for two reasons. First, the electrical service provided by a utility to the MUD is more likely to have sufficient capacity for supporting PEV charging, avoiding the need for potentially costly service upgrades such as installing a new service wire or transformer. Second, if panel upgrades such as new circuit breakers are required to provide sufficient capacity for PEV charging, replacement materials may be easier to find and less expensive.

Figure 2.4 presents the spatial distribution of MUDs by year of construction across the Westside Cities subregion. The majority of the housing stock in the Westside Cities subregion is older (built before 1970). Most of the newly built MUDs (2000 and later) are located around the Marina Del Rey area of the region.

Figure 2.4: MUD Buildings by Year of Construction Across the Westside Cities Subregion



Source: Los Angeles County Office of the Assessor Secured Basic Abstract FIle

Table 2.4: provides the total number of MUDs by building vintage across the Westside Cities subregion. MUDs built before 1970 comprise the far majority of housing stock in each city within the subregion. Very few MUDs in the region were built after 2000 (approximately 3% of the housing stock). These newer properties may be the most cost-effective locations for installing charging infrastructure, since they likely are designed to handle higher electrical loads.

Table 2.4: MUD Households by Building Vintage Across the Westside Cities Subregion

City	Pre-1970	1970 to 1989	1990 to 1999	2000 to 2009	2010 and later	Total
Beverly Hills	1,122	107	18	21	5	1,273
Culver City	1,430	297	13	18	5	1,763
Santa Monica	3,905	793	173	121	24	5,016
West Hollywood	1,998	167	31	60	8	2,264
West Los Angeles	16,670	2,390	501	570	136	20,267
Unincorporated	4	1	0	1	1	7
Total	**25,129**	**3,755**	**736**	**791**	**179**	**30,590**
% of Total	**82.1%**	**12.3%**	**2.4%**	**2.6%**	**0.6%**	**100%**

, Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

2.5 Ownership Types

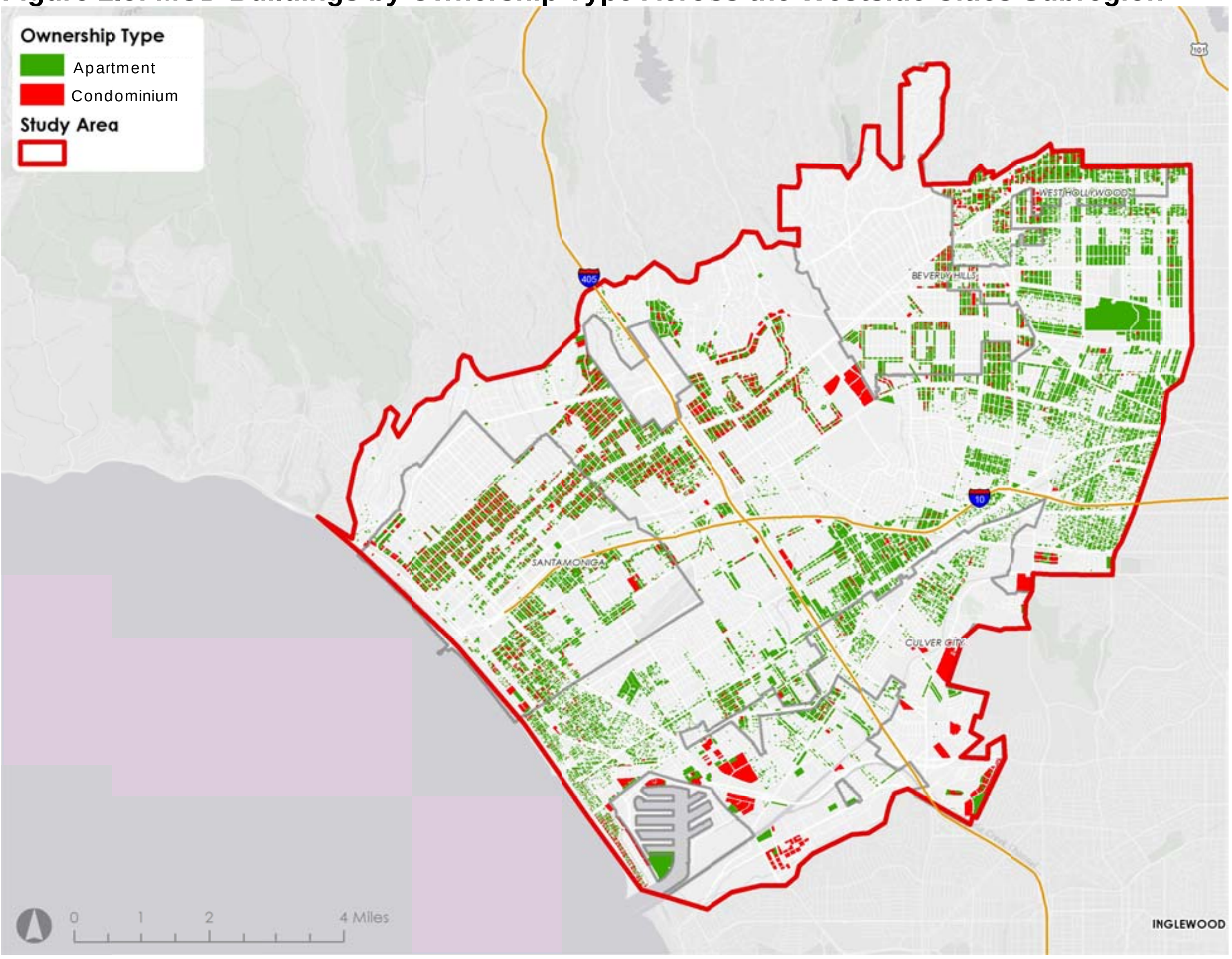
MUD ownership influences a resident's motivation to invest in home charging. MUDs include both apartment buildings and condominiums. Apartment buildings are generally owned by an individual or company that rents the units to tenants. The building owner is responsible for amenities in common spaces, such as lighting for the building's lobby. Any structural changes to the building are paid for by the owner, who makes investment decisions based on increasing the value of the units and charging higher rents. Condominiums are MUDs in which the units are individually owned and non-unit decisions, such as managing common areas, are often made by a homeowner's association (HOA) governing board. Sometimes the owner of a condominium unit may choose to live elsewhere and rent out their unit.

For renters, the investment motivation is weak or nonexistent because they are unlikely to invest a significant sum of money in immobile equipment that they would leave behind upon moving. Moreover, apartment owners and management groups may not view EVSE as an amenity by which to attract tenants. Alternatively, condominium owners are likely to view the EVSE as a property improvement positively affecting the potential resale value of their unit, although a significant installation may require approval by the HOA.

MUD ownership also determines who is responsible for managing common-area amenities, including any 110/120-volt outlets in the parking area. In an apartment building, such outlets, which can provide Level 1 charging if there is sufficient electrical capacity, are often connected to the house panel. The house panel controls the electrical supply for all shared appliances (such as laundry machines and pool pumps) and common-area amenities. Renters should seek approval from the property owner to consume electricity when the parking area electrical outlets are connected to the house panel (see **Chapter 4** for more information about the electrical configuration of MUDs).

Figure 2.5 presents the spatial distribution of MUDs by ownership type across the Westside Cities subregion. Most of the MUDs in the region are apartment buildings. However, a number of condominium buildings can be found across the subregion, particularly in the Westwood Area, the western portion of West Hollywood, and the northern portion of Santa Monica.

Figure 2.5: MUD Buildings by Ownership Type Across the Westside Cities Subregion



Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 2.5 shows the number of MUD units in apartment buildings and condominiums across the Westside Cities Subregion. Apartment units comprise about 79% of the MUD housing stock. Of all the cities in the study region, Culver City has the greatest percentage of condominium units (approximately 41% of total units).

Table 2.5: MUD Units by Ownership Type across the Westside Cities Subregion

City	Apartment Units	Condominium Units	Total Units
Beverly Hills	8,236	2,215	10,451
Culver City	6,335	4,439	10,774
Santa Monica	32,031	9,134	41,165
West Hollywood	17,990	5,376	23,366
West Los Angeles	135,798	31,900	167,698
Unincorporated	421	1	422
Total	**200,811**	**53,065**	**253,876**
% of Total	**79.1%**	**20.9%**	**100%**

Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

2.6 MUD Presence in Disadvantaged Communities

The Westside Cities subregion includes 15 census tracts that are classified as disadvantaged communities by the California Office of Environmental Health Hazard Assessment's CalEnviroScreen 2.0 screening tool. Disadvantaged communities are defined using a series of environmental, health and socioeconomic criterion, with the purpose of identifying areas disproportionately burdened by, and vulnerable to, multiple sources of pollution.[9]

Understanding the presence of disadvantaged communities within Westside Cities Subregion is important for PEV planning efforts. These communities tend to face significant financial barriers to transitioning from conventional gasoline vehicles to PEVs. To address this challenge, the California Air Resources Board (CARB) has launched a number of initiatives under its Low Carbon Transportation Program aimed at expanding PEV adoption among low- and moderate-income households. An example is the Enhanced Fleet Modernization (EFMP) Plus-Up Pilot Program, which provides significant financial assistance to low-income households in the Greater Los Angeles area and the San Joaquin Valley who scrap their old high-polluting car and replace it with a more fuel-efficient vehicle. When purchasing a PEV, low-income participants can receive $9,500 to buy or lease a new plug-in hybrid electric vehicle (PHEV) plus a $1,500 Clean Vehicle Rebate Program (CVRP) rebate, for a total of $11,000 in assistance. For a new battery electric vehicle (BEV), the rebate is $9,500 plus the $2,500 CVRP rebate, for a total of $12,000. In addition, individuals who purchase a BEV are eligible for up to $2,000 for a charging unit. To qualify, the resident must live in a zip code that includes a disadvantaged community census tract.[10]

Additionally, Southern California Edison's Charge Ready program, which aims to install up to 1,500 charging stations at parking sites where dwell times exceed four hours or longer-term parking sites including MUDs, will target at least 10% of its deployment within disadvantaged communities.[11]

