The University of Texas at Austin
Energy Institute

LBJ SCHOOL
THE UNIVERSITY OF TEXAS AT AUSTIN

Policy Research Project Report
NUMBER 204

The Energy Infrastructure of the Future (EIoF)

Electric Vehicle Charging Infrastructure:

PUBLICLY FUNDED NECESSITY OR COMMERCIALLY FUNDED CONVENIENCE?

PART OF A SERIES OF WHITE PAPERS

TEXAS
The University of Texas at Austin

THE ENERGY INFRASTRUCTURE OF THE FUTURE is an interdisciplinary initiative of the Energy Institute at the University of Texas at Austin to develop an extensive understanding of existing domestic energy infrastructure while also modeling the technical requirements and financial opportunities for a range of future infrastructures within the United States. Our goal with this study is to inform the public dialog and policy formulation about energy infrastructure with quantitative, rigorous, and dispassionate analysis that identifies and quantifies the costs, benefits, and financial opportunities of different options.

The world is undergoing a variety of energy transitions as a result of demographic, economic, climatic, technological, and social forces that are shifting how we acquire and utilize energy. These transitions will result in trillions of dollars of infrastructure investment by 2050. However, it is currently unclear what infrastructure will be needed in coming years and how different transitions will impact existing public and private stakeholders. Consequently, it is possible we will make long-lasting infrastructure investments without understanding the full range of costs and impacts. This work intends to inform those investments by creating decision support tools about and providing an extensive look at how future energy services are provided and energy resources are produced, moved, and consumed throughout the United States.

The study includes infrastructure associated with extracting and processing of traditional primary fuels (e.g., oil, gas, coal, uranium), primary-to-energy carrier conversions (e.g., wind turbines, power plants), transmission and distribution of energy (e.g., pipelines, electric grid), and end-use devices (e.g., electric vehicles). The first step of this study was to develop an extensive inventory and valuation of existing domestic energy infrastructure, including a description of the types of assets, including purpose, ownership, and vintage/depreciation. The second step of this study developed methods and tools to model future infrastructure requirements while incorporating the influence of different macro-trends that are driving change: decarbonization, electrification, regulated and unregulated market design, modularity of energy generation, abundance of hydrocarbon products, and information technology & automation. The methods and tools will be made available to allow stakeholders to consider the implications of different future scenarios, each of which will be characterized by assessing both the rate and magnitude of change across the life cycle from primary energy extraction to final energy service.

All authors abide by the disclosure policies of the University of Texas at Austin. The University of Texas at Austin is committed to transparency and disclosure of all potential conflicts of interest. All UT investigators involved with this research have filed their required financial disclosure forms with the university. Through this process the university has determined that there are neither conflicts of interest nor the appearance of such conflicts.

This paper is one in a series of white papers that examine particular aspects of the U.S. energy infrastructure.

Other white papers produced through the study can be accessed at the University of Texas Energy Institute website: **energy.utexas.edu**

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ABBREVIATION	DEFINITION
BEV	Battery-Electric Vehicle
BTU	British Thermal Unit
CPUC	California Public Utilities Commission
EIA	U.S. Energy Information Administration
EPA	Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCEV	Fuel-Cell Electric Vehicle
FERC	Federal Energy Regulatory Commission
GW	Gigawatt
GWh	Gigawatt-Hour
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IOUs	Investor-Owned Utilities
ITC	Investment Tax Credit
kW	Kilowatt
kWh	Kilowatt-Hour
MW	Megawatt
MWh	Megawatt Hour
O&M	Operation and Maintenance
PEV	Plug-In Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
PUC	Public Utility Commission
PV	Photovoltaic
Quads	Quadrillion British Thermal Units
R&D	Research and Development
T&D	Transmission and Distribution
TOU	Time of Use
TPO	Third Party Ownership

FOREWORD

The Lyndon B. Johnson School of Public Affairs has established interdisciplinary research on policy problems as the core of its educational program. A major element of this program is the nine-month policy research project, in the course of which one or more faculty members direct the research of ten to twenty graduate students of diverse disciplines and academic backgrounds on a policy issue of concern to a government or nonprofit agency. This "client orientation" brings the students face to face with administrators, legislators, and other officials active in the policy process and demonstrates that research in a policy environment demands special knowledge and skill sets. It exposes students to challenges they will face in relating academic research, and complex data, to those responsible for the development and implementation of policy and how to overcome those challenges.

The curriculum of the LBJ School is intended not only to develop effective public servants, but also to produce research that will enlighten and inform those already engaged in the policy process. The project that resulted in this report has helped to accomplish the first task; it is our hope that the report itself will contribute to the second.

Finally, it should be noted that neither the LBJ School nor The University of Texas at Austin necessarily endorses the views or findings of this report.

Angela Evans, *Dean*

ACKNOWLEDGMENTS AND DISCLAIMER

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We would like to give particular thanks to the guest speakers who gave the class invaluable insight into the workings of the electric utility industry and the business models being investigated: (in order of appearance)

- **Dr. Michael Nicholas – Senior Researcher, the International Council on Clean Transportation**
- **Karl Popham – Manager, Electric Vehicles and Emerging Technologies, Austin Energy**
- **Brett Hauser – CEO, Greenlots**
- **George W. Presses – Vice President, H-E-B Fuel and Energy**

We also want to thank the sponsorship of the Energy Institute and the support of the staff and faculty at the LBJ school of Public Affairs that made this Policy Research Project possible.

Finally, it should be noted that neither the LBJ School of Public Affairs nor the University of Texas at Austin nor the persons interviewed for this project necessarily endorse the views or findings of this report. ■

EXECUTIVE SUMMARY

Electric vehicle (EV) adoption is rapidly accelerating. While there are many financial and environmental benefits that come with widespread EV adoption, it presents a substantial infrastructure challenge. For EVs to be a compelling alternative to conventional internal combustion engine (ICE) vehicles, they require convenient and reliable charging infrastructure. To address this challenge, this report attempts to answer the following question: Is EV charging infrastructure a public necessity requiring public investment, or a convenience that should be left to the private sector?

The answer to this question is not simple, and depends on a multitude of factors around how and by who the charging infrastructure is used. Regional factors, including community specific social goals related to emission reduction will impact the answer. In regions with high levels of pollution like the LA basin, Houston, and Phoenix a strong case can be made about the social benefits of PEV charging infrastructure. Alternatively, rural areas may not see a case for public investment in PEV infrastructure as no direct benefits will accrue to local residents. Different use cases will also impact the response to this question. The vast majority of PEV owners live in single family homes, and most charging will occur in these homes. Is there really a need for public investment in providing charging in private homes? Multifamily residential structures on the other hand have more challenges with PEV charging due to shared parking arrangements. There may be a stronger case for public investment in multifamily charging infrastructure to ensure widespread, equitable access to PEV charging.

This report examines four use-cases for PEV charging infrastructure: single-family residential charging, multi-family residential charging, workplace charging, and direct-current fast-charging (DCFC). Each subsection contains unique recommendations for how the charging infrastructure should be funded.

RESEARCH METHODS

This report utilized data and publications from corporations, research agencies, and the U.S. government. This information was analyzed and synthesized to create concise recommendations for each of the report's four subsections. These recommendations are detailed below.

Single-Family Residential Charging

The vast majority of PEV owners live in single-family residences (SFRs), the most common location for PEV charging. The report makes the following recommendations on how single-family residential charging could be supported:

1. **Local governments could work with building code associations to institute PEV-ready building codes for new single-family residence construction in their jurisdictions.**

Updating building codes is a locked-in, cost-effective means of adding Level 1 or Level 2 EVSE near vehicle storage locations.

2. **Utilities and local governments could incentivize single-family resident PEV owners to adopt intelligent charging hardware and software through rebate and subsidy programs.**

Intelligent charging hardware and software benefits both PEV owners as well as utilities. This infrastructure can help utilities shave load off of peak demand, saving them money in overall fixed costs, and can help consumers by lowering their electricity costs. This recommendation depends heavily on local or regional grid needs.

3. **Utilities and local governments should not institute policies to increase deployment of DCFC EVSE for single-family residences.**

Level 1 and Level 2 EVSE already meets the majority of charging needs for PEV owners, single-family residences have no need for this functionality.

Multi-Family Residential Charging

PEV ownership is lowest among people living in Multi Family Residences (MFRs), and many MFRs do not currently provide PEV charging. Governments could take the following steps to encourage MFRs to install charging infrastructure, making PEV ownership more accessible to larger portions of the population:

1. **Local governments could work with building code associations to institute PEV-ready building codes for new multi-family residence construction in their jurisdictions.**

Many low or no cost policies are available for public officials to promote PEV charging. Examples include adopting legislation allowing tenants to request and install level 2 chargers at their own expense, streamlining permitting processes to be fast and low to no cost, and updating building code to require make-ready practices in new MFR construction.

2. **Local and state governments could require that all shared parking facilities have a minimum number of PEV parking spots allocated.**

California state code requires that all commercial or multifamily parking lots have at least 3% of parking spaces dedicated to PEV charging. Similar programs can help motivate the private owners of MFRs to provide PEV charging infrastructure without cost to the government or utility.

3. **Local governments, utilities, and state governments could utilize grants and utility rebates in the short-term to spur investment or facilitate partnerships in Level 1 and Level 2 charging infrastructure at multi-family residences and leverage intelligent charging.**

The focus of government grants and rebates should be Level 2 charging infrastructure. MFR owners can promote Level 2 charging as an amenity and potentially charge higher rents or command higher unit prices. As a result, public-private-partnerships can mitigate costs to the taxpayer while still providing the needed infrastructure. Furthermore, intelligent charging – like in the single-family charging situation – can save money for both the utility and the consumer.

Workplace Charging

The availability of workplace charging is particularly beneficial to PEV owners with long commutes. PEV drivers who charge at work can effectively double their commuting electric range if they charge both at home and their workplace. The following steps could be taken to further encourage workplace charging infrastructure installation:

1. **Local governments and utilities could consider offering information and technical guidance for worksites interested in EVSE deployment.**

Breaking down information asymmetries between workplaces that may not have the expertise to adequately assess their charging infrastructure needs will make public and private investments more efficient in the long-run.

2. **Local governments and utilities could offer rebates, tax credits, and streamline permitting for EVSE installation at workplaces to incentivize EVSE deployment.**

Workplaces are second to residences for PEV charging opportunities. The majority of workers in the US drive to work, and providing workplace infrastructure will alleviate range anxiety.

3. **Local governments and utilities could focus their rebate and subsidy programs on Level 1 and Level 2 EVSE charging infrastructure.**

Level 1 and Level 2 EVSE will provide plenty of charge for PEV owners parking on-site. DCFC may be cost prohibitive to be effectively deployed at workplaces given the need for high asset utilization: quick charge times mean that DCFC may be underutilized as workers leave their cars parked in spaces after a full charge.

4. **Local governments and utilities could require workplaces to survey employees for interest and demand**

for PEV charging infrastructure before providing subsidies for EVSE deployment. An additional requirement could mandate the release of this data to local governments and utilities.

Survey requirements will allow workplaces to understand their own PEV charging infrastructure needs, allowing them make a more informed choice as to how to invest. Furthermore, requiring survey data be given to subsidy program providers will allow utilities and local governments to gain insight into local workplace trends and how their future need for EVSE may change.

5. **Utilities could provide appropriate electricity discounts for adopting intelligent charging PEV charging infrastructure.**

Workplaces may be concerned with higher electric utility bills caused by increasing PEV adoption and electricity usage on-site. Discounting the cost of electricity for PEVs will incentivize workplaces to make investments or take part in subsidy programs by lowering the cost of ownership. Combining this with intelligent charging can save both consumers and utilities money in the long run.

Direct-Current Fast-Charging

Direct-Current Fast-Charging (DCFC) is convenient but expensive. There is demand for DCFC infrastructure in both urban and rural areas. Implementation of rural highway DCFC infrastructure can facilitate intercity travel by drastically reducing PEV driver range anxiety, while urban DCFC can be used by PEV owners without access to home-charging. Because of the different needs of these DCFC users, funding requirements can vary with location. This report makes the following recommendations for DCFC infrastructure funding:

1. **Local governments and utilities should not use public funds to invest in DCFC infrastructure, unless the installation of these charging stations would benefit a large percentage of the population and address policy goals.**

Due to the high cost of DCFC, public investment in these charging stations for the sole reason of increasing availability of charging infrastructure would be an inefficient use of taxpayer dollars. However, if a government has broad public health or climate initiatives that would benefit from an increase in PEV adoption, there may be a justification for the use of public funds for this expensive technology. In most cases, public funds could be more efficiently spent in other types of charging infrastructure (e.g. MFR Level 2 and Public Level 2).

2. **If a government decides to use taxpayer funds to help fund DCFC, local governments and utilities could do the following:**
   a. **Rebates, Incentives, Tax Credits**
   b. **Direct ownership of charging stations**
   c. **Station Specification Requirements**
   d. **Public-Private Partnerships**

If a government has significant cause to spend public funds on DCFC infrastructure, there are a few financial and regulatory approaches that could improve the efficiency and equity of that expenditure.

a. Rebates, Incentives and Tax Credits: DCFC infrastructure may help supplement limited charging infrastructure at workplaces and multi-family dwellings in urban areas. As a result, public investment, in the form of rebates, incentives or tax credits, could help increase the rollout of privately managed charging stations. These funds should be scaled to account for the revenue generation potential of these private assets.

b. Direct ownership of charging stations: Urban utilities can install DCFC infrastructure more effectively because they have substantial expertise on local grid infrastructure. By installing DCFC more efficiently, this may provide the most socially equitable allocation, especially in high need areas where rates can be regulated.

c. Station Specification Requirements: In order to ensure the effectiveness of the rollout of

DCFC infrastructure, local governments or utilities could specify sites and power capacity of these units to help ensure utilization. These sites could often be along highway corridors so that they can serve as urban and intercity charging options.

d. Public-Private Partnerships: Through formal partnerships with private companies, local governments and utilities could ensure the rollout of DCFC infrastructure meets their broader policy goals. This could also provide means for governments to recoup their investment in infrastructure through user fees, similar to tolls roads. More broadly, this form of partnership would allow governments or utilities to help complete the rollout of existing networks. (e.g. Electrify America)

1 INTRODUCTION

Say the word infrastructure and for most people an image of roads, highways, telephone poles and wires, and monumental interchanges come to mind. Maybe they also think of piping systems for water and sewage, laying below the surface of the earth. These projects can have such significant costs that often only governments can undertake them. They are mostly non-rivalrous and non-excludable, meaning that one person's use does not deter another person from using the good, and it is not possible to prevent consumers who have not paid for the good from using it. These characteristics are what make infrastructure projects public goods, as defined by economics, although different funding mechanisms can make them quasi-excludable (such as toll roads). Constrained by both politics and finances, policymakers have to consider the costs and benefits of such infrastructure projects in order to best utilize the small amount of taxpayer resources available to them. Most people, however, would not also think of what is needed to fuel the vehicles we use to traverse some infrastructure. For vehicles, this is the vast network of gas stations that dot the physical landscape.

Electric vehicles (PEVs) also require infrastructure to provide the energy necessary to power them. This infrastructure comes in various forms, specifically Level 1, Level 2, and DCFC (sometimes also called Level 3). As the number of PEVs on the road continues to increase, policymakers must make decisions regarding whether or not to invest taxpayer money in PEV charging infrastructure. Such decisions consider the efficiency and effectiveness of doing so, but must also consider the equity of such investments. Policymakers can think of PEV supply equipment (EVSE) as a public good that should be funded, and owned, by taxpayers. However, given that such infrastructure may be both rivalrous and excludable, policymakers should also consider utilizing the gas station model whereby the infrastructure is owned and paid by private firms through revenue streams. This report considers both purely-public and purely-private ownership models, along with the wide array of policy options in between.

1.1 REPORT CONCEPT AND STRUCTURE

This report provides guidance on PEV charging infrastructure deployment strategies for the future. Its scope focuses on the United States light-duty vehicle (LDV) market. The primary driving force behind sustainable infrastructure deployment is the rate of adoption for LDV PEVs, which in turn depend on a variety of other market and policy factors. Although this report cannot predict the future of the PEV market with certainty, the strategies and recommendations contained within are built around four different charging use cases for LDVs:

- Single-family residences
- Multifamily residences
- Workplace charging
- DC Fast Charging (DCFC)

The goal of this project is to deliver a comprehensive report on strategies for PEV charging infrastructure deployment, across the main use cases, for readers who need a holistic view of the EVSE landscape. Simultaneously, it provides discrete chapters for readers interested in specific use cases only. To achieve these aims, the report provides background information on important concepts related to PEVs, including the state of the present PEV market, the benefits and challenges associated with PEV adoption, the current state of PEV charging infrastructure, and the impact of PEV adoption on the electricity grid. Four chapters follow this information and present individual reports for each use. Next follows a discussion of scenarios or factors that may disrupt the PEV market, such as the rise of autonomous vehicles, the deployment of competitive hydrogen fuel cell technology, and the changing battery market. Finally, the report provides a comprehensive summary of the main conclusions and recommendations from the individual use-case chapters.

1.2 ELECTRIC VEHICLES TODAY

This section covers key concepts related to PEVs. It discusses the different types of vehicles with contemporary examples, the benefits and challenges of PEVs, and the current state of the PEV LDV market. The majority of the information contained within this section comes from the U.S. Department of Energy.

1.2.1 Types of Vehicles

Light duty vehicles (LDVs) comprise cars, small trucks, and vans. This category is the most common vehicle category on U.S. roads with about 250 million LDVs making up 92 percent of vehicles on highways.[1] The federal government classifies LDVs as a "passenger car or passenger car derivative capable of seating twelve or fewer passengers."[2] This section will examine four types of LDVs currently available on the market: internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs).

1.2.1.1 Internal Combustion Engine Vehicles (ICEVs)

The most popular LDVs on the road in 2019 are those with internal combustion engines (ICE). ICE vehicles operate by burning gasoline or diesel fuel to create thermal energy used to power the vehicle.[3] Because ICEVs burn fossil fuels, they emit CO2 from their tailpipes, making them substantially less environmentally friendly than other LDVs available on the market today. Although ICE vehicles emit a significant amount of pollution and can be generally difficult and expensive to maintain, existing infrastructure and underdeveloped PEV technology have made ICE vehicles the most practical choice for the average consumer.

1 Bureau of Transportation Statistics. "Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances". Accessed April 14, 2019. https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances

2 40 CFR § 1037.801 2016.

3 Ganesan, V. Internal Combustion Engines. New York: McGraw-Hill, 2012.

Recently, these trends have begun to change. As the twenty-first century has progressed, technology for cleaner vehicles has improved substantially, leading to new vehicle types that are beginning to compete with ICE vehicles for market share.

1.2.1.2 Hybrid Electric Vehicles (HEVs)

Hybrid electric vehicles (HEVs), such as the Toyota Prius, were the first advanced powertrain to include electric motors, power electronics, and relatively large batteries to further enhance IC engines. HEVs use both an internal combustion engine and one or two electric motors to propel the vehicle. HEVs can utilize multiple methods to charge the onboard battery. One method uses the IC engine to power a motor-generator that provides the necessary charge.[4] The other method, known as regenerative breaking, recaptures energy that conventional vehicles typically lose while braking.[5] Regardless of charging method, the hybrid vehicle's sole energy source is either gasoline or diesel fuel: HEVs do not plug-in to the electric grid to charge the onboard battery.

Today there are two main variations of HEVs on the market: mild hybrids and strong hybrids. Both general types have varying degrees of sophistication, cost, and capability. Mild hybrids typically use their battery-powered motor-generator to turn off the internal combustion engine at stop lights to save gasoline. The motor-generator then restarts the engine when the driver lifts their foot off the brake pedal to continue driving. In some configurations, the motor-generator also provides a mild boost to low-speed torque and regenerative braking.[6]

Strong hybrids, such as the Toyota Prius, include larger batteries and typically two electric motor-generators. Unlike mild HEVs, the electric motors in strong HEVs can power the vehicle for short distances at low-to-moderate speeds, provide stop-light idle elimination, and enable the IC engine to operate more efficiently.[7] These

4 U.S. Department of Energy. "Hybrid Electric Vehicles." *Alternative Fuels Data Center: Hydrogen Benefits and Considerations.* Accessed February 16, 2019. https://afdc.energy.gov/vehicles/electric_basics_hev.html

5 Ibid.

6 Ibid.

7 Ibid.

strong hybrids fully enable regenerative braking, which further increases their fuel economy.[8]

1.2.1.3 Plug-In Hybrid Electric Vehicles (PHEVs)

Like HEVs, PHEVs include both an internal combustion engine and typically two electric motor-generators. But, unlike HEVs, PHEV batteries can be charged by plugging the vehicle directly into the electric grid via Level 1 or Level 2 electric vehicle supply equipment (EVSE). PHEV batteries are larger than HEV batteries, allowing them to travel greater distances and at higher speeds on their electric motors. Conceptually, when PHEVs are powered by their battery, they operate as an PEV. After the battery is depleted, the PHEV's internal combustion engine is deployed to power the vehicle in a similar fashion to an efficient strong hybrid vehicle. Many PHEV owners who use their vehicle for their daily commutes can use their vehicle on a regular basis purely on electricity without ever deploying the combustion engine.[9]

1.2.1.4 Battery Electric Vehicles (BEVs)

BEVs have an even larger battery than PHEVs to power their electric motor-generator. This large battery is charged by plugging into the electric grid. These vehicles do not contain an additional internal combustion engine as a range extender and do not burn any liquid fuel. Because they do not produce any tailpipe emissions, BEVs are typically the cleanest option for consumers seeking an environmentally-friendly vehicle. Additionally, BEVs can have the fastest acceleration, smoothest operation, and lowest operating and maintenance cost of any vehicle type.

8 Ibid.

9 U.S. Department of Energy. "Plug-In Hybrid Electric Vehicles." *Alternative Fuels Data Center: Hydrogen Benefits and Considerations.* Accessed February 16, 2019. https://afdc.energy.gov/vehicles/electric_basics_phev.html

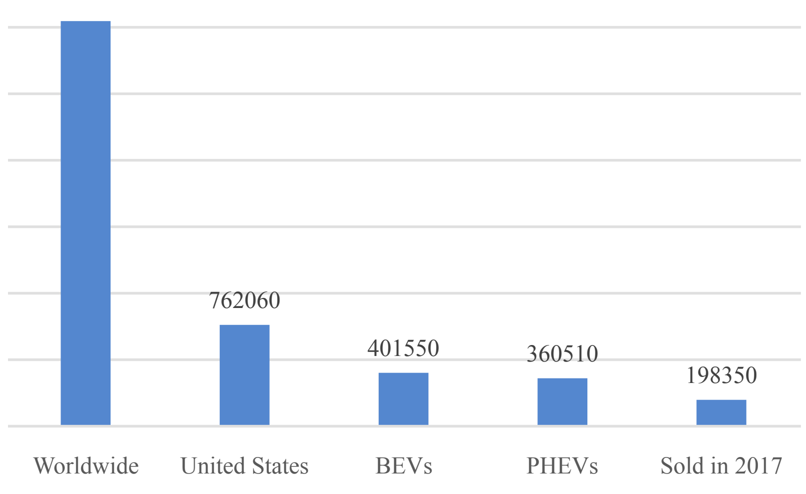
1.2.2 Current State of the PEV LDV Market

Figure 1.1 below shows the number of LDV EVs on the road worldwide, in the United States, and in the United States broken down by BEVs and PHEVs. Although the United States makes up a small portion of the worldwide market, PEV purchases are beginning to accelerate. Shown in the figure, in 2017 there were 198,350 new LDV PEVs sold in the United States alone: one can expect that this number will continue to increase in the coming years as more consumers desire an PEV.

The electrified light-duty vehicle market has grown significantly. HEVs led the way for over a decade and have been a common sight on U.S. roads. However, over the last five years PHEV and BEV sales have grown substantially, crossing 2% of the total market for new vehicle sales threshold in

FIGURE 1.1:

LDV PEV Penetration in 2017



Source: International Energy Agency, Global EV Outlook 2018 Towards Cross Modal Electrification, 2018

TABLE 1.1:

Charging Infrastructure Basics

Infrastructure Type	Voltage	Power	Miles per Hour of Charge	Optimal Locations
Level 1	120V	1.4 kW 1.9 kW	4 6	Family residences and workplaces
Level 2	200-240V	3.4 kW 6.6 kW 19.2 kW	10 20 60	Family residences, workplaces, and public/urban areas
DC Fast-Charging (Level 3)	400V+	24 kW 50 kW 90 kW 150 kW 350 kW	72 150 270 450 1050	Public/urban areas and intercity locations along highways

July 2018.[10] Within the PHEV/BEV segment of the market, BEVs have surged in popularity since 2013. While PHEVs were more popular in 2012, since 2013 the sale of BEVs has exceeded that of PHEVs, although both have a substantial share of the market. The PHEV and BEV market segments include various models and manufacturers, even though there are differences between the two segments. The PHEV market includes more manufacturers and models, whereas the BEV market has three main manufacturers presently (Chevrolet, Nissan, and Tesla), though many new models are coming to the market from new firms. Because the PEV market has grown so significantly, the two main BEV manufacturers have sold enough BEVs that their U.S. federal tax credits have started to phase out, with a third major BEV manufacturer quickly approaching the phase-out stage of the federal tax credit.

One of the most critical factors that determines electric vehicle viability and cost are their batteries. Battery cost is a primary driver of the overall total sale cost of an PEV. Because cost and range are key determinants for demand of new PEVs, battery price and capacity will need to continue advancing in order for the PEV share of the overall LDV market to increase. Such costs have decreased substantially over the past 2-5 years, and are projected to comprise a significantly lower portion of overall costs. Although vehicle and powertrain costs have not seen any recent decrease in production costs, decreasing battery costs have made the price of an PEV closer to conventional ICEVs.

1.3 CHARGING INFRASTRUCTURE

The driving patterns of most LDV consumers are relatively consistent. Short, habitual trips between home and work makeup the largest portion of driving trips. Across all driving trips in the United States, the average trip length is approximately 9 miles.[11] Because trips are generally short, the majority of PEV charging takes place at home where vehicles reside most of the time. Despite these consumer habits, access to charging away from home at locations with long dwell times, such as workplace and commerce centers where drivers park for extended periods of time, is highly valued by drivers. Fast, accessible charging infrastructure will be needed along freeways and arterial routes for long BEV trips. PHEVs include an internal combustion engine, so they have less need for such charging infrastructure.

Table 1.1 above shows the basic characteristics for the three main PEV charging infrastructures. Level 1 charging requires only a 120V outlet and a standard cord with a J1772 connector. Typically, these come free with the vehicle at the time of vehicle purchase. This infrastructure can charge an PEV – both PHEVs and BEVs – at about 2-6

10 Kane, Mark. "2018 July US Plug-In Electric Car Sales Charted: Market Share Exceeds 2%." InsideEvs.com. August 11, 2018. Accessed April 22, 2019. https://insideevs.com/news/338839/2018-july-us-plug-in-electric-car-sales-charted-market-share-exceeds-2/

11 Van Haaren, Rob. "Assessment of Electric Cars' Range Requirements and Usage Patterns Based on Driving Behavior Recorded in the National Household Travel Survey of 2009." 3,200 Miles, Powered by the Sun. July 2012. Accessed April 22, 2019. www.solarjourneyusa.com

miles per hour of charge time. Level 2 charging requires a 240V receptacle and can charge 10-20 miles per hour of charge time. Direct-Current Fast-Charging (DCFC) infrastructure includes charging cords on-site, but requires much higher voltage and power levels than either Level 1 or Level 2. As a result, it charges PEVs much faster than both of the other levels. Depending on the amount of power used it can fully charge an PEV in 30-60 minutes. The current charging infrastructure varies drastically depending on the location.