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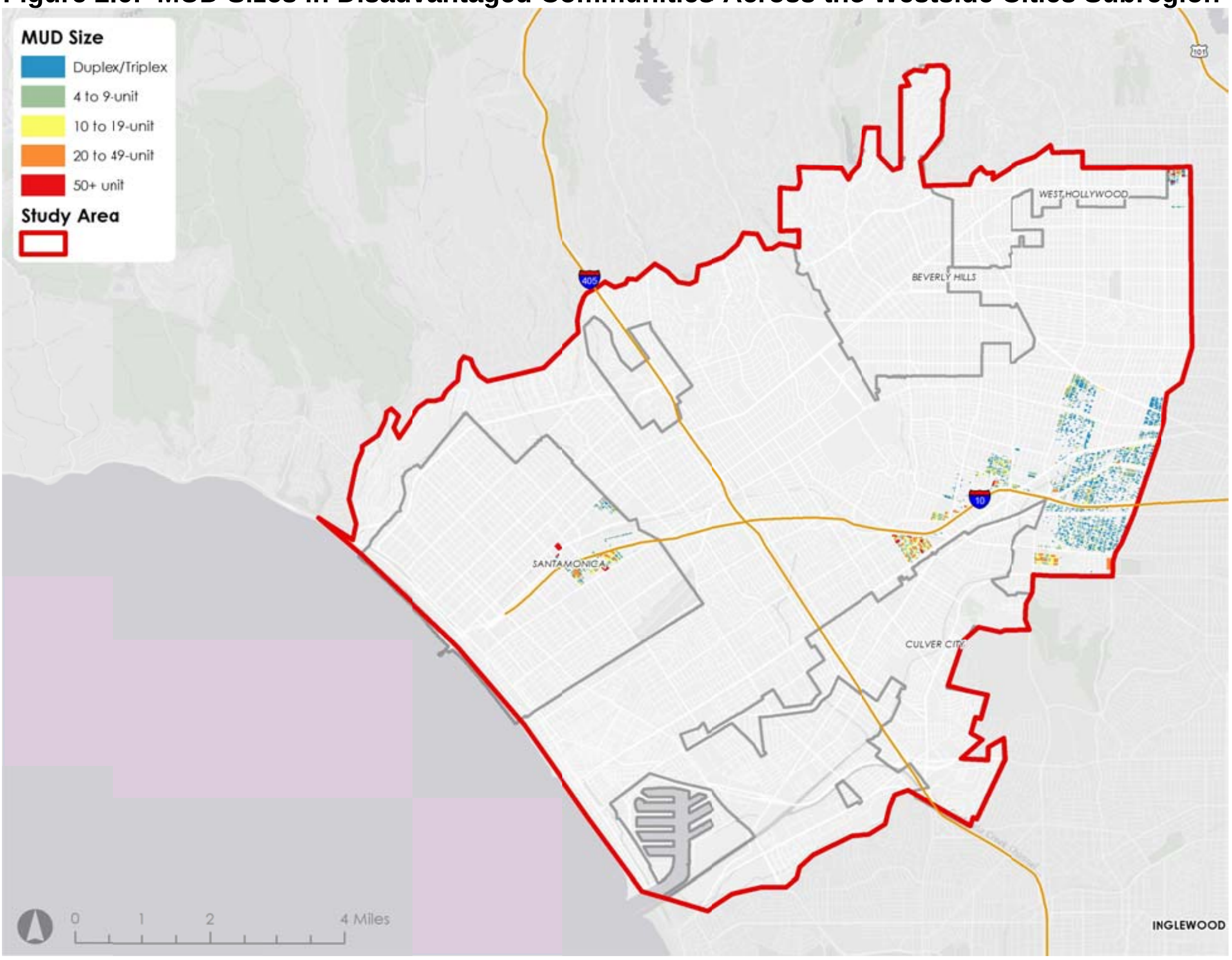
[9] California Office of Environmental Health Hazard Assessment. 2014. *CalEnviroScreen Version 2.0.* Accessed August 2017 from http://oehha.ca.gov/ej/ces2.html

[10] California Air Resources Board. 2015. "Making the Cleanest Cars Affordable." http://www.arb.ca.gov/newsrel/efmp_plus_up.pdf

[11] Southern California Edison. "Charge Ready: A Plan for California." Accessed August 2017 from http://www.edison.com/home/our-perspective/charge-ready-a-plan-for-california.html

Figure 2.6 provides an overview of the MUD building stock in disadvantaged communities across the Westside Cities subregion. Only Santa Monica and West Los Angeles are home to MUDs located in disadvantaged communities, with a much larger share located in West Los Angeles along Interstate 10. The majority of these MUDs are also smaller in scale (i.e., duplexes and triplexes).

Figure 2.6: MUD Sizes in Disadvantaged Communities Across the Westside Cities Subregion



Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 2.6.1 provides the number of MUD units in disadvantaged communities across the Westside Cities subregion. Only Santa Monica and West Los Angeles have MUDs in disadvantaged communities, totaling 16,500 MUD units, or about 6.5% of the total MUD units in the region (i.e., 253,876 total housing units).

Table 2.6.1: Total MUD Units in Disadvantaged Communities for Westside Cities

City	Number of Units	% of Total Units
Beverly Hills	0	0%
Culver City	0	0%
Santa Monica	2,482	6.0%
West Hollywood	0	0%
West Los Angeles	14,013	8.4%
Unincorporated	0	0%
Total	**16,495**	**6.5%**

Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 2.6.2 shows the number of MUDs in disadvantaged communities across the Westside Cities subregion according to building size. Most are on the smaller end of the spectrum, with about 90% of them containing fewer than 10 units.

Table 2.6.2: MUDs by Size in Disadvantaged Communities for Westside Cities

City	Duplex/ Triplex	4 to 9 units	10 to 19 units	20 to 49 units	50+ units	Total
Beverly Hills	0	0	0	0	0	0
Culver City	0	0	0	0	0	0
Santa Monica	74	158	29	16	6	283
West Hollywood	0	0	0	0	0	0
West Los Angeles	1,555	1,043	177	64	10	2,849
Unincorporated	0	0	0	0	0	0
Total	**1,629**	**1,201**	**206**	**80**	**16**	**3,132**
% of Total	**52.0%**	**38.3%**	**6.6%**	**2.6%**	**0.5%**	**100%**

Source: Los Angeles County Office of the Assessor Secured Basic Abstract File

CHAPTER 3: PEV Demand in the Westside Cities

This chapter provides an overview of where PEV demand in the Westside Cities subregion has historically been the greatest and where demand is expected to be the greatest among multi-unit dwellings (MUD) residents. The latter is calculated using a propensity-to-purchase score that estimates PEV demand as a function of historical PEV adoption trends as well as income level and MUD per unit value (see **Chapter 1.3** for a summary of methods). Subregional and municipal governments and other interested stakeholders should use this chapter to prioritize neighborhood outreach or organize other planning efforts (see **Chapter 5** for more detail on outreach strategies).

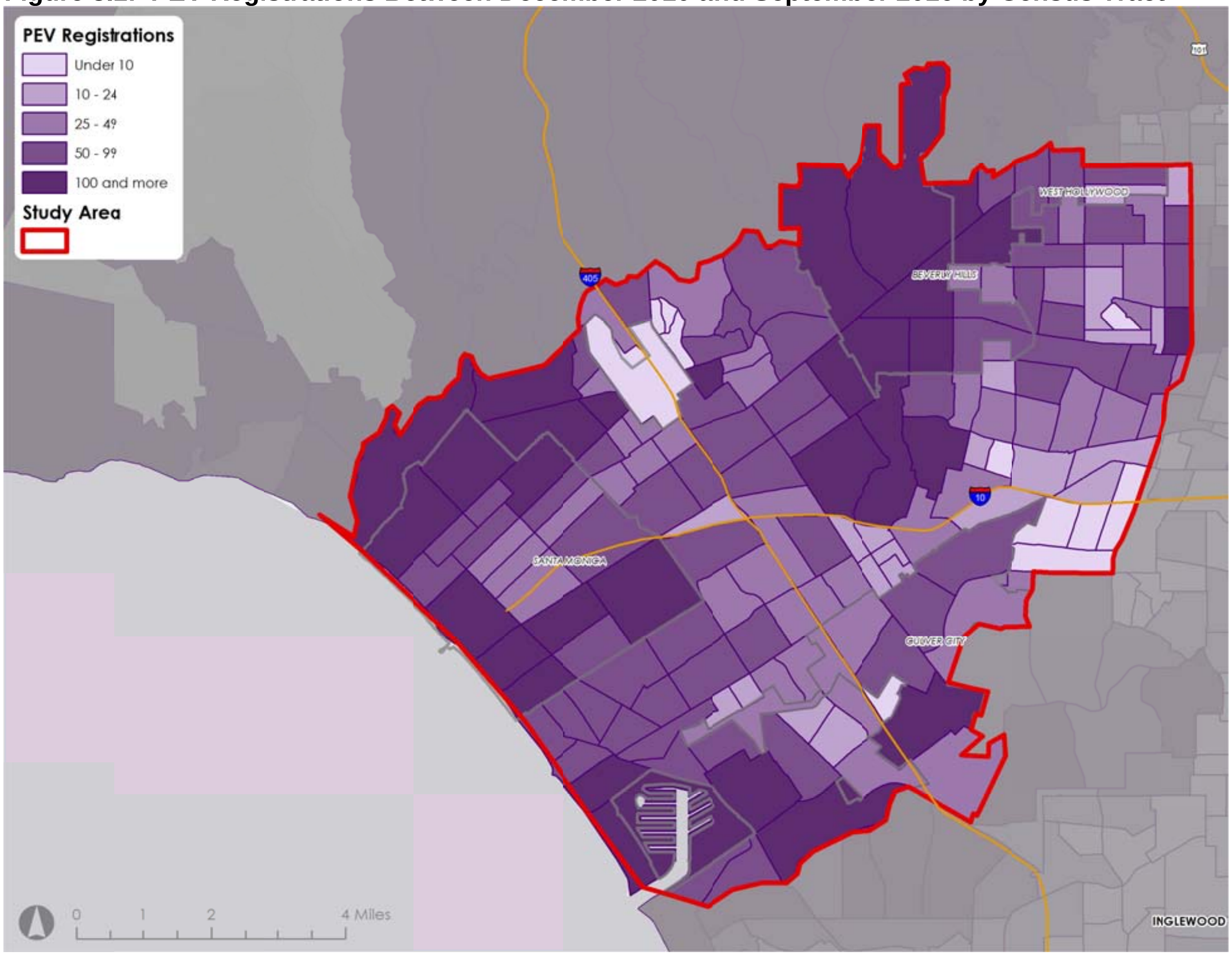
Photo Credit: City of Santa Monica

3.1 Historic PEV Demand

Knowing how many PEVs are registered in a given area helps determine the location of current and near-future demand for residential charging. By extension, this information can help planners and utilities anticipate locations likely to carry additional nighttime electrical load.

Figure 3.1 provides an overview of the cumulative number of new PEV registrations between December 2010 and September 2016 by census tract across the Westside Cities subregion. Consistent with statewide trends, early PEV drivers tend to be higher-income households. As such, Beverly Hills, the Pacific Palisades, and Brentwood are all home to a number of census tracts containing more than 100 PEV registrations. These neighborhoods are also home to a larger share of single-family residences, as seen in **Figure 2.1**. As more moderate-income households begin to view the PEV as a viable transportation option, and as prices of battery technologies continue to come down, adoption will spread beyond wealthier census tracts.

Figure 3.1: PEV Registrations Between December 2010 and September 2016 by Census Tract



Source: IHS Automotive, California Department of Transportation

Table 3.1 shows the number of PEV registrations across the Westside Cities subregion. West Los Angeles has the greatest number of PEVs, while Beverly Hill has the highest PEV purchase rate per 100 residents over the study period. BEVs are slightly more popular than PHEVs across the region, except for portions of unincorporated Los Angeles County.