The cost of infrastructure varies considerably as well. According to the Electric Vehicle Charging Association's report, "The State of the Charge", from May 2018 the PEV charging infrastructure industry "is expected to grow at a compound annual growth rate of 46.8% from 2017 to 2025."[12] Exact costs therefore carry a high amount of uncertainty. Each type of electric vehicle supply equipment (EVSE) has different requirements and costs for installation, equipment, and permitting among myriad other factors that can be involved depending on the location. Because EVSE are long lived capital assets, and thus fixed, the degree of asset utilization plays a role in the overall cost of the service. The more often the equipment is used, the lower the overall cost of the service. Single-family residences have the cheapest charging given Level 1 charging cords come free with the vehicle and plug into a common 120V power outlet and Level 2 EVSE are relatively low-cost equipment upgrades. Intercity DCFC is likely the most expensive type of infrastructure, given both the number of costs involved and the low degree of asset utilization in many locations at current BEV adoption rates. According to Karl Popham, Manager of Electric Vehicles and Emerging Technologies at Austin Energy, the deployment cost per plug or port of Level 1 EVSE is roughly $100 and in many cases is already available; the cost for Level 2 EVSE is roughly $1,800 for at-home charging and $4,500 for public Level 2 charging; and the cost for DCFC is roughly $150,000.[13]

Additionally, EVSEs can include "smart charging" or "intelligent charging" software that gives either the consumer or the grid operator managed control over charging habits. Virtually all modern PEVs include programming capability to support TOU (time of use) electricity programs. More sophisticated smart charging can be deployed to more precisely shift charging times to periods when the grid needs more or less load. Such hardware and software enhancements might require incremental costs but can benefit both the electricity consumer as well as the utility and electric grid.

1.4 ELECTRIC GRID

Although PEV charging infrastructure can be seen as a public versus private issue, utilities are one of the most significant stakeholders in the rapid growth of the PEV market. It is ultimately the responsibility of the utility or grid operator to manage anticipated increases in electric demand loads caused by PEVs. For utilities, the cost of additional PEVs charging through grid connections might include the cost of generation, transmission, and distribution system upgrades to handle the additional load. Because of its importance, understanding how the electric grid works and how EVSE affects and is affected by the grid is central to our understanding of PEV charging infrastructure.

This chapter explains these topics for the layman's understanding. It explains how electricity is generated, transmitted, distributed, and finally sold to consumers. Focusing on the Texas market, run mostly by the Electric Reliability Council of Texas (ERCOT), this chapter then discusses the issues PEV infrastructure deployment faces in each phase of the electric market, particularly with regard to the large fixed costs that grid operators and plant investors seek to profitably recover.

1.4.1 Generation

There are three types of electricity generation. The most common type is the thermal generator. Thermal generators use fossil fuels such as coal or natural gas to heat water and make steam. The steam then moves large turbines with mechanical energy that is thus transformed into electrical energy. These thermal generators are found in natural gas, coal, nuclear, concentrated solar, and

12 *The State of the Charge: Report of the Northeast's Electric Vehicle Charging Industry.* Issue brief. Electric Vehicle Charging Association, 2018.

13 Ibid.

geothermal electrical plants. Another common type of generator is the non-thermal turbine. These are often found in hydroelectric dams that use falling water to move large turbines, windmills that use wind power, as well as natural gas combustion turbines that are derived from jet engines. Finally, there are semiconductor-based generators that use photovoltaic technologies to capture photons and create electrical energy.

When considering PEV charging infrastructure there are few issues to consider at the generation level of the electric grid. Regardless of the market structure – whether it be the traditional vertically integrated utility, a generation and transmission utility alongside a rural electric co-op, or a competitive wholesale and retail market – generation inherently poses few threats to EVSE deployment so long as enough electricity generation capacity exists to meet the demand from electric vehicle uptake.

1.4.2 Transmission and Distribution

After the power plant generates electricity, it is transferred to residential, commercial, and industrial centers by way of transformers and high-voltage power lines. Electric lines from generators transmit electricity at 20,000 volts, then are stepped-up to between 69,000 and 345,000+ volts for powerlines that travel long distances. High voltages allow electricity to transmit long distances with relatively low power loss. Once these lines reach residential, commercial, and industrial centers they connect with transformer substations that step-down the voltage level (e.g. 7,400 volts). These powerlines then distribute electricity around populated areas. Once the lines reach end-users, such as commercial buildings or residential homes, the voltage on the lines is stepped-down once more to 240 volts. Common power outlets in U.S. residential and commercial buildings use plugs at 120 volts, and larger-use electric device like dryers and ovens use plugs at 240 volts.

For PEV LDV charging infrastructure, the focus of this report, transmission is not a major concern when making deployment decisions. Distribution is a consideration for DCFC infrastructure deployment, as these electrical-use points require higher voltage and current than Level 1 or Level 2 EVSE. As shown in Table 1.1, Level 1 charging utilizes 120V power outlets while Level 2 utilizes 240V outlets: both types are available in all homes and commercial buildings. One issue to consider is how to connect PEVs with the outlets themselves. Solving this problem depends entirely on the use-case location, and as such is specific to each use-case and will be discussed there. A second potential issue is over-loading distribution transformers that step-down voltages. Increasing adoption of PEVs can lead to clusters of higher electricity demand than previously estimated for electricity infrastructure deployment. Some solutions to this may include the installation of "smart-charging" or "intelligent charging", which can shift electric demand to less-utilized periods. Another solution may be to upgrade distribution transformers for certain areas, but this entails estimating the growth of PEV drivers in different areas – a highly uncertain forecast – and may be more expensive than necessary. As discussed in a later chapter, however, PEV clustering may not pose much challenge to the distribution system (see: 2.5 Policy Case Study: Pecan Street Project of this report for details).

1.4.3 Electric Retail

Connecting users with electricity generation requires investment in long-lived, potentially expensive fixed capital assets. Because of this, generation, transmission, and distribution comprise the majority of electricity retail prices in most regions. For the average residential cost of $0.12 per kWh, transmission lines are $0.011 per kWh, distribution is $0.03 per kWh, and generation is $0.057 per kWh.[14]

Grid operation contains a number of unique challenges, not least of which is that demand varies over the course of a day, a week, and a season. Figure 1.2 on page 15 shows an example of the variability of electricity demand for the week of 4/16/2019 through 4/23/2019 using forecasted numbers from ERCOT. Additionally, the production cost of different types of generators varies greatly. In order to provide a reliable supply of electricity at the lowest cost possible

14 U.S. Energy Information Administration, *Annual Energy Outlook 2012*, Reference Case, Table 8: Electrical Supply, Disposition, Prices, and Emissions.

under given conditions, grid operators use an optimization process called security constrained economic dispatch (SCED).[15] SCED includes two time periods for dispatching electricity: day-ahead and real-time economic dispatch. The former utilizes forecasts to predict needed electricity supply while the latter is done in real time.

Under either day-ahead or real-time economic dispatch, generators offer their electricity supply to the grid operator at marginal operating costs, the cost of producing one additional unit of electricity. After generators offer their supply of electricity, the grid operator dispatches electricity using supply at the lowest cost up to the highest cost until electric demand is met. This allows the grid to offer both reliable electricity output and low cost. Operators dispatch generators every 5 or 15 minutes. Because some generators have long turn-on and turn-off times, particularly nuclear and coal, these generators are available at all times of day: they will always be used so long as there is demand. Renewable, nuclear generators, and hydroelectric dams provide electricity at the lowest demand, followed by coal plants due to their high capital costs. As demand increases, natural gas-combined cycle, natural gas, and petroleum power plants can be used on the grid in order to meet extremely high demand.

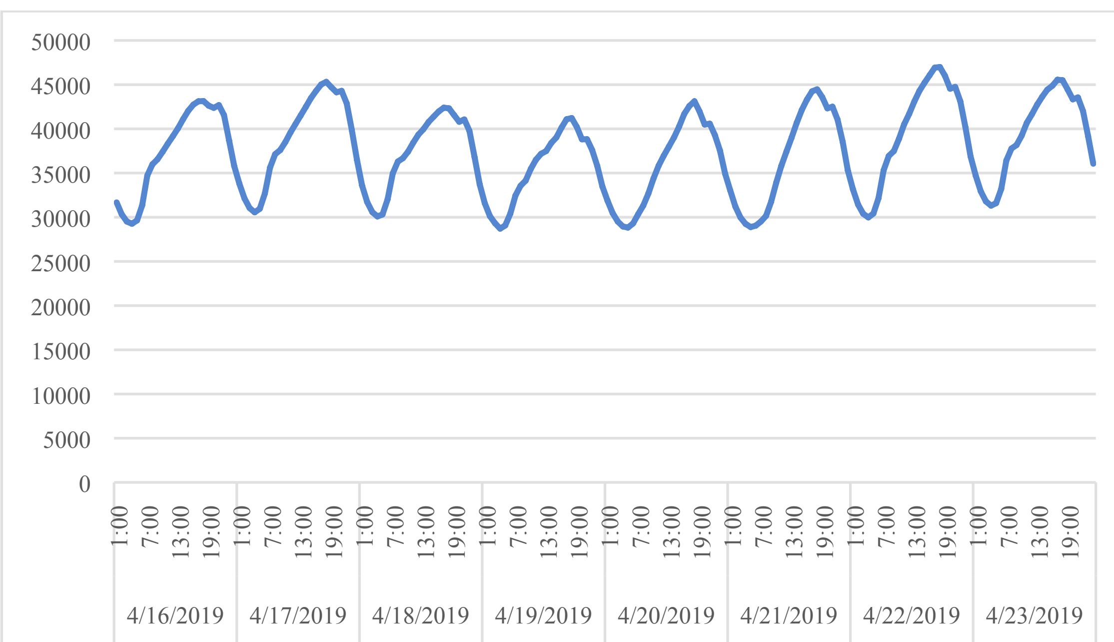
Electricity demand is highest during working hours, with its peak occurring toward the end of the workday as residents return home and utilize appliances, electrical outlets, and air conditioning. Figure 1.2 below shows this using forecasted data over a single week. Demand tapers off as people go to sleep. Because of the variability demand from day to week to season, the grid must ensure that there is always enough electricity for everyone. As a result, the grid operator includes a safety margin on top of peak demand when dispatching electricity.

Timing electricity demand is one of the most important technical challenges associated with PEV charging infrastructure. This is especially the case for DCFC infrastructure, as this type of high-power

15 United States. Department of Energy. Federal Energy Regulatory Commission. *Security Constrained Economic Dispatch, Definition, Practices, Issues, and Recommendations: A Report to Congress regarding the Recommendations of Regional Joint Boards for the Study of Economic Dispatch, Pursuant to Section 223 of the Federal Power Act as Added by Section 1298 of the Energy Policy Act of 2005.* Federal Energy Regulatory Commission, 2006.

FIGURE 1.2:

Forecasted Demand for Select Area of ERCOT Market



Source: ERCOT Seven-Day Load Forecast by Forecast Zone charging can put significantly higher stress on the electric grid. As a result, DCFC infrastructure may face demand charges in addition to their per kWh charge. These demand charges, one component of a user's electric bill, are determined based on the highest 15-minute average usage on a meter within a given month. Typically, commercial and industrial customers pay these charges, but it is not unheard of for residential consumers to also see demand charges on their electric bill. These user-fees are meant to help utilities recover the substantial fixed costs of installing long-lived capital investments required to deliver the peak amount of electricity for their customers. Because of its high-power output, DCFC can easily incur demand charges that will greatly exceed the per kWh electricity charge. Demand charges thus greatly increase the cost of operating DCFC infrastructure and must be considered when choosing whether or not to invest in such capital.

Usage timing is also important for Level 1 and Level 2 charging, but mostly from a benefits standpoint rather than a costs issue as is the case with DCFC. Because a significant amount of fixed capital is spent to meet high peak demands, PEV charging can possibly increase electricity sales that allow utilities to increase their own asset utilization and lower their overall average costs: they will generate more revenue through greater use of electric assets as PEVs charge overnight. This is not just theoretical for utilities. According to Karl Popham, Manager of Electric Vehicles and Emerging Technologies at Austin Energy, one PEV consumer is worth roughly $400 per year of new revenue to the utility; one high mileage PEV consumer is worth almost $2,700 per year of new revenue.[16] Level 2 charging with "smart-charging" or "intelligent charging" likely can further increase value to the utility. Because smart-charging allows the PEV owner or utility to shift electricity demand to periods with less demand, smart-charging further increases asset utilization for utilities.

16 Popham, Karl. "Best Practices for Electric Vehicle Charging Infrastructure." Lecture, Electric Vehicle Charging Infrastructure, Austin, TX, September 13, 2018.

2 | SINGLE-FAMILY CHARGING

2.1 EXECUTIVE SUMMARY

Single-family residential charging is the most convenient, cost-effective, and widely used charging infrastructure available to today's PEV owners. With over 80% of current PEV charging occurring at home, the ease and convenience of residential charging has been largely incentivized through private capital. Because PEV owners are solely responsible for selecting and purchasing a charger for their vehicle, policymakers can make the process of selecting and financing charging infrastructure more convenient. Policymakers have a range of potential policies to choose from to promote electric vehicle supply equipment (EVSE): financial rebates, tax credits, changes to building code requirements, and faster permitting are just a few ways to minimize the barriers of purchasing EVSE. Utility providers can also help promote EVSE deployment by providing their own rebates for smart chargers in areas where grid modernization can help manage demand.

Currently, the majority of PEV owners occupy single-family residences that function as their primary charging locations. Increasing the amount of charging infrastructure available will make it easier for consumers to make purchasing decisions that benefit policymakers' stated goals. Public activity in the form of investments and incentive structures can help the private sector mitigate barriers for affordable charging infrastructure, but these policy structures must be tailored to local circumstances.

Despite the policies that can be put forward to increase EVSE deployment, there is not a need for public investment in single family home PEV charging infrastructure upgrades. Residential PEV charging infrastructure has been implemented primarily by PEV owners upgrading their infrastructure at their personal cost. Occasionally, this cost has been mitigated with public incentives such as utility rebates and subsidies for EVSE at single-family residences. In such cases where subsidies are already in place, utility Time-of-Use rates or incentives to use intelligent charging may be more appropriate.

It should be noted that single-family residential PEV charging infrastructure is funded through the private sector, as most residential homes are already equipped with the infrastructure needed to charge their PEVs: public sector intervention is largely unnecessary. However, utilities and the public sector may need to provide financial incentives depending on specific regional needs.

Our 3 recommendations for single-family residential PEV charging infrastructure investment follows:

1. **Local governments could work with building code associations to institute PEV-ready building codes for new single-family residence construction in their jurisdictions.**
2. **Utilities and local governments could incentivize single-family resident PEV owners to adopt intelligent charging hardware and software through rebate and subsidy programs, depending on grid capacity and regional needs.**
3. **Utilities and local governments should not institute policies to increase deployment of DCFC EVSE for single-family residences.**

2.2 INTRODUCTION

This chapter exclusively discusses the case for promoting the deployment of PEV charging infrastructure at single-family residences. These residences are private property housing units physically and financially detached from surrounding construction. They are either owner-occupied or renter-occupied. Such housing units present a number of characteristics favorable to PHEV and BEV owners. First, PHEV and BEV owners can charge their vehicles at single-family homes at any time without waiting. Second, aside from the electrical outlet and cord costs, PEV owners only pay for the cost of electricity. Finally, nearly all single-family detached housing units include at least a driveway if not a garage; PEV owners occupying single-family homes thus already have access to needed charging infrastructure. These conveniences of easy access, low cost, overnight charging, and no wait-times result in the majority of PEV owners charging on-site at single-family homes. This makes single-family residences an important use case for the further deployment of PEV charging infrastructure, which this chapter explores in depth.

We compiled this chapter through an extensive literature review on the characteristics of this use case and its available policy options. Utilizing a number of research articles, contemporaneous news articles, and data provided by the U.S. Government and other entities, we discuss the need for further deployment of charging infrastructure. A majority of the information we use comes from federal agencies and research laboratories. The U.S. Census Bureau, the U.S. Department of Energy, and the National Renewable Energy Laboratory were utilized extensively in the making of this report. We also incorporate work done by the International Council on Clean Transportation, the Smart Energy Power Alliance, the California Public Utilities Commission, and Austin Energy. Of particular note for this section is the work done by Pecan Street Incorporated to unify a neighborhood containing a high concentration of PEVs into a singular Smart Grid. Using this information, this section discusses the unique characteristics of single-family homes pertinent for the overall PEV charging system, the policy levers available for decision makers, barriers to policy adoption, and potential business models for the infrastructure.

Existing PEV charging infrastructure for single-family homes is pervasive. All such housing units come equipped with 120v electrical outlets that can be utilized via cord to level 1 charge PEVs. Virtually all U.S. housing units also come equipped with 240v electrical service that PEV owners can use to level 2 charge at a much faster rate than by level 1 charging. However, DCFC infrastructure is nearly nonexistent in single-family homes, most likely due to the added expense of installation. Despite the popularity of charging at single-family homes, this use case presents a number of unique issues. Utility tariffs, outlet locations, and the homeowner-renter divide are just a few of the issues discussed. The following section describes thus various characteristics of single-family home charging infrastructure and the potential issues it has.

2.3 USE CASE CHARACTERISTICS

2.3.1 Demographics

Current single-family residential demographics shed insight on who might have Level 1 and Level 2 charging infrastructure already available. Table 2.1 below shows the U.S. Census Bureau's 2012-2017 5-year estimate of different housing unit numbers pertinent to the single-family detached residence

TABLE 2.1:

Single Family Residence Housing Characteristics

Statistic	Absolute Amount	Percentage of Total Housing Units
Total Housing Units	135,393,564	100%
Currently Occupied	118,875,550	87.8%
Single-Family Detached	83,537,829	61.7%
Owner Occupied	86,381,094	63.8%

Source: U.S. Census Bureau. 2013-2017 *American Community Survey 5-Year Estimates.* November 28, 2018. Distributed by U.S. Census Bureau. Accessed April 25, 2019. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2017/5-year.html use-case. Importantly, it demonstrates that policies affecting single-family residences will affect 61.7% of all housing units in the United States.

When determining infrastructure needs, the link between income levels and PEV adoption rates is an important consideration, especially with regard to single-family residences. The Economic Research Organization at the University of Hawaii found during a 2010-2016 period that higher income areas in the state of Hawaii were associated with increased PEV adoption levels. Specifically, an increase of $10,000 in median household income was associated with 6 more PEVs.[17] However, this study occurred as PEVs began to reach cost parity with conventional ICEVs. To achieve similar numbers of PEV sales, future trends may show lower increases in median household income as PEV prices go down due to decreasing production costs. This trend highlights a direct correlation between PEV adoption and income levels: lower-income single-family residence occupiers may not be incentivized to purchase PEVs and thus have lower need for requisite infrastructure. Utilities that rate-base capital expenditures as PEV adoption increases – explored in a future section – will regressively affect lower-income groups.

Single-family detached residences currently lead the way on PEV adoption, but likely have their infrastructure needs already met as will be shown in the next section. According to the International Counsel on Clean Transportation, a survey of California in 2017 found that 83% of California PEV buyers lived in single-family detached houses.18 A survey of California Nissan Leaf owners found that 96% of those surveyed owned their homes with 95% living in a single-family residence.19 However, these current trends may not account for future market shifts. While single-family residence occupiers have been the main source of growth for electric vehicles, infrastructure needs may not be as severe for this use case as it is for other locations.

A final important demographic for the single-family residence use case is the owner-occupier rate. As noted previously, 63.8% of all housing units are owner-occupied while 36.2% are renter-occupied. Lucas Davis at the UC Berkeley Energy Institute at HAAS estimates that 0.87% of all homeowners and 0.25% of all renters own an PEV, demonstrating an owner-occupier renter-occupier gap in PEV ownership.[20] Even when controlling for income, as the University of Hawaii survey did, there is a gap between owners and renters in PEV adoption. Davis finds that for the United States as a whole, when controlling for income, household characteristics, and state location, homeownership has a positive correlation with PEV adoption by 3 PEVs per 1000 homeowners. Although renters encompass all housing units (single-family residential as well as multi-unit residences), it underscores the difference between renters and homeowners in the PEV market. Ease of access to charging is a common concern among renters, especially those living in multi-unit residences that do not have convenient access to physical electric connections. Additionally, single-family residential renters may face access challenges similar to other renters. Investing in electric circuit upgrades to a rental property may not be of interest to either the renter that does not have an PEV or the landlord and may regressively impact lower-income renters.

The renter-homeowner gap might not be a short-term issue. But as fewer young Americans invest in homeownership, the renter-homeownership gap might become a more serious issue for PEV adoption. According to the U.S. Census Bureau, homeownership rates for Americans above the age of 35 were at least above 60%.[21] For Americans under the age of 35, the homeownership rate

17 Makena Coffman, Scott F. Allen, and Sherilyn Wee, The Economic Research Organization at the University of Hawaii, *Who are Driving Electric Vehicles?* (Hawaii, Honolulu: May 30, 2018), 3. *An Analysis of Factors that Affect EV Adoption in Hawaii* https://www.uhero.hawaii.edu/assets/WP_2018-3.pdf

18 United States Department of Energy, Energy Efficiency and Renewable Energy, *A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects* (Washington, DC: January 2014), 16. https://afdc.energy.gov/files/u/publication/guide_ev_projects.pdf

19 Lucas Davis, University of California, Berkeley, Energy Institute at HAAS, *Evidence of a Homeowner-Renter Gap for Electric Vehicles*, (California, Berkeley: July 2018), 2. https://ei.haas.berkeley.edu/research/papers/WP291.pdf

20 Lucas Davis, University of California, Berkeley, Energy Institute at HAAS, *Evidence of a Homeowner-Renter Gap for Electric Vehicles*, (California, Berkeley: July 2018), 2. https://ei.haas.berkeley.edu/research/papers/WP291.pdf

21 U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates

is less than 35% in 2017.[22] This gap has to be considered when implementing policy to incentivize PEV adoption and the deployment of charging infrastructure at single-family residences. If expenditures on infrastructure are financed through debt, younger Americans may be paying for infrastructure that they won't get to utilize.

2.3.2 Charging Infrastructure

Charging at home provides conveniences that other charging locations cannot offer. PEV owners in single-family residences can connect their PEV to the grid at any time and leave the vehicle to charge for as long as they wish. In addition, the only added cost for PEV charging is the cost of electricity after the fixed cost of infrastructure installation is accounted for. Low-cost and convenience explain why approximately 80% of all light-duty PEV charging is conducted on-site at single family residences.[23]

Single-family residential charging allows PEV owners to utilize Level 1 or Level 2 charging outlets for long periods of time without concern for the grid or cost. Although both Level 1 and Level 2 charging are slower than DCFC, which is not practical in a single-family residence, PEV owners find it convenient because it offers them the ability to charge overnight. Because of this added battery charge, PEV owners with single-family residences can drive further than those using purely public or workplace charging locations. PHEV and BEV owners using only Level 1 charging at-home drove roughly 2000 more miles than those owners with no home charging.[24] Those owners able to utilize Level 2 charging at times drove almost 3000 more miles.[25] Overnight charging means that single-family residential charging use has the longest dwell-time (the vehicle is stationary and charging without being used) for PEVs of any charging location option.

The above conveniences stem from the low fixed-cost of the charging infrastructure. The vast majority of single-family homes already contain the requisite PEV charging infrastructure for Level 1 charging. The J1772 is the standard cord for Level 1 charging and comes with PEV purchases.[26] However, charging stations must be located near vehicle storage locations for PEV owners to actually utilize the available infrastructure. Depending on how close the Level 1 outlet is to the vehicle, the standard cord-set may be all that is necessary for PEV owners to charge at-home. If the distance is greater than what the standard cord-set allows, an extension cord may be required to reach the vehicle. Owners also have to ensure that the outlet chosen for their PEV charging needs does not also supply other appliances, as the charge may require all the current the circuit allows. Because Level 1 charging is so prevalent for single-family residences, the vast majority of PEV owners utilizing at-home charging do not have to pay the additional fixed cost of the infrastructure.

Despite its widespread prevalence, some additional factors need to be considered when assessing the infrastructure needs of Level 1 charging. For PEV owners in single-family residences that do not have access to Level 1 charging near the parked vehicle, outside circuit upgrades may be necessary. If the PEV is stored in a garage attached to the home this is unlikely, but for single-family residences that have a detached garage or no garage at all it is more likely. Data from a 2015 Energy Information Administration Residential Energy Consumption Survey (RECS) is shown below in table 2.2. The table demonstrates the percentages of single-family detached residences with attached garages and with cars parked near outlets, and that number as a percentage of total housing units. Roughly 30-40% of single-family residences may not be able to adequately charge using either Level 1 or Level 2 EVSE. As a result, some PEV owners might need to pay for the fixed cost of outlet installation to access the convenience and low-cost amenities of even just Level 1 charging at-home. Using the 2015 data, we can expect roughly 30-40% of single-family residences may require upgrades.

For PEV owners who want a faster at-home charge time, Level 2 charging is an attractive

22 U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates

23 "Charging at Home." Energy.gov. Accessed April 22, 2019. https://www.energy.gov/eere/electricvehicles/charging-home

24 Nicholas, Michael, Dale Hall, and Nic Lutsey. 2019. "Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets". The International Council on Clean Transportation, January.

25 Ibid, 5.

26 "Charging at Home." Energy.gov. Accessed April 22, 2019. https://www.energy.gov/eere/electricvehicles/charging-home

TABLE 2.2:

Parking Locations for Single-Family Residences

Statistic	Absolute Number	Percentage of Single-Family Detached	Percentage of Total Housing Units
Single-Family Detached	83,537,829	100%	61.7%
With Attached Garage	49,571,348	59.34%	36.61%
With Car parked within 20 feet of an outlet	54,800,160	65.6%	40.48%

Source: "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Energy Information Administration (EIA) - About the Residential Energy Consumption Survey (RECS) Table HC1.1 Fuels Used and End Uses in U.S. Homes by Housing Unit Type, 2015. Accessed April 22, 2019. https://www.eia.gov/consumption/residential/data/2015/hc/php/hc2.1.php

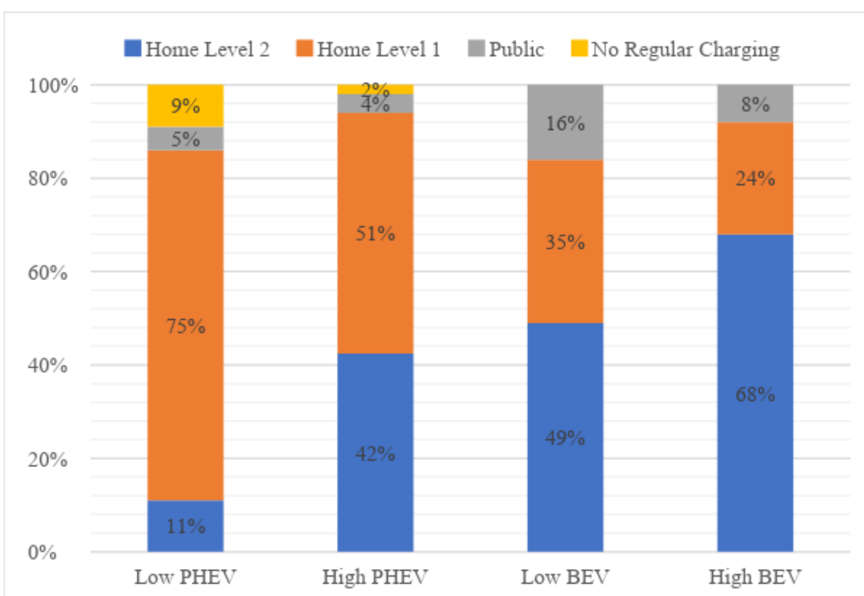
option. Virtually all U.S. homes typically have 240V electric service with 240V wiring for such devices as dryers, electric ovens, HVAC systems, and other heavier appliances that are often already installed. But, as was the case with Level 1 charging, a Level 2 outlet must be located close enough to the vehicle parking location for the PEV owner to make use of it. Whether that be an attached garage, a detached garage, or exterior parking, single-family residences will likely have to install an additional circuit as well as a 240V plug to utilize it. If a Level 2 outlet normally used for a dryer is located near the garage, an extension cord may suffice for the PEV owner to utilize it, but in most cases an upgrade is necessary. Installation costs range from $500 to $2000 dollars depending on the type of charging equipment, the necessary circuit upgrades, installation fees, and permitting fees.[27] Since 65.6% of single-family residential occupiers do not park a car within 20 feet of an outlet, we can expect that at most roughly 35% of residences will not have Level 2 EVSE readily available.