Table 3.1 PEV Adoption for the Westside Cities Subregion

City	PEV Registrations (December 2010–September 2016)	% BEV	% PHEV	Population	PEVs per 100 Residents
Beverly Hills	932	64.9%	35.1%	30,89	3.0
Culver City	481	47.8%	52.2%	33,902	1.4
Santa Monica	1,929	57.8%	42.2%	92,169	2.1
West Hollywood	504	55.2%	44.8%	35,332	1.4
West Los Angeles	6,368	55.3%	44.7%	465,409	1.4
Unincorporated	205	45.9%	54.1%	10,277	2.0
Total	**10,419**	**56.1%**	**43.9%**	**667,891**	**1.6**

Source: IHS Automotive; Los Angeles County Office of the Assessor Secured Basic Abstract File; U.S. Census Bureau, 2011–2015 American Community Survey 5-Year Estimates

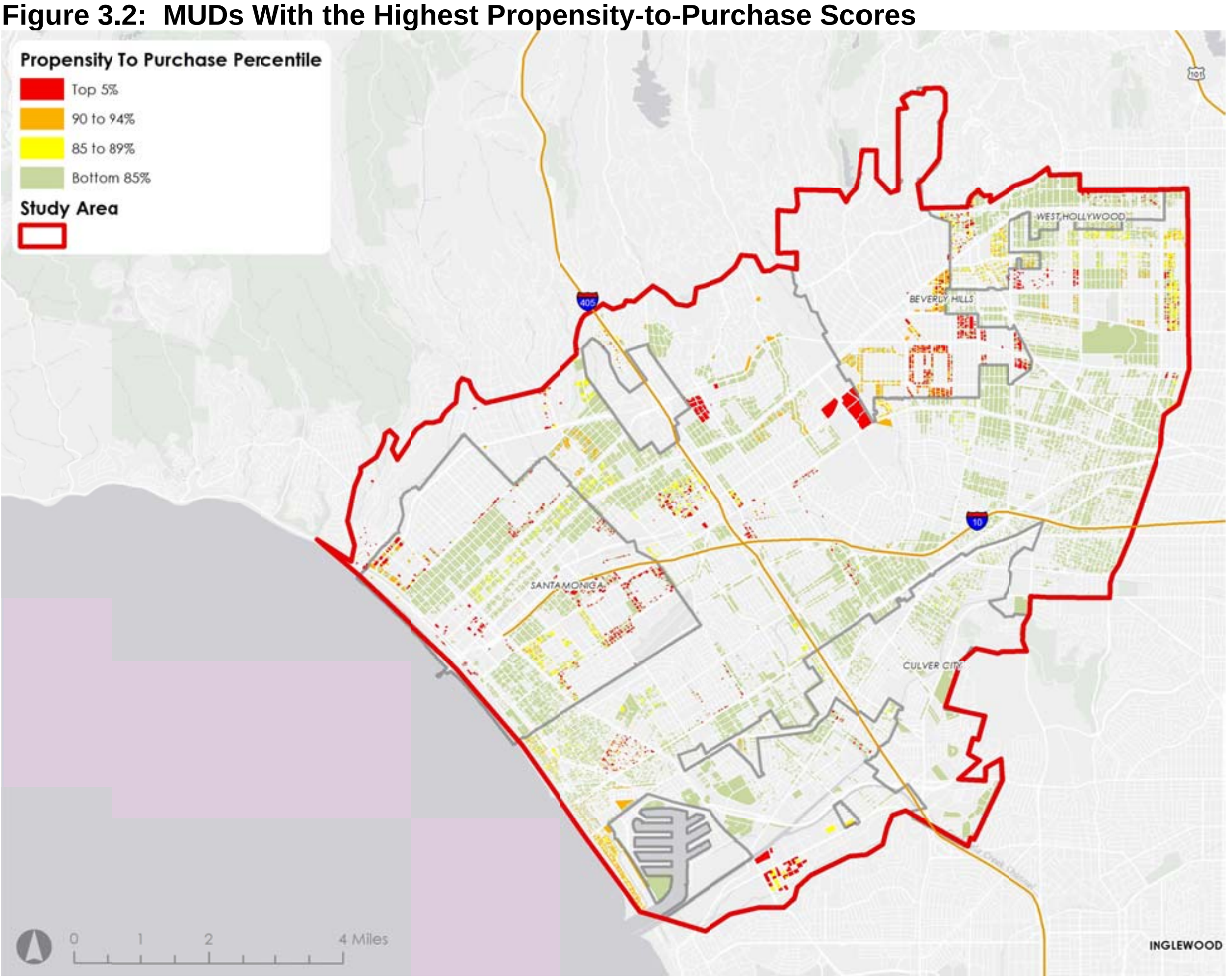
3.2 Latent PEV Demand within MUD Parcels

Census tracts with high PEV adoption and a high share of MUDs may be areas with high latent PEV demand. If MUD residents here do not have access to home charging, it is likely that the MUD is serving as a constraint to these census tracts' full PEV adoption potential.

To identify and prioritize the MUD households with high latent PEV demand, we calculated a propensity-to-purchase score for each MUD parcel in the Westside Cities subregion. The score accounts for the historical adoption rate of PEVs in each census tract, the distribution of PEV sales among households at different income brackets, and the probability of a household with a certain income level living in a home with a given value. Considering that a large share of PEVs are purchased by high-income individuals who are likely to live in high-value homes, the propensity-to-purchase score model allocates a greater score to high-value homes. Refer to **Appendix 1** for an overview of how the propensity-to-purchase model was constructed.

Figure 3.2 presents the distribution of MUDs with the highest propensity-to-purchase scores across the Westside Cities subregion. Since Beverly Hills has a high adoption rate of PEVs, and is home to a number of high-income households, it has a disproportionate share of MUDs with high propensity-to-purchase scores.

Figure 3.2: MUDs With the Highest Propensity-to-Purchase Scores



Source: IHS Automotive, Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 3.2 summarizes the number of MUDs with the highest propensity-to-purchase scores across the Westside Cities subregion. About 61% of the MUDs in Beverly Hills fall within the top 15th percentile of propensity-to-purchase scores for the region. In contrast, only 1% of the MUDs in Culver City fall within the top 15th percentile of propensity-to-purchase scores. West Los Angeles is home to the greatest number of MUDs in the top 15th percentile of propensity-to-purchase scores (2,388 of 4,506), which is a consequence of the region's size, since most of the MUDs in the region do not have high propensity-to-purchase scores. Only 7% of the MUDs in West Los Angeles fall within the top 15th percentile of propensity-to-purchase scores.

Table 3.2: MUDs With the Top Propensity-to-Purchase Scores Across the Westside Cities

City	Total MUDs	Bottom 85%	Top 15%	Top 10%	Top 5%
Beverly Hills	1,273	421	852	777	421
Culver City	1,763	1,702	61	17	0
Santa Monica	5,016	4,217	799	508	415
West Hollywood	2,264	1,861	403	249	104
West Los Angeles	20,267	17,879	2,388	1,442	581
Unincorporated	7	4	3	2	2
Total	**30,590**	**26,084**	**4,506**	**2,995**	**1,523**

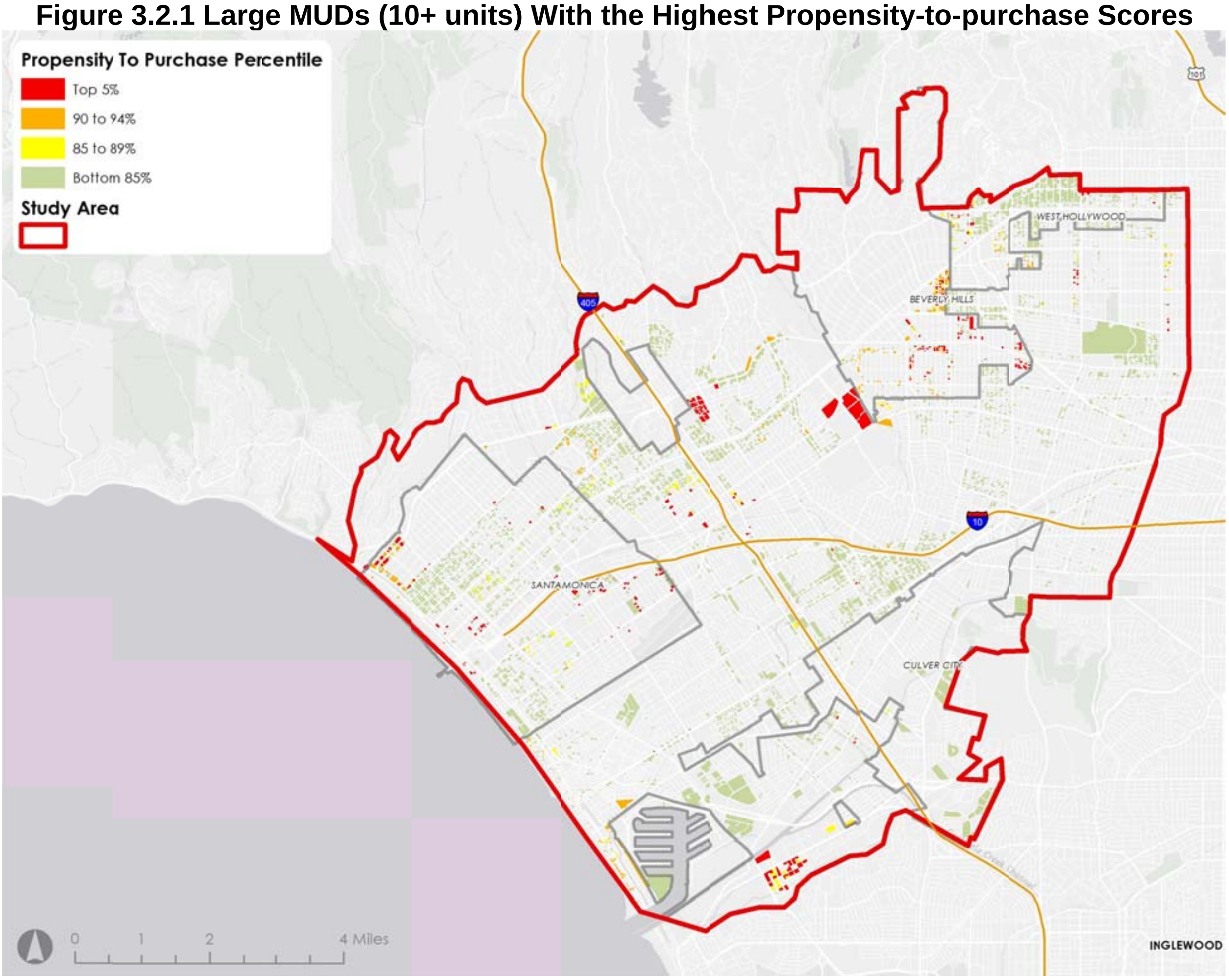
Source: IHS Automotive, Los Angeles County Office of the Assessor Secured Basic Abstract File

3.2.1 Latent PEV Demand for Large MUDs

There may be significant advantages to installing multiple EVSE and sharing installation costs among PEV drivers. Additionally, Southern California Edison's (SCE) Charge Ready program requires a minimum of 10 EVSEs per site (or five EVSEs for sites in disadvantaged communities). Thus, large MUDs serve as prime candidates for outreach programs aimed at increasing PEV adoption and promoting the potential cost savings to group investment in EVSE installation.

Figure 3.2.1 presents the distribution of large MUDs (i.e., more than 10 units) with the highest propensity-to-purchase scores across the Westside Cities subregion. Again, Beverly Hills has a disproportionate share of large MUDs (10+ units) with high propensity-to-purchase scores because of its high adoption rate of PEVs and its population of high-income households.

Figure 3.2.1 Large MUDs (10+ units) With the Highest Propensity-to-purchase Scores



Source: IHS Automotive, Los Angeles County Office of the Assessor Secured Basic Abstract File

Table 3.2.1 summarizes the number of large MUDs (i.e., more than 10 units) with the highest propensity-to-purchase scores across the Westside Cities subregion. About 70% of the large MUDs in Beverly Hills fall within the top 15th percentile of propensity-to-purchase scores for the region. In contrast, 0% of the large MUDs in Culver City fall within the top 15th percentile of propensity-to-purchase scores. West Los Angeles is home to the greatest number of large MUDs in the top 15th percentile of propensity-to-purchase scores (357 of 788), which again, is a consequence of the region's size, since most of the large MUDs in the region do not have high propensity-to-purchase scores. Only 10% of the MUDs in West Los Angeles fall within the top 15th percentile of propensity-to-purchase scores.

Table 3.2.1: Large MUDs (10+ units) with the Highest Propensity-to-Purchase Scores

City	Total MUDs (10+ Units)	Bottom 85%	Top 15%	Top 10%	Top 5%
Beverly Hills	289	87	202	177	98
Culver City	115	115	0	0	0
Santa Monica	1,163	994	169	111	90
West Hollywood	779	720	59	39	20
West Los Angeles	3,708	3,351	357	221	125
Unincorporated	3	2	1	0	0
Total	**6,057**	**5,269**	**788**	**548**	**333**

Source: IHS Automotive, Los Angeles County Office of the Assessor Secured Basic Abstract File

CHAPTER 4: The Cost of Installing Charging Infrastructure in MUDs

In place of a 15-minute detour to a gas station, most PEV owners refuel when they are at home and their PEVs are plugged-in throughout the night. To charge PEVs at home, drivers generally choose a Level 1 or 2 charger, depending on charging preference, recharging needs, and cost of installation. Level 1 charging requires a 110/120-volt outlet, the standard 3-prong plug that is already available in many parking layouts. It requires 15 amps of continuous load to charge 4–6 miles per hour. Seventy-eight percent of PEV drivers average 15 to 45 miles of driving per day, which can be satisfied with 3 to 8 hours of Level 1 charging.[12] Level 2 charging units charge PEVs at a much faster rate of 8–24 miles per hour, but they require a 208/240-volt outlet.

For single-family homeowners, home charging is generally an easily available amenity. Single-family homes tend to have sufficient electrical capacity to support overnight charging, and the installation of the necessary electric vehicle supply equipment (EVSE) is straightforward and has a predictable cost. The same cannot be said for PEV home charging at MUDs. The cost of installing EVSE in a MUD parking environment varies greatly from site to site and can quickly become a barrier. To begin, all PEV drivers need EVSE equipment for plugging their vehicle into an electrical outlet (covered in **Section 4.1**). Once the desired EVSE unit is obtained, proper wiring and conduit is needed to connect the charging outlet to the electric panel at the MUD (covered in **Section 4.2**). If the panel cannot produce adequate electricity and/or the utility service is not providing enough electricity to the property, then panel and/or service upgrades will be necessary (covered in **Section 4.3**).

See **Figure 4.1** for an overview of the various costs at the different stages of EVSE installation for a single charging unit. Depending on the electrical configuration of a given MUD, not all stages may be relevant. It's worth emphasizing that the ranges provided below are ballpark estimates and do not reflect the absolute lower or upper limit of installation costs at each stage, especially considering the variation in electrical configurations among MUDs, and the variation in charging preferences among PEV drivers (i.e., Level 1 or Level 2 charging).

Figure 4.1: Potential Costs at the Different Stages of EVSE Installation at MUD Locations

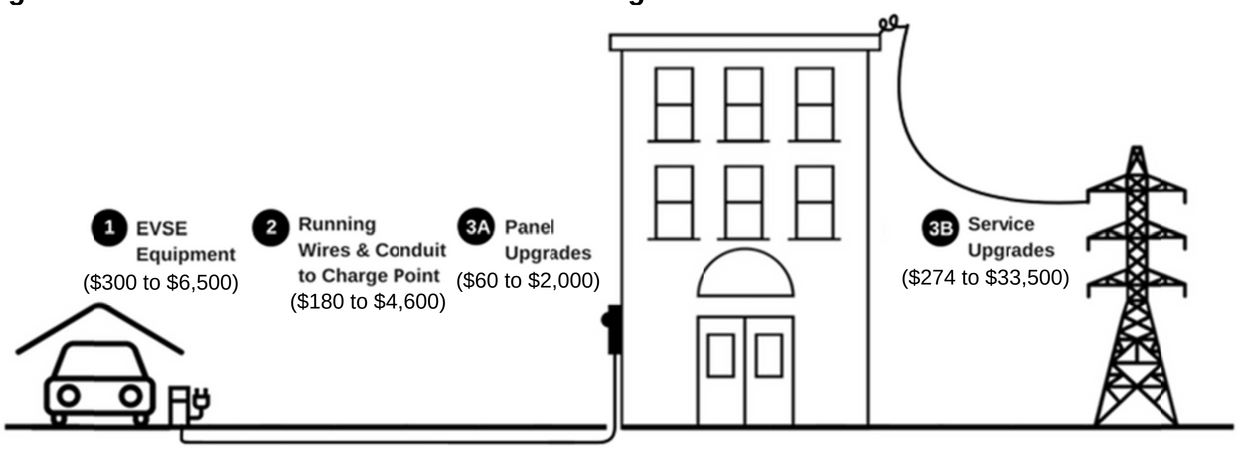


Image Source: Noun Project; car by Tracy Tam; electric equipment by Prosymbols; building by Nicholas Menghini; pylon by Arthur Shlain.

[12] Center for Sustainable Energy. *California Plug-in Electric Vehicle Driver Survey Results – May 2013.*

Background on the Electrical Configuration of Multi-Unit Dwellings

The electrical configuration of an MUD is complex. Utilities distribute power to each property's electric meter through either an overhead service drop or an underground service connection. An overhead drop often comes from a utility pole to the roof of the property and down to the meter section or to the electric box. Underground service connections come from a pull section or pull box — an underground compartment that serves as the main termination point for the utility feed. The connection is then run up to the MUD's electric box. Alternatively, an underground service connection can run down a utility pole, be tunneled underground, and then resurfaced at the property's electric box.

Inside the electric box is the property's meter section, which includes the house and unit meters as well as the main breakers (pictured in **Figure 4.2**). Each residential unit has its own meter and main breaker. Power is distributed from the meter section to a panel located in each unit, or the **unit panel**, where circuit breakers safely manage each unit's electric load. The house meter(s) and main breaker(s) distribute power to a **house panel(s),** which then provides electricity to common areas and general electrical loads such as parking outlets, laundry machines, pool pumps, electric water heaters, and more. The house panel can be located in the electric box or in another common space.

Figure 4.2: Photos of Overhead Service Drops and Meters at MUDs

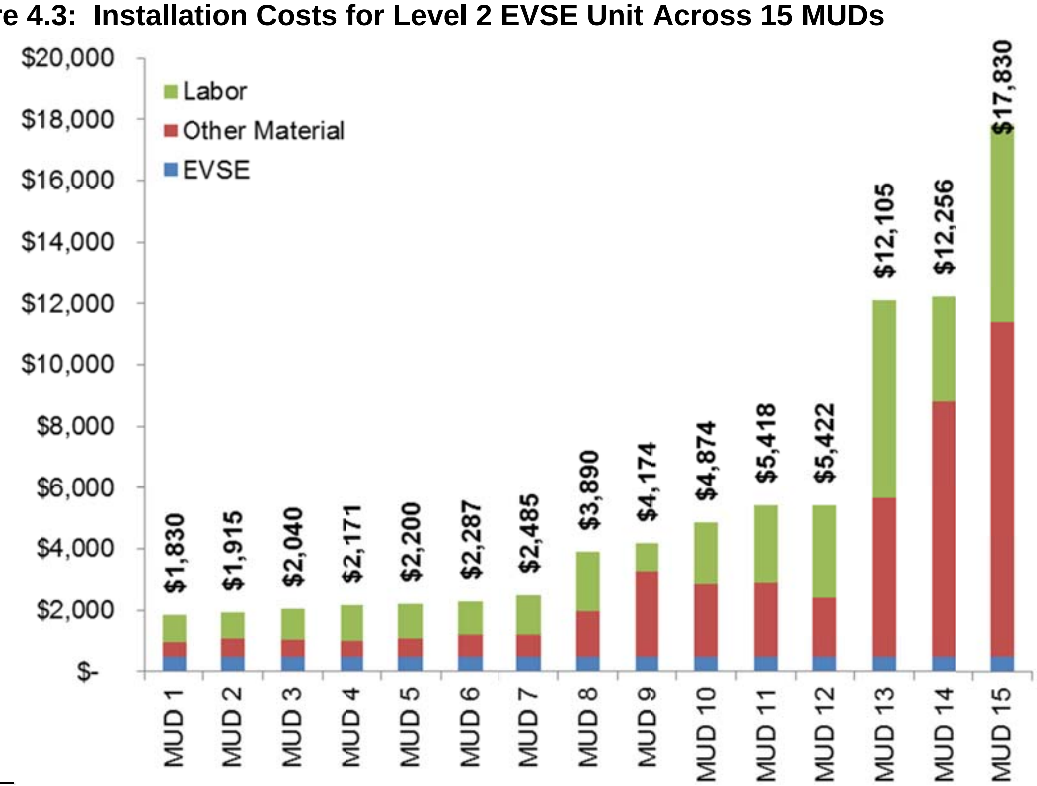
Two examples of overhead service drops providing electricity to the MUD's electric box (Photo credit: UCLA Luskin Center).

A cluster of house and unit meters (i.e. ,the meter section) and their main breakers inside an electric box (Photo credit: UCLA Luskin Center).

Case Study Findings
This chapter reviews findings from the 2016 report *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study,* in which cost estimates were developed for installing charging infrastructure at sample MUD sites in the South Bay.[13] The estimates were developed by a qualified electrician who considered the following: electrical configuration of MUDs, necessary panel and service upgrades, and opportunities for savings. Researchers requested 30 MUD site visits to assess Level 1 and Level 2 charge readiness, and to estimate the cost of installing a single Level 2 EVSE unit. From the 30 selected sites, a total of 27 sites were actually visited, and a total of 15 complete cost estimates were obtained.[14] Based on these 15 cost estimates, the electrician estimated Level 2 EVSE installation costs ranging from $1,800 to $17,800 per site, with an average of $5,400 per site (including the cost of any panel upgrades, but not including the cost of service capacity upgrades). In contrast, Level 2 installation costs for single-family residences average $1,500.[15]

The most significant component of installation costs across the 15 estimates was labor, which on average was 45% of the total project cost. Materials (other than EVSE) were the second-greatest cost, comprising 40% of total project costs on average. A constant price of $480 was assumed for EVSE across all estimates, comprising about 15% of the total project cost on average. See **Figure 4.3** for installation costs across the15 sample estimates.

Figure 4.3: Installation Costs for Level 2 EVSE Unit Across 15 MUDs



[13] UCLA Luskin Center for Innovation. 2016. *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study.*

[14] Complete cost estimates were not obtained for all 30 properties because some property owners were unable to be found, were not interested in participating in the study, or were unable to provide permission to determine the electrical service being provided to the MUD, which is necessary for determining whether the MUD receives enough power to provide Level 2 charging for one or more vehicles.