Despite these locational issues, a large number of current PEV owners already utilize both Level 1 and Level 2 charging. Figure 2.1 below

27 "Charging at Home." Energy.gov. Accessed April 22, 2019. https://www.energy.gov/eere/electricvehicles/charging-home

FIGURE 2.1:

Detached Housing Charging Usage



Source: Nicholas, Michael, Dale Hall, and Nic Lutsey, 2019.

breaks down the type of charge used by PEV type for detached homes in California.

This data from the International Council on Clean Transportation shows that, despite the potential factors mitigating the cost of charging at single-family residences, the majority of PEV owners who reside in such units charge at home. BEV owners prefer Level 2 charging over Level 1, likely because the faster charge time enables them to more quickly fill their BEV battery capacity to reduce range anxiety, whereas PHEV owners have smaller battery capacities and thus do not have to charge as long. As a result, PHEV owners have less need for Level 2 charging. As PEVs continue to penetrate the market share of all vehicle sales, installing Level 2 chargers might increase the value of single-family residences by adding an amenity that homebuyers will be willing to pay a premium for. Landlords looking to attract renters and increase rental values in a future with high PEV market penetration might also consider installing Level 2 chargers or 240V NEMA 14-50R outlets. Nonetheless, using either Level 1 or Level 2 charging, PEV consumers occupying single-family homes derive most of their battery charge from the home's connection to the electric grid.

2.3.3 Electric Grid

While PEVs affect the electric grid, it is only when a cluster of PEVs charging using Level 2 or higher power ranges simultaneously that utilities may see distribution issues. The more important PEV effects for the grid are through filling demand issues. Falling aggregate demand for electricity due to more energy efficient devices, sharper demand ramps due to intermittent renewable sources like solar and wind, and larger peak buffers for the grid are all affected by single-family residential charging. Rather than creating a problem for the grid, at-home charging can actually provide a number of benefits. Smart-charging – combined with Level 2 charging – can mitigate peak-load charging and save PEV owners demand charges. Overnight charging can help the grid utilize a larger amount of intermittent wind power generation, as wind generation is often highest at night. However, depending on the growth of PEVs in the single-family use case, utilities may have to perform distribution upgrades to effectively service customers.

Smart-charging combined with both Level 1 and Level 2 charging automatically responds to grid load and demand. Although more expensive than standard cord-sets, a number of charging cords now come with smart-charging equipped as PEV owners' demand for it has increased. This type of automatic charging software can prevent charging during peak load times for the average residential consumers when high numbers of PEVs are charging at the same time. Furthermore, it can charge only during the grid's off-peak times, saving the PEV owner in rates if the utility connected to the single-family residence includes Time-of-Use rates as well. This type of active management of charging behavior benefits the utility by allowing them to shave the amount of electricity needed at the most expensive times of the day, mid-afternoon to early evening.

While PEV owners in single-family residences do not need smart charging to charge their vehicles overnight, overnight charging also benefits the utility. As the amount of intermittent wind generation increases, utilities will have to find ways to sell that electricity to consumers. Since wind capacity is highest at night, overnight charging at single-family residences allows the utility to utilize this excess electric generation that is available on the grid during off-peak hours regardless. This type of utilization requires work done by the utility to ensure it works, but PEV single-family residential charging provides this benefit and thus utilities may be incentivized to promote overnight PEV charging through Time-of-Use rates.

One of the main problems at-home PEV charging creates for the grid is the distribution requirement massive electrification requires. Although transmission from electric generation to consumer residences will not likely be impacted by growing PEV market penetration, distribution can be affected. Because some homes may require Level 1 or Level 2 charging upgrades, distribution lines may also need to be increased to meet this growing circuit demand. As the number of lines increase, so too do the number of transformers needed to ensure a safe voltage output. While these higher capital costs may not be impactful in the short-term, in the long-term they will likely become contentious. Since a large number of capital investments are rate-based across the entirety of a utility's retail market, non-PEV owners occupying single-family residences may end up subsidizing PEV use while seeing none of the benefits, as noted previously in the demographic section. This type of energy equity is an important policy issue as PEVs become a larger part of the market.

2.4 POLICY CONSIDERATIONS

2.4.1 Utility EVSE Rebates

To realize the benefits of single-family residential PEV charging noted previously, utilities must invest in intelligent PEV charging infrastructure. Financial incentives for single-family residential PEV smart-charging, as well as special PEV electricity rates, are still in the planning stages for a variety of utilities. So far only 27 of the 486 utilities surveyed offer incentives on residential chargers.[28] A few examples of utility incentives are shown in Table 2.3 below. Although utilities in western states have led the way on innovative rebate

28 "Electric Vehicles: Tax Credits and Other Incentives." Energy.gov. Accessed April 22, 2019. https://www.energy.gov/eere/electricvehicles/electric-vehicles-tax-credits-and-other-incentives

TABLE 2.3:

EVSE Utility Subsidy Programs

Utility Name	Qualifying Groups	Rebate Amount
Austin Energy[1] Texas	PEV owners	50% of the cost to purchase and install a qualified Level 2 EVSE, up to $1,200
Los Angeles Department of Water and Power (LADWP)[2] California	Commercial customers	Up to $5,000 for each Level 2 charger and an additional $750 for extra charge ports. Does not cover installation costs.
	Residential customers	Up to $500 for wall-mounted Level 2 chargers within LADWP service area.
Gunnison County Electric Association (GCEA)[3] Colorado	Residential customers	35% of the cost of a Level 2 EVSE up to $250. When purchased directly through GCEA receive a 5% discount on EVSE.
Green Mountain Power (GMP)[5] Vermont	Residential customers	Eligible for a free Level 2 EVSE when purchasing a new BEV. Owners of BEVs can rent a Level 2 EVSE for a low monthly fee.
Georgia Power[5] Georgia	Residential customers	$250 rebate for each dedicated Level 2 EVSE circuit installed before 2019.
	Businesses	$500 rebate for each dedicated Level 2 EVSE circuit installed before 2019.
	Builders	$100 rebate for each dedicated Level 2 EVSE circuit installed before 2019.

Source: "Electric Vehicles: Tax Credits and Other Incentives." Energy.gov. Accessed April 22, 2019. https://www.energy.gov/eere/electricvehicles/electric-vehicles-tax-credits-and-other-incentives

1 "Home Charging." Austin Energy. Accessed April 22, 2019. https://austinenergy.com/ae/green-power/plug-in-austin/home-charging/home-charging

2 "Electric Vehicles (EVs)." LA DWP. Accessed April 22, 2019. https://www.ladwp.com/ladwp/faces/ladwp/residential/r-gogreen/r-gg-driveelectric?_adf.ctrl-state=1d4357epvd_4&_afrLoop=321958678746245&_afrWindowMode=0&_afrWindowId=null#@?_afrWindowId=null&_afrLoop=321958678746245&_afrWindowMode=0&_adf.ctrl-state=196t293pr_4

3 "EV Charger Rebate." EV Charger Rebate. Accessed April 22, 2019. https://gcea.coop/content/ev-charger-rebate

4 "In-Home Level 2 EV Charger." Green Mountain Power. Accessed April 22, 2019. https://greenmountainpower.com/product/home-level-2-ev-charger/

5 "Electric Vehicles." ON Georgia News Center. Accessed April 22, 2019. https://www.georgiapower.com/residential/save-money-and-energy/products-programs/electric-vehicles.html?nav=footer_ee_plugin&hp=bm_ci_electric_vehicles

strategies, a few eastern states such as Vermont are also innovating different business models.

2.4.2 Utility Time of Use Rates

Another popular strategy being explored as a way to manage the increased number of PEVs on the market is Time of Use Rates (TOUs). These price models shift the peak load away from afternoon peak hours when demand for electricity is the highest by offering much lower rates overnight (e.g. from 11pm to 5am). TOU rates also require the installation of TOU meters on single-family residences. Many utilities offer rebates and incentives for the installation, reducing the fixed cost near zero to homeowners while also reducing the variable costs of each kWh consumed.

Moving residential customers to TOU plans attempts to increase the economic efficiency of utilities by creating a retail price signal that more accurately reflects current demand and wholesale price of electricity. Some states, such as California, have mandated that all investor-owned utilities develop TOU rates to meet energy efficiency standards. Although investor-owned utilities have reported moderate success in shifting electricity demand to off-peak periods, concern remains for low-income households and for dealing with intermittent solar generation. Low-income households generally use less energy than the standard customer. As a result, these households may be less responsive to price changes. Both a smaller magnitude of savings and an inability to switch charging behavior without greatly affecting their livelihoods limits the effect of TOU rates on low-income households. Additionally, the traditional TOU peak/shoulder/off-peak structure may not align well with desired price signals given large-scale deployment of photovoltaic to address the duck curve. While TOU rate plans provide a number of benefits to both the utility and the consumer, they do not solve everything.

2.4.3 Utility Real Time Pricing + Smart Charging

Combining smart charging EVSE with real time prices, through demand response for peak shaving, is a relatively new innovation that utilities are still piloting in the single-family residential market. A residential customer must have a smart charger that is able to react to signals from their utility to use this combination. This type of charging relies on real time electricity prices to encourage customers to dynamically respond to price changes. It differs from the TOU rates described above by utilizing automation technology. Without smart charging, TOU rates require the PEV owner in a single-family residence to manually choose when to and when not to charge their vehicle. However, this type of programming could be completely automatic if programmed correctly.

However, this type of policy requires more expensive EVSE on the consumer side as well as more labor and implementation cost on the utility side. Although this could effectively reduce electricity costs for consumers and save utilities production costs in the long-run, the equipment required for instituting this policy could raise the total cost of ownership for electric vehicles. More research should be done to determine if this is a meaningful added cost for PEV owners or if it should be subsidized.

2.4.4 Business Model Options

While utility and state policies make up the majority of financial incentives for single-family residential chargers, the EVSE itself is almost exclusively built and installed by private sector companies. While close to half of PEV consumers purchase a home charger at the point of sale, over 50% of PEV owners shop for their own Level 2 EVSE charger and installation. Because installation involves changing the residence's circuit breaker, it's highly recommended that the PEV owner hire a professional electrician to conduct the necessary work. More specifically, Level 2 EVSE installation requires attaching a double-pole circuit breaker to 2 120V buses at once using a 3 or 4-strand wire. The installer must attach a ground wire to the ground bus bar, a neutral/common wire to the wire bus bar, and two "hot" wires to the double-pole breaker. However, this assumes that the circuit breaker is compatible with this type of installation: some owners may have to replace the entire circuit breaker panel to make such changes if their home is very old and in need of an upgrade. Local building codes may require the single-family residence owner to purchase a building permit, as well as have a professional inspection conducted. Both factors raise the price of installation: some estimates show the full costs of installation – after the Level 2 stand is accounted for – to be anywhere from $200 to $2,000.[29]

As part of its value proposition to prospective PEV owners, Tesla has the option to purchase a home charging DIY kit.[30] However, such kits presume the purchaser already has an updated electricity panel and access to sufficient current capability alongside the physical location needs highlighted in a previous section. For non-Tesla PEV buyers, the charger market is much more fragmented. Consumers have to navigate the different types of equipment available, as well as the usual installation and permitting markets in their local areas. To streamline this part of the PEV ownership experience, Amazon offers its own home installation service as an optional add-on for anyone who buys a third-party EVSE from its website. Chargepoint, an original equipment manufacturer of Level 2 EVSE chargers, also offers a network of installation contractors through their partnership with Qmerit.[31] These private sector investments in the business of single-family residential charger installation suggests that the market is betting not only on demand for PEVs to rise, but also that installations can be a profitable enterprise.

2.4.5 Accelerated Permitting and Building Codes

A final policy lever that local governments can use to accelerate the deployment of EVSE is through changing building codes and ordinances. Some cities in California have begun pursuing PEV-ready wiring codes with the goal of avoiding costly retrofitting for consumers. In 2016 the City of San Francisco published a report that found installing EVSE infrastructure during initial construction is cost-effective compared to retrofitting. Although research at a larger scale needs to be done on how changing building codes impact single-family residential construction and the availability of PEV charging infrastructure, a small number of cities are moving forward on implementing such changes. Particularly, Palo Alto, California and Atlanta, Georgia have both passed legislation requiring single-family residential homes to be PEV-ready. PEV-ready building codes require new construction to have sufficient electric service capacity, a spare breaker location for each additional 240V circuit, and running conduit or prewiring a NEMA 14-50R outlet.

A number of building and electrical codes must be changed to influence EVSE deployment. The two most important bodies of regulation are the existing National Electric Code and the International Building Code. Although changing these codes can encourage state and local governments to change their building, permitting, and inspection codes, the controlling authorities are still local building and fire departments and thus requires buy-in from myriad organizations: changing codes will be a patchwork process. Despite these challenges, changing specification requirements presents the greatest opportunity to simplify EVSE deployment given the demographic and infrastructure considerations previously discussed.

2.5 POLICY CASE STUDY

The Pecan Street Project case study presented here demonstrates a combination of the policy levers previously discussed. The Pecan Street Project in Austin, Texas' Mueller neighborhood incorporates PEVs and energy efficient single-family residences into the construction of a Smart Grid. By demonstrating the feasibility of PEVs for the overall electric grid using a combination of incentives, the Pecan Street Project exemplifies how utilities can use policy to mutually beneficial aims for consumers and utilities. Furthermore, it allows us to better understand PEV charging behavior and how infrastructure meets PEV owners' needs.

Begun in 2009 in Austin, Texas' Mueller development, the Pecan Street Project is an initiative to create energy efficient homes connected

29 Ference, Audrey. "Electric Car Charger Installation in Your Home: True Costs - and What You Need to Know." The Cost of Installing an Electric Car Charger in Your Home. November 2, 2017. Accessed April 22, 2019. https://www.realtor.com/advice/home-improvement/installing-electric-vehicle-charger/.; "Install an EV Charging Station." EnergySage. January 17, 2019. Accessed April 22, 2019. https://www.energysage.com/electric-vehicles/charging-your-ev/install-a-home-charging-station/

30 Lambert, Fred. "Tesla Launches New Wall Connector with NEMA 14-50 Plug." Electrek. January 16, 2019. Accessed April 22, 2019. https://electrek.co/2019/01/15/tesla-wall-connector-nema-14-50-plug/

31 "ChargePoint Home EV Charger." ChargePoint. Accessed April 22, 2019. https://www.chargepoint.com/drivers/home/

to a smart grid system. The project comprises 1,115 residences and businesses, including 250 solar homes and 65 PEVs.[32] Data collected from residential energy generation and use have been applied in various research projects to study the neighborhood. Pecan Street's main areas of focus are on energy, water, and transportation research. One of the first projects of its kind, research from Pecan Street can be extrapolated to broader policy perspectives, especially as they relate to single-family residential PEV charging infrastructure policy levers.