[15] Electric Power Research Institute. 2013. *Electric Vehicle Supply Equipment Installed Cost Analysis.* Accessed August 2017 from https://www.epri.com/#/pages/product/000000003002000577/

Savings Opportunities

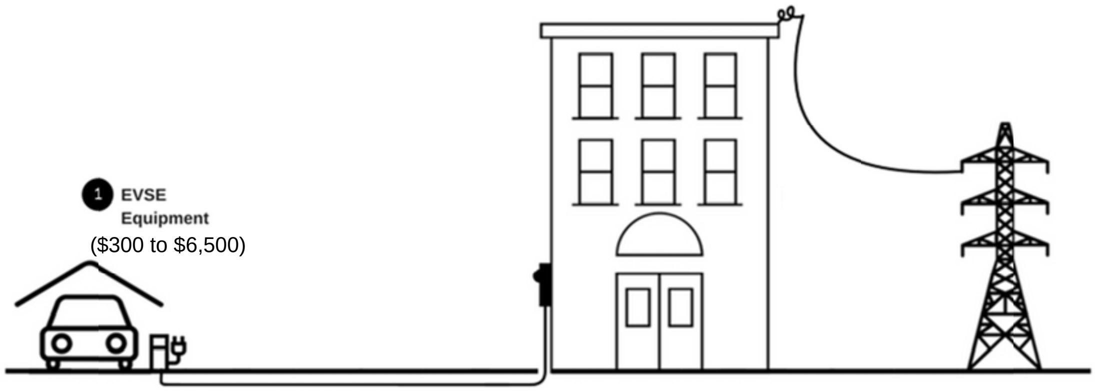
Although the estimated installation costs were high in this exercise, some potential cost-reduction strategies emerged. These costs savings are detailed in **Section 4.4** and summarized below:

- Using Level 1 charging, particularly in dingbat parking lots (see **Figure 4.4**).
- Sharing EVSE installation costs across multiple PEV drivers.
- Identifying parking layouts and electrical configurations that lend themselves to lower-cost Level 2 charging infrastructure installation (e.g., parking spots close to existing electrical outlets).

Figure 4.4: Dingbat Parking Layouts With Medium to High Probability of Electrical Outlet Access

Photo credit: UCLA Luskin Center

4.1. Electric Vehicle Supply Equipment



Level 1 and Level 2 Electric Vehicle Supply Equipment (EVSE) provides alternating current power — the typical power supplied to residences and business — to the PEV's onboard charging equipment, which then converts it into direct current power for battery charging. Level 1 EVSE can supply up to 120 volts of power, or six miles per hour, while Level 2 EVSE can supply up 240 volts, or 60 miles per hour. Level 1 EVSE can typically be directly plugged into any common outlet as long as there is enough available power supply at the panel level. Level 1 EVSE typically comes at the point of PEV purchase and is the cheapest option. Level 1 EVSE can range from $300 to $1,500, while Level 2 EVSE can range from $400 to $6,500, depending on the included features and whether the unit is mounted on a wall or a freestanding pedestal.[16] See **Figure 4.5** for sample photos of EVSE at each charging level.

Figure 4.5: Examples of Level 1 and Level 2 Charging EVSE

Level 1 Charging Example

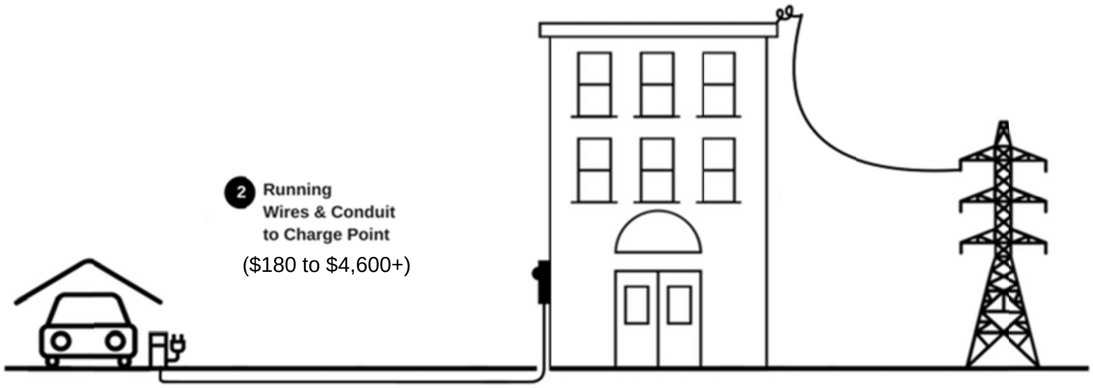
Source: Voltrek

Level 2 Charging Example

Source: Clipper Creek

[16] U.S. Department of Energy. 2015. *Costs Associated with Non-Residential Electric Vehicle Supply Equipment.* Accessed August 2017 from https://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf

4.2 Running Wires and Conduit to Charge Point



To provide electricity to EVSE equipment, an electrician may need to run wires from the electrical panel to the PEV charge point. If the panel is close to the EVSE location, the installation process can be straightforward. As the length between the panel and the EVSE site extends however, additional costs can arise from materials, labor, and construction activities like trenching through concrete or asphalt. In MUDs where parking areas represent a significant structural feature (e.g., subterranean garages), EVSE installation may require engineering tests like x-raying concrete to ensure structural integrity.

Soft costs include permitting and inspection fees, tool rentals for construction or engineering activities, taxes on the materials purchased, and contractor fees. Labor is often the most significant cost component of project installation and can vary depending on the contractor's experience, trade union membership, and the complexity of the job. The cost of tool rentals will be related to the materials and type of labor required and will vary greatly from project to project. Taxes on materials vary by state and profits vary by the company contracted for labor.

Permits, inspection requirements, and associated fees vary by city and by county. The installation of EVSE and any corresponding electrical upgrade will likely require engineering drawings that must be reviewed by the responsible agency, such as a Department of Building and Safety. Requirements for engineering drawings can vary and may require electrical load studies of the property.

Once there is sufficient electrical capacity to perform PEV charging, a contractor needs to run conduit and wire from the relevant panel to the PEV parking spot, overcoming any physical barriers that might arise. The cost of connecting charging infrastructure to the building's electrical system varies from site to site. The strongest predictor of costs is the distance between the panel with the EVSE-dedicated circuit and the PEV parking spot.

EVSE installations that traverse long distances not only require greater lengths of conduit and wiring but also increase the likelihood of requiring significant construction and engineering activities. For MUD sites where the PEV parking spot was 100 feet or greater from the relevant electrical panel, these additional construction and engineering activities accounted for $180 to $4,600 in material and labor, comprising 5% to 48% of total material and labor costs.[17]

[17] UCLA Luskin Center for Innovation. 2016. *Overcoming Barriers to Electric Vehicle Charging in Multi-Unit Dwellings: A South Bay Case Study.*

4.3 Upgrading Electrical Panel and Utility Service

Sometimes the installation of a Level 1 and Level 2 EVSE will require additional electrical capacity. Electrical upgrades can occur in two ways within an MUD's electrical configuration:

A. Adding capacity to the unit or house panel, and/or

B. Upgrading electric service capacity to the MUD from the utility.

These upgrades should be made in consultation with an electrician, or ideally, an electrical engineer. An electrical engineer can provide an installation quote that looks holistically at the overall energy supply and demand of a building, and make recommendations for reducing the building's electrical load. Load reduction efforts may allow residents to use the building's existing electricity supply to access Level 1 charging (see **Section 4.4** for more information).

The following section reviews costs associated with upgrading MUD panel capacity and utility service. It provides utility-specific information from Southern California Edison (SCE) Electric Service Requirements and other SCE Guidelines, plus observations made during site visits at 27 different MUDs across the South Bay with a qualified electrician.

A. Adding Electrical Capacity to the Unit or House Panel

Level 1 charging requires a dedicated 20-amp breaker rated for continuous use. In many instances, 110/120-volt outlets are available in the parking area and receive electricity from a 15- or 20-amp breaker on the house panel. The amount of available capacity often depends on the other loads tied to that panel, such as electricity needed for common areas. A confluence of loads on the same house panel may trip the main breaker — a safety response that shuts down service to all loads sharing the panel.

To assess the feasibility of Level 1 charging, the resident, property manager, or owner, and an electrician or electrical engineer should review the annual peak load of the house panel to determine if there is available capacity. This information is often available from an individual's electric utility at the request of the person named on the bill.

Level 2 charging requires a dedicated 40-amp circuit. If there is sufficient capacity and breaker space on the panel, then an electrician can simply add breakers to the panel to create the necessary dedicated circuits.

When there is insufficient capacity or space on the panel for a dedicated circuit, an electrician must create additional capacity in one of the following ways:

a. **Upgrade to a new panel.**
   A panel upgrade replaces the existing panel (e.g., 50-amp) with one that has additional breaker space or greater capacity (e.g., 100-amp).
   Cost estimate: $1,000 or more for a panel upgrade with new breakers

b. **Reconfigure the current panel to provide more breaker space.**
   Electricians can reconfigure the breakers on the existing panel to free up space for additional breakers. For example, a tandem circuit breaker allows for two circuits to be installed in one circuit breaker space.
   Cost estimate: $60 to $500, depending on panel breaker's type, size and age

c. **Add a subpanel for the EVSE unit.**
   Electricians may also install a subpanel. Electricians can, for example, replace multiple breakers with a tandem circuit breaker and run a wire from it to the new subpanel. The result is a subpanel with space for multiple breakers, including a dedicated one for Level 2 charging.
   Cost estimate: $500 to $2,000, depending on distance between panel and subpanel, and the number and type of breakers

d. **Add a separate panel from the existing service.**
   An electrician can add a separate panel with a dedicated service for PEV charging. This requires a newly installed panel to connect to the current service drop or connection (sometimes called "tapping into" or "tapping off"). The resident and property manager or owner and an electrician should work with their local utility to ensure they follow all electrical service guidelines.
   Cost estimate: $1,000 or more to install a new dedicated panel and to connect to existing service, depending on the space available for the panel and the distance between the new panel and the service connection.

For Level 1 charging, 78% of the sites we visited had access to 110/120-volt outlets in the parking environment. Depending on the parking layout, outlets were either scattered randomly throughout the parking environment or were available at each individual parking spot. Of these sites, 96% of the 110/120-volt outlets were connected to a 15- or 20-amp circuit on the house panel. Without permission to review the annual peak load, it was unclear whether there was sufficient capacity on the house panels for Level 1 charging.

For Level 2 charging, 93% of the sites visited did not have sufficient panel capacity or breaker space and would require upgrades. At these sites, additional capacity would need to be added through the one of the four options described above (i.e., a panel upgrade, a reconfiguration of panel breakers, the installation of a subpanel, or the installation of a new dedicated panel that is connected to the existing service).

Before an electrician can make any panel adjustments, a utility representative must visit the site to review the installation plan and provide electrical code instructions. Any electrical upgrade that requires utility approval will also require bringing the property up to Electrical Service Requirement code. For example, SCE requires flat ground below meters have three feet of clear working space in front of them so that staff can easily and safely access and read meters. If the current panel is not up to the utility's standards or there is no space for an additional panel, the electrician may be required to move the entire meter section, which would increase costs.

B. Upgrading Electric Service Capacity to the MUD from the Utility

To add capacity at the panel level for EVSE, the property must receive enough power from the utility to support the added load. If there is insufficient power, tenants or owners must apply for a utility service upgrade to replace service wires fed to the MUD and/or upgrade distribution lines (e.g. replacing or upgrading the transformer).

Adding capacity at the panel level may require upgrading the MUD's utility service. Service upgrades may be more likely when the MUD is located at the end of the utility's electrical lines served by a substation or in urban areas where building density has already maximized the electric service capacity.[18] To accommodate additional capacity, the utility may need to perform service line and/or distribution line upgrades.

For these types of upgrades, SCE is "responsible for the cost of the service connector, connectors, support poles, and metering."[19] These costs are covered by a residential allowance and any amount over the allowance is billed to the customer. The customer is "responsible for any trenching, conduit, substructures, or protective structures required for the upgrade. These costs are not covered by the allowance."[20]

Within SCE territory, if the service capacity from an overhead drop increases to over 200 amps, the customer is responsible for burying the overhead feed underground.[21] This likely will require costly construction activities, including trenching and the demolition of concrete. Medium-sized MUDs (10–19 units) receiving electricity from an overhead drop may be at or above the 200-amp threshold and thus subject to this rule and associated costs.

Out of 9,300 on-site residential service assessments for PEV charger installations completed before November 2014, SCE required service upgrades only 26 times (0.3%).[22] The service upgrade costs ranged from $274 to $33,499, with service line upgrades averaging $2,055 and distribution line upgrades averaging $7,165.[23] It is important to note that these include a significant share of single-family households that are more likely to have sufficient capacity available. SCE also needed nine service upgrades for commercial installations, which may be more reflective of medium- and large-sized MUDs. In the event that a service upgrade is required, the applicant shall be granted an allowance of $3,402 per residential dwelling unit.[24]

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[18] California Department of Housing and Community Development. 2013. *Electric Vehicle Ready Homes*. Accessed August 2017 from http://www.hcd.ca.gov/building-standards/state-housing-law/docs/ev_readiness.pdf

[19] San Diego Gas & Electric. 2014. *Joint IOU Electric Vehicle Load Research Report.* Accessed August 2017 from http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M143/K954/143954294.PDF

[20] Ibid.

[21] Phone Interview with Southern California Edison, November 28, 2015.

[22] San Diego Gas & Electric. 2014. *Joint IOU Electric Vehicle Load Research Report.* Accessed August 2017 from http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M143/K954/143954294.PDF

[23] Ibid.

[24] Southern California Edison Tariff Books. Rule 15. Accessed August 2017 from https://www.sce.com/NR/sc3/tm2/pdf/Rule15.pdf

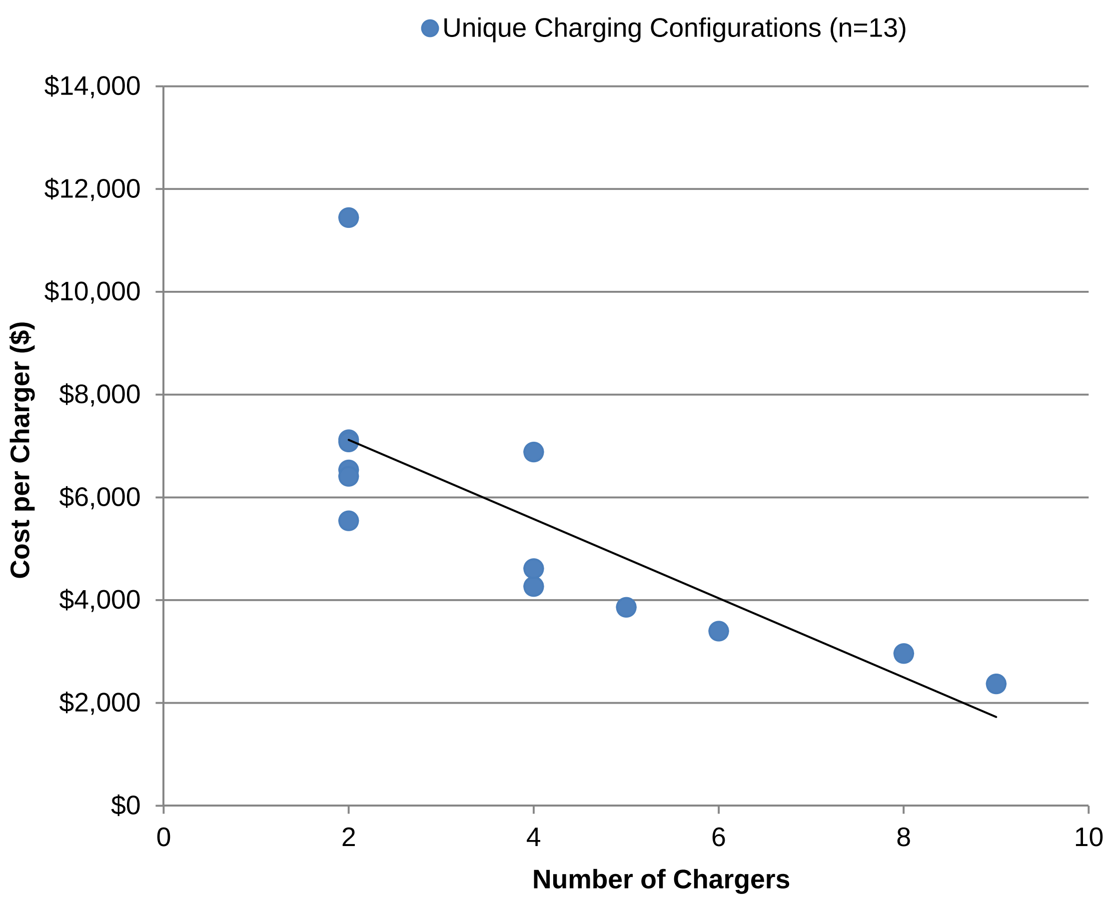
4.4 Cost-Saving Opportunities to Reduce Charging Fees

To help reduce the cost of EVSE installations at MUD sites, multiple PEV drivers at one location can split the up-front installation costs. If this isn't an option, PEV drivers can opt to rely on Level 1 charging and possibly avoid installation costs altogether. This section reviews these two cost-saving strategies.

Cost Advantages to Group Investing in Level 2 Charging Infrastructure

PEV owners can share EVSE installation costs at MUD residences. **Figure 4.6** shows the decreasing cost per added EVSE on a site, as based on 13 different potential charging configurations at eight different sample sites.[25] When considering EVSE installation, an owner or renter should survey neighbor units to gauge interest in PEV ownership and sharing of costs associated with EVSE installation.

Figure 4.6: Cost Reductions Achieved Due to Multiple EVSE Installations



Source: On Target Electric, for study purposes only

[25] UCLA Luskin Center for Innovation. 2016. *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study.*

Technological solutions can support group investments in EVSE installation. For example, energy-saving technologies such as energy management systems (EMS) can be installed to optimize multiple PEV charges. The management of energy in response to the charging needs of PEVs and the available electrical capacity of a building can delay the need for costly electrical upgrades. For example, if a building's electrical capacity can handle only one PEV charging at full capacity but there are three PEVs in the building, EMS technology can distribute power to each PEV at different times so that all three PEVs can charge overnight. This prevents the need to upgrade the electrical capacity of the building to accommodate all three PEVs.

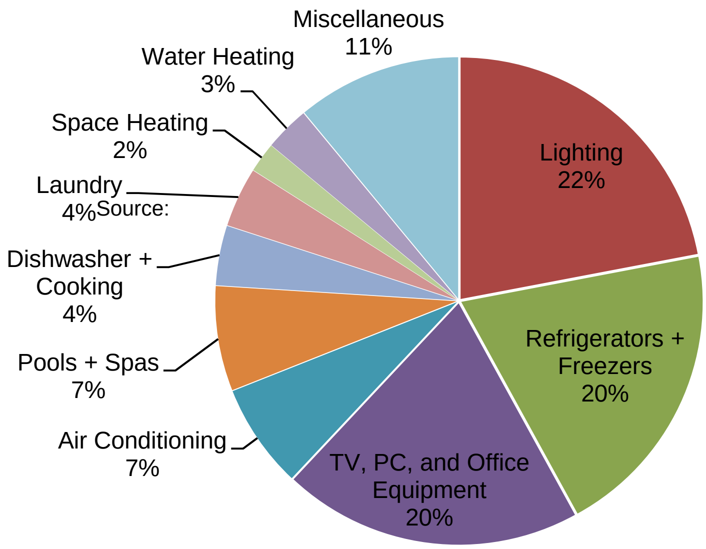
Accessing Level 1 Charging to Avoid Electrical Upgrades

Depending on a PEV driver's available charge time and daily commute, MUD parking environments with access to 110/120-volt outlets may be good candidates for Level 1 EVSE charging. The resident, property manager, or owner, along with an electrician or electrical engineer, should review the annual peak load of the house panel to determine if there is available capacity considering other loads tied to the panel, such as laundry machines, pool pumps, etc. This information is often available from the utility provider at the request of the person named on the electric bill.

If the house panel does not have sufficient capacity to accommodate Level 1 charging, strategic energy efficiency measures may be deployed to reduce the overall load of the house panel. This can include efficient lighting, or energy-efficient replacements for a property's electric water heater, washer/dryer, or pool pump. Electric utilities offer a number of rebates and incentives to improve efficiency. See **Figure 4.7** for an overview of how the average household in California consumes electricity. The greatest savings can be achieved in improving the efficiency of lighting fixtures, refrigerators/freezers, and household devices with screens (e.g., televisions, personal computers, etc.).

Figure 4.7: Average California Electricity Consumption per Household[26]

(6,296 kWh per Household)



[26] California Energy Commission, 2010. *2009 California Residential Appliance Saturation Study*. Accessed August 2017 from http://www.energy.ca.gov/appliances/rass/

4.5 Charging Potential in the Westside Cities by Parking Layout

In Southern California, and specifically the Westside Cities subregion, the private vehicle has played a significant role in shaping land use patterns and the built environment, as well as MUD architectural designs. The latter tend to change over time and location depending on construction trends and sociodemographic changes. These changes can influence unit size, the availability of on-site amenities such as laundry services, and the parking layout of the property.

The parking layout is of particular importance to PEV ownership and EVSE installation. Indeed, one of the most significant drivers of EVSE installation costs is the distance from the electrical panel to the PEV charging spot and a MUD's parking layout will greatly influence this length of distance. The parking layout may also determine whether a PEV driver will have access to an electrical outlet for Level 1 charging. And finally, some parking layouts such as shared garages may provide opportunities for sharing the installation costs for multiple EVSE or the deployment of new technologies such as energy management systems (EMS) which allow for the strategic charging of multiple PEVs by optimally balancing each vehicle's state of charge with available electrical capacity.

Eight common MUD parking layouts across the Westside Cities Subregion include: 1) dingbat with door, 2) dingbat without door, 3) detached parking with door, 4) detached parking without door, 5) podium garage, 6) subterranean garage 7) parking lot, and 8) driveway only. **See Table 4.1** for a description of each parking layout.