As part of the research program, Pecan Street initiated a behavioral research project to understand residential charging patterns, charging preferences, and how charging impacts utilities. To have a large concentration of PEVs within the study area, Pecan Street offered incentives through an EVSE rebate program. Participants were also provided with the installation of a Level 2 EVSE charger in their homes. Within 6 months of the program's start, 69 homes within the Pecan Street project bought or leased PEVs.[33]

With a large concentration of PEVs in the development, the project aimed to understand how PEV clustering can impact the electric grid. For its research, Pecan Street collected data on 4,000 charging events during a 7-month period in 2012 and 2013.[34] Furthermore, PEV adoption in the development largely coincided with increasing rates of single-family residential solar photovoltaic adoption, and as a result all homes in the study were equipped with PV systems. Nearly all homes also had Level 2 EVSE, and those that did not were able to use publicly available Level 2 EVSE in the surrounding area.

The project found that roughly 60% of all charging events lasted between 41 and 160 minutes, with 12% more charges occurring on workdays than on weekends, and 35% of all charges start between 4PM and 8PM.[35] These results cement our understanding that single-family residential PEV owners primarily use their vehicles for commuting to work, but the results also contradict previous assumptions that single-family residential charging occurs mostly overnight. This study showed that charging in short bursts of less than 3 hours provided sufficient energy for most PEV owners. Given that the study used Level 2 EVSE, overnight Level 1 EVSE usage might be higher given that PEV owners would need more time to get a similar charge for their work commutes. Another consideration is that PEV owners are charging as much as they need to while still awake: since so few charging events occurred overnight, it is likely that PEV owners also plugged in to workplace charging infrastructure.[36]

Regarding the impact of PEVs on the electric grid, the study found that PV generation on-site provided sufficient energy to completely offset PEV charging, suggesting that advancements in PV energy storage could be used to mitigate peak demand.[37] PEV charging during the summer was a small fraction of the total energy used, which is a result of higher HVAC system use to accommodate higher temperatures.[38] Pecan Street concluded that, while PEV charging was concentrated during peak demand hours, it did not rise to a level that would trigger negative distribution system impacts.[39] This means that higher PEV adoption does not necessarily require transformer and distribution upgrades to the grid. Such success for a high-PEV concentration neighborhood shows the viability of higher PEV market share in the future. Furthermore, it demonstrates that PEV integration to the grid with intermittent power generation through solar or wind is a highly viable option. This mutually beneficial combination can enable cost savings, prevent peak loads, and better stabilize the grid.

32 Pecan Street Grid Demonstration Project. 2015. "Final Technology Performance Report." Pecan Street Project, U.S. Department of Energy. https://www.smartgrid.gov/project/pecan_street_project_inc_energy_internet_demonstration.html

33 Ibid, 150.

34 Ibid.

35 Ibid, 151.

36 Ibid.

37 Ibid, 152.

38 Ibid.

39 Ibid, 158.

2.6 CONCLUSIONS AND RECOMMENDATIONS

Despite the wide prevalence of Level 1 and Level 2 charging already available for single-family residences, local governments, municipalities, and utilities still must provide incentives to increase the deployment of such PEV charging infrastructure. The report makes the following recommendations on how single-family residential charging could be funded:

1. **Local governments could work with building code associations to institute PEV-ready building codes for new single-family residence construction in their jurisdictions.**

Updating building codes is a locked-in, cost-effective means of adding Level 1 or Level 2 EVSE near vehicle storage locations.

2. **Utilities and local governments could incentivize single-family resident PEV owners to adopt intelligent charging hardware and software through rebate and subsidy programs.**

Intelligent charging hardware and software benefits both PEV owners as well as utilities. This infrastructure can help utilities shave load off of peak demand, saving them money in overall fixed costs, and can help consumers by lowering their electricity costs. This recommendation depends heavily on local or regional grid needs.

3. **Utilities and local governments should not institute policies to increase deployment of DCFC EVSE for single-family residences.**

Level 1 and Level 2 EVSE already meets the majority of charging needs for PEV owners, single-family residences have no need for this functionality.

3 | MULTI-FAMILY CHARGING

3.1 EXECUTIVE SUMMARY

Multifamily residential (MFR) housing poses significant challenges to expanding PEV charging infrastructure in the United States. MFR complexes make up over 18 percent of residential units. MFR residents, however, lag single family residents in terms of PEV adoption with as few as 4 percent of PEV owners living in MFR housing.[40] While factors such as family income contribute to such phenomena, characteristics unique to MFR complexes also impact PEV adoption. First, in most cases MFR residents share parking spaces and therefore do not have access to Level 1 or Level 2 charging readily available to single family residents. Limited access to charging constrains demand for electric vehicles. Second, investing in MFR charging infrastructure involves multiple stakeholders: residents, building owners, HOAs and utilities, to name a few. Multiple stakeholders significantly complicate the question of who should invest in PEV charging infrastructure. As strategies for emissions reduction evolve to include accelerated PEV adoption, the MFR sector will require a diverse set of strategies to build out PEV charging infrastructure.

This chapter draws on secondary research involving literature review and analysis of publicly available datasets. Research includes analysis of American Community Survey (ACS) data and Pew Research data on multifamily residences in the United States and a literature review of past case-studies of MFR PEV charging infrastructure plans. To estimate projected costs of Make-Ready and Retro-fit MFR PEV infrastructure, we used reports from the U.S. Department of Energy. Additionally, the MFR Research group relied on research conducted by the Luskin Center for Innovation to frame our work within the broader framework of best practice suggestions for incentives to reduce the cost of EVSE installation, implementation of PEV-ready construction codes, and the expansion of public charging options for MFR residents. To identify issues unique to the MFR sector, our team also reviewed publications from the major trade associations, including the National Apartment Association and the National Multifamily Housing Council.

Lack of charging infrastructure in MFR complexes is in part responsible for MFR PEV adoption lagging single family residential PEV adoption. Multiple stakeholders, particularly in landlord owned MFR scenarios, create split incentives for PEV charging infrastructure adoption. This results in sub-optimal private investment. Private activity is unlikely to be sufficient for the MFR sector to meet PEV charging infrastructure needs over the next 10 years. Public investment in the form of government grants, tax credits, and utility rebates as well as changes to local building codes are required to spur investment in MFR sector PEV charging infrastructure. This will be necessary in the short- to mid-term until PEV adoption is sufficient to make fully private investment economically feasible. While MFR structures share the long dwell time of single-family residential structures, level 2 charging infrastructure may be the preferential option for MFR PEV charging. Level 1 infrastructure is feasible in MFR complexes with the caveat that the length of time to charge is prohibitively long and unsuitable for shared parking spaces. The upfront cost of DCFC is prohibitively high for residential structures.

Based on the key findings, we make the following three recommendations.

1. **Local governments could work with building code associations to institute PEV-ready building codes for new multi-family residence construction in their jurisdictions.**

40 Hardman, Scott, Rosaria Berliner, and Gil Tal. 2018. "Who Will Be the Early Adopters of Automated Vehicles? Insights from a Survey of Electric Vehicle Owners in the United States." Transportation Research Part D: Transport and Environment, no. December: 1–17. https://doi.org/10.1016/j.trd.2018.12.001

2. **Local and state governments could require that all shared parking facilities have a minimum number of PEV parking spots allocated.**

3. **Local governments, utilities, and state governments could utilize grants and utility rebates in the short-term to spur investment or facilitate partnerships in Level 1 and Level 2 charging infrastructure at multi-family residences and leverage intelligent charging.**

3.2 INTRODUCTION

Residences provide the most convenient and cost-effective PEV charging because LDVs spend most of their downtime in these locations. In the single-family use case, charging is relatively easy; PEV owners can simply plug in to 120- or 240-volt in their garage or other available outlets. In the multifamily use case, however, shared parking arrangements mean residents typically may not have access to an external outlet to plug-in their car. Multifamily residential (MFR) structures exist in many forms, from duplexes to complexes with hundreds of units. For this report we define MFR structures as housing complexes with 5-or-more units. Housing structures with 4-or-less units are more like single-family residents with regard to PEV charging infrastructure. Within our definition there are still a very wide range of building types, ownership models, demographics, and other characteristics that impact the potential for PEV charging infrastructure. In this section we present a summary of these characteristics and the impact of these characteristics on PEV charging infrastructure need, demand, and payment.

3.3 USE CASE CHARACTERISTICS

3.3.1 Multifamily Residential Building Characteristics

MFR structures — typically apartment buildings or townhouse developments — vary widely by size, age, quality, geographic location, and resident demographics. Strategy and policy for EVSE deployment will need to be equally as diverse. In total, approximately 18.1% of all residential units in the United States are in MFR structures.[41] Table 3.1 below describes MFRs by size and age. Forty-eight percent of apartments are in complexes built before 1979, and 21% of apartments are in complexes built after 1999. Apartment units are relatively evenly split across complex size with roughly 20-25% of units in each category.[42] Note that the table presents the total number of individual units in complexes. This suggests that when looking at complexes alone, the majority of complexes are small (5-9 units) and medium (10-19) units.

3.3.1.1 MFR Complex Ownership

Ownership of MFRs is an important factor in EVSE deployment and installation

41 U.S. Census Bureau, *2013-2017 American Community Survey 5-Year Estimates*

42 Ibid.

TABLE 3.1:

Multifamily Units by Complex Size and Year Built (2017)

Year	All Apartments	5 to 9 Units	10 to 19 Units	20 to 49 Units	50 or More Units
1939 or Earlier	2,143,460	621,447	378,029	552,409	591,575
1940 to 1959	1,901,533	530,952	415,876	399,785	554,920
1960 to 1979	6,041,488	1,667,239	1,557,643	1,178,805	1,637,801
1980 to 1999	6,241,109	1,769,333	1,832,324	1,158,448	1,481,004
2000 or Later	4,364,527	789,740	998,057	872,125	1,704,605

Source: U.S. Census Bureau, *2013-2017 American Community Survey 5-Year Estimates* decisions.[43] MFR units are either rented by an occupant or owner-occupied. There are three general ownership models:

- **Single property owners** that own an entire property and rent individual housing units. Property owners, corporations, or property management companies typically manage these complexes.
- **Condominiums** in which each housing unit is separately owned but common areas are jointly owned and managed through a condominium association, usually with an elected board.
- **Cooperatives (Co-ops)** in which occupants are shareholders in the property. Occupants do not own their individual units but own a share of the property. A board of directors selected from shareholders manages a co-op.

Each ownership case presents challenges to EVSE deployment. In each case individual owners are typically not the EVSE installation decision maker. Instead property owners, managers, or management boards make these decisions.

In the case of single property owners, the owners or management companies will make decisions about building retrofits or upgrades. Owners will have to determine whether to install EVSE based on return on investment, whether they can generate revenue directly from the EVSE, or whether they can make a business case that such EVSE will increase demand or rental prices for their units. Current tenants have little ability to impact such decisions. Even in cases where tenants may have the opportunity to invest in EVSE themselves, for example if there are dedicated parking spaces, there is limited incentive for tenants to invest in an amenity that they may move away from or do not have ownership over. This is an issue referred to as a landlord-tenant problem.[44]

43 Turek, Alex, and DeShazo, J.R. "Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study" *UCLA Luskin Center for Innovation and the South Bay Cities Council of Governments* (2016).

44 Blumstein, Carl, Betsy Krieg, Lee Schipper, and Carl York. "Overcoming social and institutional barriers to energy conservation." *Energy* 5, no. 4 (1980): 355-371.

Similar challenges exist in other sectors. "Split incentives" are a barrier to deployment of energy efficiency measures in multifamily buildings. These barriers exist when renters pay energy bills but owners make capital investment decisions; owners are often unwilling to make capital upgrades that will benefit occupants but provide unclear, little, or no benefit to the owner. Split incentives result in significant under-investment in energy efficiency measures.[45]

One possible solution to this issue would be for property owners or landlords to install a simple NEMA 14-50R receptacle per garage or parking space. These receptacles are used for dryers, generators, and RVs and would provide PEV owners the opportunity to plug in a level 2 charging cord at 240V for 7.5kW charging. Landlords owning such receptacles might mitigate investment concerns because receptable costs could be passed down to renters or be marketed as an amenity.

Where PEV owners also own a share of the building — in the case of condominiums, home-owner associations (HOAs), or cooperatives — residents may view EVSE as an investment that will improve the resale value of their unit. Personal preferences and unit owner needs may also have greater influence on investment decisions as unit owners are voting members of associations or boards. Because capital investments under these models are still made at the group level, investment decisions are still more challenging than if there was a single owner making the decision.

Metering EVSE is an immense challenge for infrastructure deployment at MFRs. Such metering must ensure that the PEV owner is the individual who pays for the electricity and is not shared with non PEV-owning residents. MFR structures must select a metering model that allows individual EVSE owners to pay for charging costs without unduly burdening other, non-PEV users. For further discussion on metering models, see Table 3.4 later in this chapter.

45 Melvin, Jesse. 2018. "The Split Incentives Energy Efficiency Problem: Evidence of Underinvestment by Landlords." Energy Policy 115 (April): 342–52. https://doi.org/10.1016/J.ENPOL.2017.11.069

Despite these challenges, installing EVSE provides benefits for each ownership structure. PEV charging provides a marketable service that can increase demand and rents for single property owners, and increase the value of units for owner-occupiers. EVSE charging also serves to future proof units against future increases in PEV adoption. Additionally, all ownership types benefit from opportunities to build publicity and property value from green credentialing, and EVSE can help property owners and managers meet sustainability goals.