Table 4.1: Common MUD Parking Layouts Across the Westside Cities Subregion

Parking Layout Type	Sample Photo
Dingbat With Door • Enclosed individual garage partitioned by walls • Equipped with private garage door • Often located directly below driver's housing unit • At or below grade • High probability of electrical outlet access	
	Photo credit: UCLA Luskin Center
Dingbat Without Door • Open or partitioned parking spots • Not equipped with private garage door • Located below housing units • At or below grade • Medium probability of electrical outlet access	
	Photo credit: UCLA Luskin Center
Detached Parking With Door • Enclosed individual garage partitioned by walls • Equipped with private garage door • Detached from main MUD structure • At grade • Medium to high probability of electrical outlet access	
	Photo credit: UCLA Luskin Center
Detached Parking Without Door • Open parking structure often partitioned by walls • Not equipped with private garage door • Detached from main MUD structure • At grade • Low to medium probability of electrical outlet access	
	Photo credit: UCLA Luskin Center

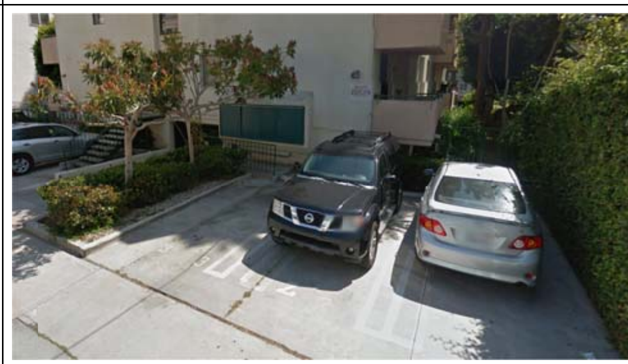
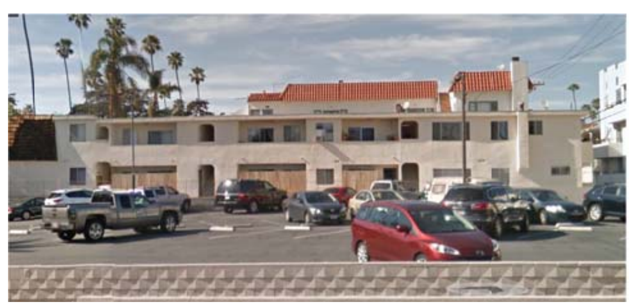
Podium Garage • Enclosed shared garage • Not equipped with private garage door • Located below housing units • At grade • Medium to high probability of electrical outlet access	
	Photo credit: UCLA Luskin Center
Subterranean Garage • Enclosed shared garage • Not equipped with private garage door • Located below housing units • Below grade • Medium to high probability of electrical outlet access	
	Photo credit: UCLA Luskin Center
Driveway Only • Open parking spot or spots not partitioned by walls • Not equipped with private garage door • Located adjacent to main MUD structure • At grade • Zero to low probability of electrical outlet access	
	Photo credit: Google Map Data
Parking Lot • Open parking lot not partitioned by walls • Not equipped with private garage door • Located adjacent to main MUD structure • At grade • Zero to low probability of electrical outlet access	
	Photo credit: Google Map Data

Table 4.2 describes opportunities for installing Level 1 and 2 charging EVSE in different MUD parking layouts based on our observations from sample MUD sites in the South Bay.[27] The eight layouts in **Table 4.1** were consolidated into six in **Table 4.2,** based on overlapping information.

Table 4.2: Evaluation of Charging Potential Across Different MUD Parking Layout

⚡ Straightforward ⚡⚡ Moderately Complex ⚡⚡⚡ Very Complex

		Level 1 Charging		Level 2 Charging
Dingbat With Door	⚡	Likely access to a 110/120-volt outlet in the garage, particularly with an automatic door that relies on electricity. Outlets in this configuration are typically connected to the house panel. If the outlet does not already serve energy intensive loads (e.g., laundry machine, pool pump), it may provide a convenient opportunity for charging.	⚡⚡	Many provide convenient access to the unit panel if the garage is below or in front of the unit, which reduces the distance between the panel and parking spot. Even though the distance between the two may be minimal, electricians may still need to core the wiring and conduit through unit walls and/or the floor.
Dingbat Without Door	⚡	Likely access to 110/120-volt outlets, although outlets may be scattered across the parking environment. These outlets are almost always connected to the house panel. PEV drivers should consider electrical capacity of the panel in light of shared loads. In scenarios where tenants have assigned parking, a PEV driver may swap spots for easier access to the outlet.	⚡⚡	Many have convenient access to the unit panel if the garage is below or in front of the unit, which reduces the distance between the panel and parking spot. The conduit and wiring can often be surface-mounted along the length of the parking site.
Detached Parking	⚡⚡	Possible access to an outlet in each detached garage. Higher value and newer MUDs with detached parking are more likely to have outlets. With an automatic door, there is also a higher likelihood of access to an outlet. When parking is assigned, residents may need to swap parking spots to gain access to Level 1 charging.	⚡⚡⚡	Most are separated from the MUD structure and the house and unit panels by concrete or asphalt. Thus, running wiring and conduit from the panel to the EVSE is likely to require a construction activity such as trenching
Subterranean/ Podium Garage	⚡	Likely access to 110/120-volt outlets. Every subterranean garage and podium garage we visited did have at least one outlet available. In scenarios where tenants have assigned parking, a PEV driver may swap spots for easier access to the outlet.	⚡⚡⚡	Wiring and conduit may need to traverse through building material and/or earth. Large subterranean garages may have multiple levels of parking and require coring through concrete decks. MUDs with podium parking garages are likely to have an electrical box on the same level as the parking area, which may reduce the risk of coring through the structure or ground.
Driveway Only	⚡⚡	Unlikely access to a 110/120-volt outlet. There may be access in MUDs where there is an outlet on the outside wall of the MUD that faces the driveway.	⚡⚡⚡	Unlikely access to 110/120-volt outlet.
Parking Lot	⚡⚡⚡	Unlikely access to an electrical outlet.	⚡⚡⚡	Unlikely access to an electrical outlet.

[27] UCLA Luskin Center for Innovation. 2016. *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study.*

CHAPTER 5: Policy Tools to Overcome Barriers to PEV Adoption in MUDs

To achieve the State of California's ambitious zero-emission vehicle (ZEV) adoption goals, and to ensure equitable distribution of the ZEV benefits, residents of multi-unit dwellings (MUDs) must have the option to charge their plug-in electric vehicles (PEVs) at home. This is particularly true for the Westside Cities subregion, which has 253,876 MUD units. As reviewed in Chapter 4, EVSE installation costs at MUD sites are variable and often high. Moreover, renters and property owners show a low to nonexistent motivation to invest in charging infrastructure at their residence or property. To this end, regional, subregional, and municipal governments, as well as state agencies, air quality management districts, and utilities (hereafter "other administrative entities") can deploy the following policy tools to overcome MUD-related EVSE installation barriers to PEV adoption:

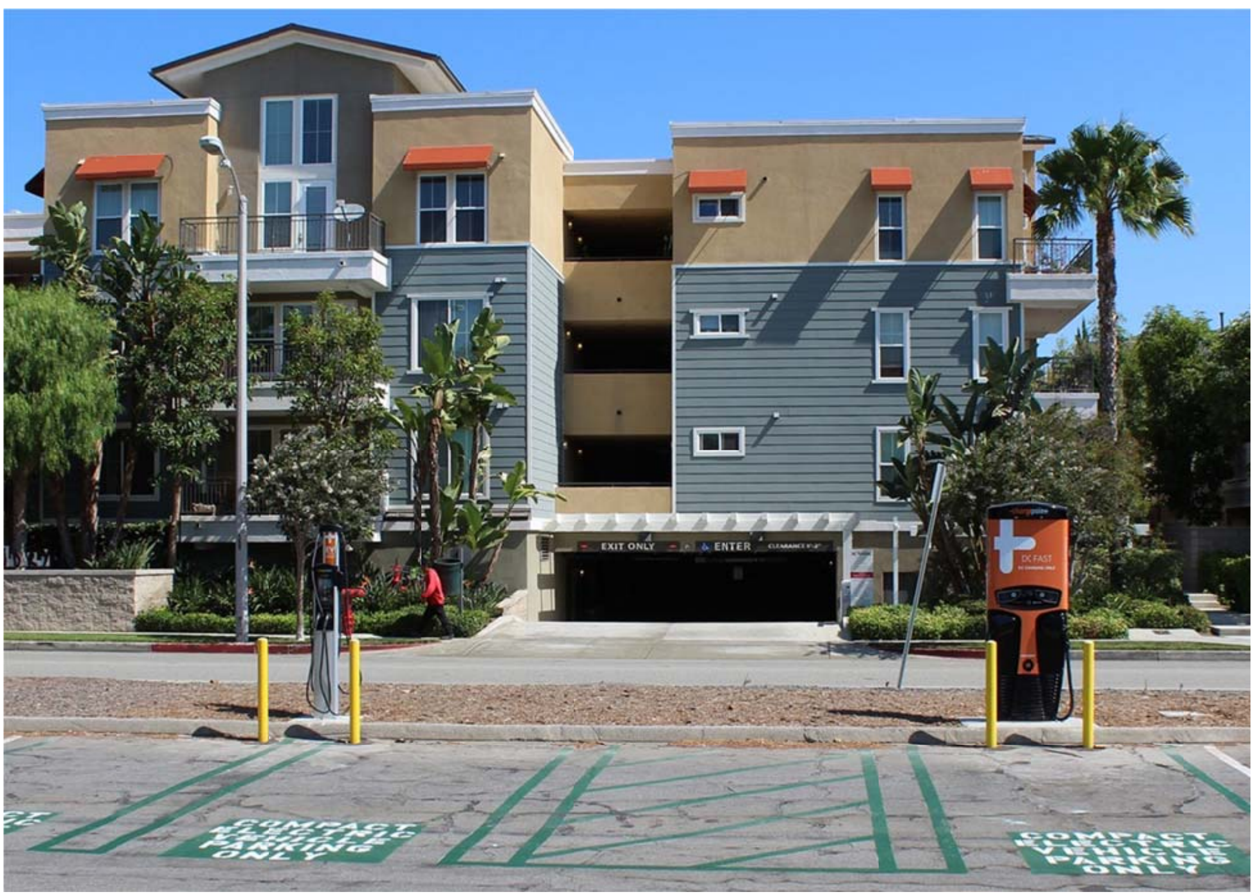
1. Design incentives to reduce the cost of EVSE installation.

2. Implement PEV ready new construction codes.

3. Expand availability of public PEV charging opportunities for MUD residents.

4. Conduct outreach to drive PEV ownership and EVSE installation in MUDs.

These policy tools are the focus of this chapter.



An example of public charging infrastructure sited near a MUD (Photo credit: City of Torrance).

5.1 Design Incentives to Reduce the Cost of EVSE Installation

Policymakers can design public financial incentives such as price subsidies, rebates, tax credits, sales tax exemptions, and subsidized financing to induce consumers to adopt PEV technology. The Clean Vehicle Rebate Program (CVRP) offers PEV buyers $1,500 for a plug-in electric hybrid vehicle (PHEV), or a $2,500 rebate for a battery electric vehicle (BEV) after purchase. Sixty-five percent of PEV drivers found the CVRP to be extremely or very important to their purchase decision.[28] The state, local municipalities, and other administrative entities can also provide free or subsidized Level 2 chargers. Sixty percent of early PEV adopters found a rebate to be extremely or very important to their decision to install a Level 2 charger.[29] Due to the variable and often high cost for installing EVSE at MUD sites, a specific installation rebate may be an effective policy tool to ease the cost barrier and expand PEV access.

To increase the cost effectiveness of rebates for EVSE installation, and to maximize the adoption of PEVs at MUDs, we recommend requiring multiple PEV drivers per single MUD to qualify. As reviewed in **Chapter 4**, the high variable costs for EVSE installations provide an opportunity to share costs across multiple residences.

To accommodate a range of incomes, administrative entities could offer tiered rebates based on consumer income levels. These types of progressive rebates have proven to be more cost-effective, have lower total policy costs, and result in greater allocative equity.[30] We recommend designing rebate tiers so that they vary by household income or locational attributes such as MUDs within disadvantaged communities.

Rebates for Level 1 charging can also be an effective option. If drivers at MUDs have access to an outlet, the driver would only need to ensure that the outlet is connected to a panel with sufficient electrical capacity for Level 1 charging. For this level of charging, we recommend a program that partners with utilities and covers the cost for local electricians or electrical engineers to review the electrical capacity of the panel and to conduct an overall assessment of charging readiness.[31]

5.2 Implement PEV-Ready New Construction Codes

Local jurisdictions can also set guidelines for remodels and new MUD construction that require developers to provide Level 1 or 2 charging readiness. Many new building code examples exist throughout California that can serve as models for the cities on the Westside. At a minimum, local jurisdictions must implement the 2016 California Green Building Standards, which in relation to PEVs in MUDs states, at least “3% of the total number of parking spaces provided for all types of parking facilities, but in no case less than one, shall be electric vehicle charging spaces (EV spaces) capable of supporting future EVSE.”[32] Beyond that minimum, local

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[28] Center for Sustainable Energy. *California Plug-in Electric Vehicle Driver Survey Results – May 2013.*

[29] Ibid.