3.3.1.2 Parking

A critical barrier to PEV adoption, and thus demand for EVSE infrastructure, among MFR residents is a lack of convenient home charging at MFR complexes. A 2013 survey of 1,004 households found that while 61 percent of single-family homes had easy access to charging, only 27 percent of MFR residents had access to parking spots with access to electricity.[46] Overcoming this barrier is a key factor in preparing for a shift to PEVs among in this residential sector which accounts for 18.1% of household units. The design of MFR parking varies greatly and is a major factor when considering EVSE investment. Additionally, who owns and has control of each individual parking space varies by ownership type and complex structure.

MFR complexes assign parking in different ways including dedicated parking spots, shared parking, and in some cases leased parking. Cases where residents have dedicated parking spaces allow for greater individual choice for renters and owners alike. Assuming that a resident bears the cost of installation, the main challenges in these cases are who bears the cost of upgrading infrastructure, and how the resident may be charged for the electricity used to charge the PEV.

For MFR complexes with shared spaces, property owners will almost always bear the upfront cost; individual residents will generally not bear the cost of EVSE installation because they will not be able to secure exclusive use of the space. In addition, for shared parking, the managing body will need to create rules around use of charge-enabled spaces and how electricity payment is managed.

Lastly, in MFR complexes with no parking available, residents must resort to on-street parking. In these cases, the MFR owner is not involved in EVSE investment decisions and it falls to the local government to decide on EVSE investments. For areas where MFR residents rely heavily on on-street parking, public local investment in DCFC charging may prevail. As discussed in chapters 5 and 6 of this report, DCFC charging, whether via the Electrify America network or other local solutions, may stand in for readily available PEV charging.

Conversely, in the case of significant private investment in workplace charging infrastructure, residential MFR charging or DCFC reliance may diminish. Outside of residential dwell time, workplaces provide long downtime. The ability of drivers to rely on workplace charging as primary charging location though relates to their commute time.

The design of parking structures also impacts EVSE installation. Dedicated parking garages, below ground parking, and ground level parking are just a few examples of different parking schemes MFRs may have. The differences among these parking designs will heavily affect retrofitting as each has different trenching and material costs related to the proximity of electric service, meters, and subpanels to parking areas.

Similarly, the overall electric service capacity available to the parking structure may constrain the decision to invest in infrastructure. Intelligent charging may play a significant role in balancing the service capacity with available level 1, level 2, and DCFC installations.

3.3.2 Multifamily Residential Building Demographics

The demographic composition of individuals residing in MFR units is an important factor for understanding demand for PEV charging infrastructure. Resident income, the rental versus

46 Consumers Union and the Union of Concerned Scientists. 2013. Electric Vehicle Survey Methodology and Assumptions: American Driving Habits, Vehicle Needs, and Attitudes Towards Electric Vehicles. December. http://www.ucsusa.org/assets/documents/clean_vehicles/UCS-and-CUElectric-Vehicle-Survey-Methodology.pdf

ownership rate, commute time, and car ownership in particular are key demographic factors.

As noted in previous sections, income level is correlated with PEV ownership. This is likely to hold true in MFR households as well. In California, the cities with the highest growth in PEV sales are ones with median incomes exceeding $100,000.[47] Meanwhile, residents of MFR dwellings on average have lower incomes than single-family home residents. Data from the American Community Survey suggests that the majority of household incomes for apartment dwellers are less than $50,000. The mean income of all apartment dwellers is about $32,000 less than people who live in single-family units.[48]

Electric vehicle adoption is also higher among home owners than renters. A study by the Haas School of Business found that among households with annual income between $75,000 and $100,000, 1 in 130 homeowners owns an electric vehicle, compared to 1 in 370 renters.[49] MFR structures are disproportionately occupied by renters. According to the 2017 5-year ACS Public Use Microdata (PUMS), 88 percent of households in structures with 5-or-more units are renters, compared to 18 percent of single-family structures.[50] This suggests that one reason for lower adoption of PEVs among renters may be lack of access to convenient charging.

The amount of commute time, whether for errands, work, or leisure time also impacts the propensity of multi-family unit dwellers to own cars. As we will discuss in the next section, commute time is related to geography and specifically whether residents are in urban, suburban or rural regions. Residents of MFRs in urban areas typically reside in mixed-use neighborhoods; are often close to work, entertainment, and shopping; and have shorter commuting and driving times. Suburban MFR dwellers have longer commute times, while rural MFR dwellers have even longer commute times. The length of time spent commuting for MFR residents impacts residential car ownership adoption. If residents of apartments and condos do not own cars, there is little reason to consider EVSE investments. Additionally, urban residents in MFRs may rely on public transit for travel, leaving EVSE underutilized. Often, apartment dwellers use buses, subways, walkways, or other forms of transportation at a higher rate. Research from the University of South Florida found that Urban populations in the United States are more than 2.5 times likely to make public transit trips than the national average[51].

In contrast, suburban residents' longer commute time may relate to higher car ownership rates. High car ownership in suburban areas may mean that suburban MFRs need to account for PEV charging. However, MFR residents in the suburbs also use public transportation at a higher rate (6.6%) than suburban single-unit dwellers. While this rate is still relatively low, policy makers need to consider the propensity of multi-unit dwellers in both urban and suburbs to use public transit.[52]

Research from the Brookings Institute finds that the largest metropolitan areas are the places in which there is the lowest car ownership. Over 60 percent of zero-vehicle households live in the 100 largest cities. In contrast only 25 percent of suburban dwellers do not own a car.[53] The Department of Energy estimated that suburban residents drive 3-4 more miles daily than those residing in urban

47 Turek, Alex, and George DeShazo. *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A South Bay Case Study*. Report. Luskin Center, University of California Los Angeles.

48 U.S. Census Bureau, *2013-2017 American Community Survey 5-Year Estimates.*

49 Lucas Davis, University of California, Berkeley, Energy Institute at HAAS, *Evidence of a Homeowner-Renter Gap for Electric Vehicles*, (California, Berkeley: July 2018), 2. https://ei.haas.berkeley.edu/research/papers/WP291.pdf

50 Steven Manson, Jonathan Schroeder, David Van Riper, and Steven Ruggles. IPUMS National Historical Geographic Information System: Version 13.0 [Database]. Minneapolis: University of Minnesota. 2018. http://doi.org/10.18128/D050.V13.0

51 Thompson, Gregory. *Where Transit Use Is Growing: Surprising Results.* Report. Center for Urban Transportation Research, University of South Florida.

52 Larco, Nico. "THE CASE FOR SUBURBAN MULTI-FAMILY HOUSING DEVELOPMENTS." *Journal of Architectural and Planning Research*27, no. 1 (2010): 69-87. Accessed March 2018. InformeDesign.

53 Tomer, Adie. "Transit Access and ZeroVehicle Households." Www.brookings.edu. August 11, 2011. Accessed March 8, 2019. https://www.brookings.edu/wp-content/uploads/2016/06/0818_transportation_tomer.pdf

cities.[54] However, suburban MFR resident commute times compared to single-unit dwellers are about 1.5 miles shorter. Therefore, PEV infrastructure may have more relevance in suburban multi-unit dwellings who rely on their own vehicles to commute to work and travel long distances.

3.3.3 Multifamily Residential Building Geography

MFR characteristics, and the characteristics of their residents, may differ considerably depending on their geographic location, specifically if they are in urban, suburban, or rural areas. The Pew Research Center's 2018 study, "What Unites and Divides Urban, Suburban and Rural Communities," provides specific guidelines on classifying areas as urban, suburban, or rural. To identify the key differentiating characteristics of these classifications we refer to the three counties that Pew has identified as representative of typical urban, suburban and rural counties across the country. Within each of these representative counties we looked at the population demographics and housing density. We also examine the proportion of the community that rents and the commuting patterns for each area. Lastly, we note the electricity provider structure.

3.3.3.1 Urban – Franklin County, OH

The US Census Bureau defines an urbanized area as a densely developed territory that contains 50,000 or more people.[55] According to the Pew Research Center's 2018 study, Franklin County, Ohio is representative of the typical urban US county, with a population of 1.2 million, 30.6% of whom are between the ages of 0-18, 42.3% of whom are between 18-65, and 11% of whom are 65 and older. 17% of Franklin County residents live in poverty. In terms of density, in 2010, Franklin County's population per square mile was 2,186 persons. There are a total of 496,337 households in Franklin County, and 46.7% of all housing unit occupants rent. As of 2017, 64% of housing structures in Franklin County were single unit structures and 36% were multi-unit structures (MFRs). The most common number of units in an MFR is between 5 and 9.[56]

According to the US Census Bureau, in 2017, 33.1% of Franklin County's 16 and older residents spent between 15 to 24 minutes commuting to work on a daily basis, the most common amount of time spent commuting by all eligible Franklin County residents.[57] Additionally, 2017 ACS reports that over 80% of workers drive to work, with less than 5 percent walking or using public transit.[58]

3.3.3.2 Suburban – Hunt County, TX

The US Census Bureau notes that suburbs can best be defined as "urban clusters", referring to densely developed territory that has at least 2,500 people but fewer than 50,000 people.[59] The Pew 2018 study identifies Hunt County, Texas as a model for the typical suburban US county, with a growing population of roughly 89,000, 24% of whom are between the ages 0f 0-18, 60% of whom are between the ages of 18-64 and 16% of whom are older than 65. 19% of Hunt County residents live in poverty.[60] In terms of density, in 2010, Hunt County's population per square mile was 102.5 persons. There are a total of 31,781 households in Hunt County, and 31% of all housing unit occupants rent. As of 2017, 71% of housing structures in Franklin County were single unit structures

54 "Fact #759: December 24, 2012 Rural vs. Urban Driving Differences." Energy.gov. December 24, 2012. Accessed March 15, 2019. https://www.energy.gov/eere/vehicles/fact-759-december-24-2012-rural-vs-urban-driving-differences

55 Geographic Products Branch. "2010 Geographic Terms and Concepts - Urban and Rural." Census Bureau QuickFacts. September 01, 2012. Accessed February 21, 2019. https://www.census.gov/geo/reference/gtc/gtc_urbanrural.html

56 U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates

57 Mitchell, Travis. "Demographic and Economic Trends in Urban, Suburban and Rural Communities." Pew Research Center's Social & Demographic Trends Project. May 22, 2018. Accessed February 21, 2019. http://www.pewsocialtrends.org/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/

58 "Commute." Census Reporter. Accessed February 21, 2019. https://censusreporter.org/topics/commute/

59 Geographic Products Branch. "2010 Geographic Terms and Concepts - Urban and Rural." Census Bureau QuickFacts. September 01, 2012. Accessed February 21, 2019. https://www.census.gov/geo/reference/gtc/gtc_urbanrural.html

60 Mitchell, Travis. "Demographic and Economic Trends in Urban, Suburban and Rural Communities." Pew Research Center's Social & Demographic Trends Project. May 22, 2018. Accessed February 21, 2019. http://www.pewsocialtrends.org/2018/05/22/demographic-and-economic-trends-in-urban-suburban-and-rural-communities/

and 29% were multi-unit structures (MFRs). The most common number of units in a MFR is between 5 and 9.[61] In 2017, the most common amounts of time that Hunt County residents spent commuting to work each day were 10 to 19 minutes (26.2% of working, 16 and older residents in Hunt County reported doing so) and 60 to 89 minutes (13.7% of the same population claimed a one-way commute of this duration every day).[62]

3.3.3.3 Rural – Potter County, PA

Rural areas are defined as everything that cannot be measured as an urbanized area or urban cluster.[63] According to the Pew Study, Potter County, Pennsylvania is a good representation of rural counties in the US. With a declining population of 17,000, Potter County, like other rural counties, is aging, with 22% of the population now 65 or older. In terms of density, in 2010, Potter County's population per square mile was 16.1 persons. There are a total of 6,536 households in Potter County, and 23% of all housing unit occupants rent. As of 2017, 80% of housing structures in Franklin County were single unit structures, 14% were mobile homes, and 6% were multi-unit structures (MFRs). The most common number of units in a MFR is 2.[64]

A comparison of urban, suburban, and rural areas based on the information above is important when considering MFR structures for EVSE investment. There is a strong argument that EVSE infrastructure in many MFR applications is not needed. Rather, in rural areas EVSE infrastructure should be focused on other use cases, particularly inter-city charging, and single-family charging. While MFR EVSE is needed in urban settings, there is a risk of low utilization because of lower car ownership and the availability of other transportation options. Additionally, in urban areas parking is in higher demand and there are more instances of MFR structures with limited or no onsite parking.

3.3.4 Electric Vehicle Adoption

PEV adoption among MFR residents lags behind single-family residents.[65] In California, the state with the highest rate of PEV adoption, an PEV consumer survey found multifamily residents own approximately 8% of all privately owned zero emission vehicles (PHEV, BEV, and fuel cell electric).[66] Among the 8% of zero emission vehicle owners in MFR complexes, less than 23% had an income of less than $100,000. A national survey of 2,715 new car buyers in February 2018 found approximately 4% of new PEV owners live in multi-family residences.[67] While low PEV ownership in MFR residents is driven by lower incomes, other factors are also play a role. As discussed in previous sections, multifamily residents are less likely have access to convenient charging.