[30] Sheldon, Tamara L., J.R. DeShazo, Richard T. Carson, and Samuel Krumholz. 2016. *Factors Affecting Plug-in Electric Vehicle Sales in California*. Accessed August 2017 from http://innovation.luskin.ucla.edu/content/factors-affecting-plug-electric-vehicle-sales-california

[31] A utility’s primary role can be to be responsive to annual peak load requests per site.

[32] California Department of Housing and Community Development. 2016. “Residential Mandatory Measures Effective January 1, 2017.” Accessed October 2017 from http://www.hcd.ca.gov/building-standards/calgreen/docs/HCDSHL605_2016.pdf

jurisdictions can require a greater number of PEV ready parking spaces. The city of Los Angeles, for example, has a Green Building Code (Chapter IX, Article 9, of the Los Angeles Municipal Code), which mandates newly constructed multi-family dwelling (larger than 2 units) to provide Level 2 ready outlets at 5 percent of the total number of parking spaces.[33]

Unfortunately, much of the residential land use in the Westside Cities subregion is already built out. If new construction codes were adopted by the cities in the subregion, it would take many years at current construction rates for a significant percentage of MUDs to be capable of providing PEV charging access. Thus, this policy tool should not be adopted in isolation of the other policy tools discussed in this chapter.

5.3 Expand Public Charging Opportunities for MUD Residents

Local governments can also provide alternative public charging sites in locations such as city-owned parking lots. Strategic siting of Level 2 or DC Fast Chargers near clusters of MUDs may provide an option for multi-unit dwellers who cannot charge at home. To ensure reliable access to a charger, local governments may need to also administer a charging program that coordinates charging sessions among potential users.

The City of Torrance, for example, launched the "One Mile, One Charger Project" with the goal of expanding PEV infrastructure throughout Torrance so that a PEV driver is never more than one mile from a charging station within the city.[34] The city worked with ChargePoint to install, operate, and maintain publicly accessible PEV charging infrastructure at six public locations (e.g., parks, libraries, civic buildings, etc.). All sites included a minimum of two Level 2 charging units and one DC Fast Charging unit.

5.4 Conduct Outreach to Encourage PEV / EVSE Investments at MUDs

The PEV remains a relatively new technology. Substantial sales of BEVs started only in 2010, and most believe we are still in the very early stages of PEV adoption.[35] As with many new technologies, consumers have been hesitant to switch out their internal combustion engine (ICE) for a PEV. Some of this hesitation can be rooted in the comfort level drivers have with the ICE and/or the uncertainty, real or perceived, of new technologies, like range anxiety – the fear of running out of battery power mid-trip. ICEs have been the dominant form of private transportation for over a century. Its refueling infrastructure is robust and easily accessible.

Outreach and education can help address this hesitation and introduce potential PEV drivers to the new technology by promoting its environmental and financial benefits as well as answering common questions and concerns. From an EVSE in MUD perspective, the goal with outreach and education is to drive demand for home charging among MUD residents, and shift the investment motivation from the renter to the property owner, who may be motivated to attract tenants by providing new amenities. With strong PEV adoption rates in the Westside Cities

[33] City of Los Angeles. 2017. *Official City of Los Angeles Municipal Code.*

[34] City of Torrance. “EV Project.” Accessed August 2017 from https://www.torranceca.gov/our-city/community-development/planning/ev-project

[35] Sheldon, Tamara L., J.R. DeShazo, Richard T. Carson, and Samuel Krumholz. 2016. *Factors Affecting Plug-in Electric Vehicle Sales in California*. Accessed August 2017 from http://innovation.luskin.ucla.edu/content/factors-affecting-plug-electric-vehicle-sales-california

subregion, as well as a large number of high-value MUDs (3,798 MUDs with an average unit value of $500,000 or greater), the subregion may help lead this shift in investment motivation.

Outreach and education can include direct-mail initiatives, advertising, workshops, and e-newsletters. Local governments and/or Southern California Edison should focus neighborhood-level outreach on MUDs, identified in **Chapter 3**, that are high-quality candidates because of their estimated latent PEV demand. Outreach and education materials should focus on a series of topics including:

- **New technology education,** including available PEV models and associated lifespan, electric mile range, and maintenance requirements; purchase or lease costs and associated rebates; charging technologies such as Level 1 and Level 2 charging, including a tool for estimating charging times (with Level 1 highlighted as a feasible charging choice); and location of public chargers.
- **Environmental and financial benefits,** including emissions avoided and fuel savings.
- **Charging in MUDs,** including instruction on how to evaluate panel electrical capacity for Level 1 (20-amp circuit with available panel capacity), Level 2 charging (40-amp circuit with available panel capacity), and how to identify cost drivers for EVSE installation (as reviewed in Chapter 4).
    - **For Level 1 charging**, instruction on how to verify available electrical capacity on the house or unit panel by reviewing shared loads such as laundry machines, pool pump, etc., as well as the annual peak load from the utility bill.
    - **For Level 2 charging**, instruction on how to evaluate installation cost drivers including the distance from the electrical box or relevant electrical panel to the PEV parking spot, and insight into the cost advantages of group purchases for Level 2 charging installation including recommendations to survey other tenants' interest in PEV ownership.
- **Renters' rights,** including information about California law SB 880 (Corbett), which makes it illegal to impose any condition that "effectively prohibits or unreasonably restricts" installation of charging equipment in an owner's designated parking space, and California law AB 2565 (Muratsuchi), which requires a lessor of a dwelling to approve a request to install EVSE at a designated parking spot if the installation "complies with the lessor's procedural approval process for modification of the property."
- **Westside specific benefits,** including the cost and time savings that come from access to high-occupancy vehicle (HOV) lanes, a benefit that has had a significant impact on PEV sales.[36]
- **Specialized and culturally sensitive outreach and education** including Spanish-language materials and income-adjusted rebate information, such as with the Enhanced Fleet Modernization Program (EFMP) Plus-up Program (see below), for the disadvantaged communities of the South Bay.

[36] Sheldon, Tamara L., J.R. DeShazo, Richard T. Carson, and Samuel Krumholz. 2016. *Factors Affecting Plug-in Electric Vehicle Sales in California*. Accessed August 2017 from http://innovation.luskin.ucla.edu/content/factors-affecting-plug-electric-vehicle-sales-california

Increasing adoption among low- and moderate-income households within disadvantaged communities is a particular challenge but important to achieve the environmental equity goals of California. Low- and moderate-income households are less likely to purchase new vehicles (PEVs or otherwise) and many reside in MUDs without access to home charging.

To address this challenge, the California Air Resources Board (CARB) has launched a number of initiatives under its Low Carbon Transportation Program aimed at expanding PEV adoption among low- and moderate-income households. The EFMP Plus-Up program, for example provides low-income households up to $12,000 for the purchase or lease of a battery electric vehicle (BEV).[37,38] In addition, individuals who purchase a BEV are eligible for up to $2,000 for a charging unit. To qualify, the household must reside in a zip code that includes a disadvantaged community census tract.

Additionally, Southern California Edison's Charge Ready program — which aims to install up to 1,500 charging stations at parking sites where dwell times exceed four hours or at longer-term parking sites including MUDs — will target at least 10% of its deployment within disadvantaged communities.[39]

We recommend that city governments in the Westside Cities subregion, CARB, SCE, and the South Coast Air Quality Management District collaborate to optimize outreach effectiveness by conducting joint efforts within disadvantaged communities. Events such as "ride and drives" with representatives from both programs can showcase the PEV as well as the significant savings that can be realized when participating in both programs. Additional direct-mail campaigns and workshops can promote both programs and the potential savings (see **Section 2.6** for locations of disadvantaged communities within the Westside Cities COG). Event staff and outreach materials should be conscious of language and cultural barriers and adjust accordingly.

[37] Includes the $2,500 Clean Vehicle Rebate Program (CVRP) rebate.

[38] California Air Resources Board. "Making the Cleanest Cars Affordable." Accessed August 2017 from https://www.arb.ca.gov/newsrel/efmp_plus_up.pdf

[39] Edison International. "Charge Ready: A Plan for California." Accessed O 2017 from https://www.edison.com/home/innovation/electric-transportation/charge-ready-a-plan-for-california.html

APPENDIX

Appendix 1. Propensity to Purchase Model Methodology

Researchers constructed the propensity to propensity-to-purchase model using statewide survey data from the Clean Vehicle Rebate Project (CVRP), census tract level PEV registration data from IHS Automotive, census tract level socioeconomic data from the 2011–2015 American Community Survey (ACS), and parcel level data from the Los Angeles County Office of the Assessor. The model was constructed according to these five steps:

i. First, researchers forecasted the number of PEV purchases per census tract based on historical PEV purchases within that census tract between October 2015 and September 2016. Here, researchers assume that as many PEVs that were sold during the sample period will also be sold during the next 12-months (i.e., October 2016 through September 2017). All else equal, the likelihood that a household will purchase a PEV increases with the total number of PEVs historically sold in that household's census tract.

ii. Second, researchers computed the number of PEV purchases across different income groups for each census tract. That is, how many of the total PEV purchases will be made by households with annual incomes of less than $24,999, between $25,000 and $49,999 and so on. To accomplish this, researchers applied the distribution of CVRP rebates across household income brackets to the forecasted total number of PEV purchases within a census tract. Here, researchers assume that the income distribution of PEV buyers at the census tract level reflects that of CVRP recipients statewide. Researchers also assume that the historical relationship between income and PEV adoption will continue in the short run, such that the majority of PEV purchases will be made by households with incomes above the California median household income.

iii. Third, researchers calculated the probability that a household belonging to a given income group in a given census tract will purchase a PEV. This probability is simply the forecasted number of PEVs purchased by that income group (as derived in the previous step) divided by the number of households belonging to that that income group (as obtained from ACS data). This probability can also be understood as the PEV adoption rate for a particular income group. All else equal, the likelihood that a household will purchase a PEV increases with the PEV adoption rate associated with that household's income group.

iv. Fourth, researchers calculated the probability distribution of a household living in a home of a given value belonging to the income groups from step 2. That is, the chance that the occupant of a home worth $500,000 will have an annual income that is less than $24,999, between $25,000 and $49,00, and so on. Researchers used tract-level ACS data on the relationship between home value and household income to complete this step. The operation is necessary because microdata on individual household income in the study area is not available. Researchers assume that the relationship between home values and income is transferable to condos and apartments. Researchers also assume that the historical relationship between home values and income will continue into the future, such that households with higher incomes will occupy higher value properties.

v. Fifth, researchers estimated the probability that a household occupying a unit of a given value in a given census tract will purchase a PEV in the next year. To do so, researchers joined the data from the two previous steps, multiplying the probability that a household will purchase a PEV given that household's income by the probability that the same household will occupy a MUD unit given that unit's value. Researchers then summed the resulting probabilities for each income group, yielding an expected value of the probability that any given occupant of that unit might purchase a PEV. In effect, the greater the value of a condo or apartment, the higher the likelihood that the occupant has an income above the median, and the higher the propensity-to-purchase score assigned to that unit.

After calculating propensity to-purchase scores for different property values, researchers then assigned the scores to specific MUD parcels within the study region using parcel data from the Los Angeles County Office of the Assessor. Propensity-to-purchase scores are assigned to an MUD parcel based on an MUD's average unit value (i.e., total property value divided by number of units), rather than the MUD's total property value.