An additional factor that impedes PEV ownership in MFRs is the used car market for light-duty PEVs. Lower income vehicle purchasers might choose to purchase a used vehicle rather than a new one. In fact, the used car market is more than three times the new car market. However, there is a time delay for PEV availability on the used car market. The average age of light duty vehicles is nearly 12 years, with original owners holding on to their vehicles for more than six years on average.[68] Based on 2018 data, of the 57.63 million light vehicles sold

61 U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates

62 "Commute." Census Reporter. Accessed February 21, 2019. https://censusreporter.org/topics/commute/

63 Geographic Products Branch. "2010 Geographic Terms and Concepts - Urban and Rural." Census Bureau QuickFacts. September 01, 2012. Accessed February 21, 2019. https://www.census.gov/geo/reference/gtc/gtc_urbanrural.html

64 U.S. Census Bureau, 2013-2017 American Community Survey 5-Year Estimates

65 Lucas Davis, University of California, Berkeley, Energy Institute at HAAS, *Evidence of a Homeowner-Renter Gap for Electric Vehicles*, (California, Berkeley: July 2018), 2. https://ei.haas.berkeley.edu/research/papers/WP291.pdf

66 Center for Sustainable Energy (2018). California Air Resources Board Clean Vehicle Rebate Project, EV Consumer Survey Dashboard. Retrieved [insert date retrieved] from http://cleanvehiclerebate.org/survey-dashboard/ev

67 Hardman, Scott, Rosaria Berliner, and Gil Tal. 2018. "Who Will Be the Early Adopters of Automated Vehicles? Insights from a Survey of Electric Vehicle Owners in the United States." Transportation Research Part D: Transport and Environment, no. December: 1–17. https://doi.org/10.1016/j.trd.2018.12.001

68 Vehicles Getting Older: Average Age of Light Cars and Trucks in U.S. Rises Again in 2016 to 11.6 Years, IHS Markit Says." IHS Markit News Releases. November 22, 2016. Accessed May 01, 2019. https://news.ihsmarkit.com/press-release/automotive/vehicles-getting-older-average-age-light-cars-and-trucks-us-rises-again-201

in the U.S. that year, only 30% were new carsales.[69] Thus, one of the reasons for low penetration into the renter market may simply be a lack of used PEV options. As first generation PEV's start entering the used car market in large numbers, it is likely that renters would begin adopting at higher rates, regardless of income level.[70]

3.3.5 Charging Infrastructure

Most EVSE for MFR structures where dedicated parking is not available will be Level 2 EVSE. MFR complexes with dedicated parking or other arrangements where 120V or 240V electricity is easily accessible to individual tenants will operate similarly to single-family residents. When easy access to electric outlets is not available, installation of dedicated, freestanding hardware is required to house and run EVSE in shared parking spaces. Any such installations will almost always be Level 2 charging for two reasons:

1) The cost differential between the cost of installing standalone Level 1 and Level 2 charging is minimal, and;

2) The shared nature of the charging stations necessitates faster charging capability than Level 1 so more vehicles can be charged.

The cost of Level 2 charging stations in a multifamily setting are greater than in a single-family setting. According to a US DOE study, Level 2 charging stations in a shared parking situation cost on average approximately $3,800 and can range from $300 to over $10,000. Table 3.2 below presents the cost ranges of a Level 2 charger in an MFR setting.

In addition to the hardware costs, MFR installations may also incur costs for running conduit and wiring, electric panel upgrades, and other infrastructure upgrades. MFR owners also need to consider permitting costs that can vary between jurisdictions.

3.3.6 Electric Grid

EVSE installation for MFR structures has a greater impact on the grid than single-family residential installation. MFR complexes concentrate PEV owners in one geographic area. Multiple charging stations, particularly Level 2 or DCFC chargers, if used simultaneously, could add significant load to the local distribution network. If the additional load is above the capacity of the local feeder and transformers, grid failure can occur. Cases where demand could overload the grid require capital expenditure to add feeder lines, transformers, and other technology to reinforce or upgrade the distribution infrastructure.

69 Automotive News. *Number of new and used light vehicle sales in the United States from 2000 to 2018 (in millions)*. https://www.statista.com/statistics/183713/value-of-us-passenger-cas-sales-and-leases-since-1990/ (accessed 5/1/19, 2:46 PM).

70 Plungis, Jeff. "It's a Great Time to Buy a Used Electric Vehicle." Consumer Reports. August 31, 2018. Accessed May 01, 2019. https://www.consumerreports.org/hybrids-evs/great-time-to-buy-a-used-electric-vehicle/

TABLE 3.2:

Cost of Level 2 EVSE at MFRs

Technology	Low-End Cost	High-End Cost
PEV Supply Equipment	$300	$6,500
Running Wires & Conduit to Charging Point	$180	$4,600
Panel Upgrades	$60	$2,000
Service Upgrades	$274	$33,500
Total Cost	**$814**	**$46,600**

Source: Turek, et al, "Overcoming Barriers to Electric Vehicle Charging in Multi-Unit Dwellings: A South Bay Case Study." http://innovation.luskin.ucla.edu/sites/default/files/Overcoming Barriers to EV Charging in Multi-unit Dwellings.pdf

Installation of additional grid infrastructure can drastically increase the cost of EVSE. The question of who pays for these upgrades in the MFR use-case is an important one to consider. If an MFR structure requires its own dedicated transformers and lines, then the case could be clearly made that the cost should be borne by the MFR owners alone. If the MFR structure is on shared transformers or lines, and upgrades are required, the utility may have to bear the cost and will pass this cost on to ratepayers who do not benefit from the charging stations. Local utility commissions and utilities will need to establish protocols for these cases in order to equitably distribute the cost of EVSE. With privately held utilities, any investment in additional infrastructure may appear to be private but again, because of rate basing ultimately passes the costs to the general public.

There are also potential benefits from high concentrations of PEVs geographically:

1) The business case for charging providers improves with scale, and the opportunity to install multiple, frequently used charging stations could improve profitability.

2) MFR complexes give utilities the opportunity to encourage and deploy smart charging and vehicle to grid charging. As renewable resources are integrated more often, strategies to take advantage of intermittent generation are required. By harmonizing charging with time of use rates, PEVs can charge at times when cheaper renewable energy is available. Vehicle to grid charging, while still a nascent technology, could provide flexible energy storage options for utilities.

3.4 POLICY CONSIDERATIONS

Policymakers have an array of options for accelerating MFR PEV charging infrastructure, from no- or low-cost policies to policies requiring a large investment of public funds.

3.4.1 Building Codes and Permitting

Local governments and utilities can accelerate PEV infrastructure development in MFR complexes through code changes and reduced permitting costs. Traditionally, building codes have reacted to new technologies. Because codes are behind the technology curve, policymakers may need to adapt codes to encourage PEV charging readiness.[71] A large portion of the installation cost in MFR complexes comes from necessary electrical upgrades and the trenching needed to run conduit and electrical wire to parking spaces (see Table 3.2). State and local governments could change building codes for new construction to require adequate electrical infrastructure and conduit laid under parking lots. This will facilitate cheaper PEV charging installation in the future.

The costs of these changes are low for new MFR developers because these electrical upgrades are made during construction; the cost of new electrical codes is built-in to the fixed cost of initial construction and amortized over the cost of the entire structure. As a result, PEV-ready codes in new construction are cheap compared with upgrading and trenching parking lots in existing buildings.

Similar codes for existing buildings can be made to require new conduit laying during the replacement of parking lots, or electrical upgrades when new electrical work is completed. There are many examples around the United States of similar code changes. California's mandatory building codes will require new multifamily dwellings to be capable of supporting future charging installations. Los Angeles municipal code requires 5% of the total number of parking spaces be capable of supporting future EVSE. The city of Lancaster, PA has a similar code requiring 20% of all parking spaces in new MFR buildings be EVSE ready.

Beyond code changes, local governments and utilities can decrease the cost of permitting and grid connection for PEV charging stations in new and existing MFR complexes., Leveraging intelligent charging technology, customers will shift their charging to times when excess electricity is available.

71 Clements, Denis, et al. "EV-Ready Codes for the Built Environment" Georgetown Climate Center (2012).

3.4.2 Subsidies

Mechanisms for making public investment in MFR EVSE include tax credits, government grants, utility rebates, or other incentives. Many states and local jurisdictions use these mechanisms to encourage MFR EVSE installation. The Sacramento Municipal Utility District offers rebates to multi-family housing complexes installing chargers: up to $1500 for up to 20 Level 2 PEV charging stations, or up to $100,000 for a Level 3 PEV charging station.[72] Austin Energy offers a rebate of up to $4,000 or 50% of the cost to install approved Level 2 charging stations for multifamily properties.[73]

In addition to direct rebates, utilities can incentivize PEV infrastructure expansion through beneficial rate structures, which in turn increase charging and improve the business case for PEV charging companies. Table 3.3 below presents a sample of utility incentives.

Grant and rebate programs can raise questions of equity. These programs effectively socialize the cost of EVSE installation by either using taxpayer funds or rate-payer funds. As noted, PEV owners are typically at the higher end of the income distribution. By socializing the cost of infrastructure development, there is a valid argument that non-PEV drivers, including low- or middle-income families, are subsidizing benefits for PEV owners who tend to be wealthier. And subsidies and rebate programs may expire by the time general PEV adoption is widespread and has penetrated the used car market.

Although increased PEV use reduces emissions and has benefits for all members of society, it is important to ensure equity is a priority when developing approaches to accelerate PEV infrastructure development.

3.4.3 Business Model Options

As the market for PEV charging infrastructure grows, charging companies have adopted several business models. Some of these are suited to MFR applications. The PEV charging market is in a transition from a niche market with little profit potential to one of increasingly widespread importance as PEVs become more popular. Despite the growing importance, however, there are still questions around the viable revenue streams and profit potential for these companies. If adoption of PEVs among MFR residents increases, this sector could become a high value target for companies providing PEV charging services.

Based on research of existing charging infrastructure companies in the United States we identify eight main business models in

72 California Air Resources Board. Electric Vehicle (EV) *Charging Infrastructure: Multifamily Building Standards*. California. CARB. 2019. https://arb.ca.gov/cc/greenbuildings/pdf/tcac2018.pdf

73 Austin Energy. "Plug-In Austin". *austinenergy.com*. Accessed April 22 2019. https://austinenergy.com/ae/green-power/plug-in-austin/multifamily-charging

TABLE 3.3:

EVSE Utility Subsidy Programs

Entity Name	Qualifying Groups	Rebate Amount
Pasadena Water and Power	Multi-Unit Dwellings	Level 2: $3,000 DCFC: $6,000
Pacific Gas and Electric	Multi-Unit Dwellings and Workplaces	Level 2: $1,500 per port
Colorado Energy Office	Multi-Unit Dwellings; Local Governments; Businesses	80% of cost up to: Level 2: $9,000 DCFC: $30,000
Duke Energy Florida	Multi-Unit Dwellings and Businesses along high traffic corridors	100% of Level 2 or DCFC Installation Costs
Massachusetts Electric Vehicle Incentive Program	Multi-Unit Dwellings with 10 or more units	60% of Level 2 EVSE up to $50,000

the charging infrastructure sector. Table 3.4 below describes these business models.

MFR owners are likely to opt for one of business models (1), (3), (4), or (5). Under business model (1), (3), and (4), the MFR site acts as a host site for a charging company offering charging services. The MFR site would have no ownership over the charging infrastructure, although they may need to pay the charging company for the service installation. This offers a low cost, low risk solution for MFR complexes. However, charging companies may have little incentive to engage in these partnerships due to a risk of under-utilization in MFR complexes, resulting in low performing revenue streams. Under business model (5), the MFR complex would purchase and own the charging infrastructure and pay a fee for operations and maintenance. MFR complexes would have control over the fees charged to residents. This business model increases the risk to MFR owners.

3.4.4 Investment Approaches

This report questions who should take the lead in investing in electric vehicle charging infrastructure. In the case of MFR complexes there are three general options: fully private investment, private investment with public assistance, and fully public investment.

3.4.4.1 Fully Private

Using this approach, investment in PEV charging infrastructure is entirely private with no public sector involvement. There would be two general options for this approach:

1) MFR complex owners would purchase and operate charging infrastructure at the going market price. MFR complex owners would have control over how they charged tenants, for example as a free amenity or a paid service.

TABLE 3.4:

PEV Charging Infrastructure Models

Number	Business Model	Description
1	Branded end-to-end manufacturers	Companies design, build, maintain, and support charging infrastructure. Multiple payment methods.
2	Unbranded manufacturers	Companies design and build charging infrastructure for sale to private entities or other charging companies. Do not operate or support charging infrastructure.
3	Charging as a service - Membership	Companies purchase charging infrastructure. Provide operations and support services. Charge membership fees to customers.
4	Charging as a service - Pay-as-you-go	Companies purchase charging infrastructure. Provide operations and support services. Charge pay-as-you-go fees to customers.
5	Indirect billing	Companies purchase charging infrastructure. Provide operations and support services. Charge fees to building owners who then charge customers according to their business needs.
6	Smart Charging and V2X (grid, home…)	Companies provide software solutions for smart charging and vehicle to home, or vehicle to grid operations.
7	Automobile Manufacturers	Auto manufacturers build network of charging structures and charge fees or free charging to owners of their car models.
8	Utility Provided	Utilities provide charging infrastructure at no cost and bill customers directly.

2) PEV charging companies would invest in charging infrastructure and provide charging as a service to MFR tenants. They would provide the service through either an arrangement whereby they obtain parking spaces from MFR complexes and charge tenants directly, or they charge the complex and the complex passes costs on to tenants.

If a government entity does not have specific socioeconomic goals related to advancing PEV adoption, this is the preferred option. If there are social goals that require increased PEV adoption, it is unlikely that fully private options will promote PEV infrastructure development at the desired rate. Furthermore, fully private options will likely result in investment in high income MFR complexes, and low to no investment in MFR complexes with low- and middle-income residents.

3.4.4.2 Private with Public Assistance

In contrast to the fully private approach, public policies would subsidize the infrastructure costs. Investment could occur through one or more policies, including taxpayer funding, government grants and tax incentives, or ratepayer funded utility rebates. This approach provides a wide array of implementation options. Some implementations include: MFR owners purchasing and operating equipment with grants or rebates offsetting some of the cost, and; PEV charging companies receiving grants or rebates and providing services at reduced cost to MFR complexes. Utilities could additionally offer beneficial electricity rates to MFR owners for charging.

For government entities with socioeconomic goals related to PEV adoption and emissions reduction this is likely to be a common approach. When designing programs for PEV charging infrastructure, it is important for jurisdictions to account for potential free riding and ensure public funds are invested with the maximum potential for market influence.

3.4.4.3 Fully Public

In this final scenario, PEV infrastructure in MFRs is entirely funded through public investment.

While fully public investment may be required for public charging options, such as along inter-city corridors, fully public funding for PEV charging infrastructure at privately owned MFR complexes is likely to be less politically and economically feasible. Public funding should be weighed against other options including public transportation investment. There may be some exceptions for this approach, such as public housing or low-and -medium income facilities.

3.5 POLICY CASE STUDY

The City of Sacramento has adopted a set of ambitious goals around PEV adoption to compliment Sacramento's overarching goal of becoming the most livable city in the United States.[74] Sacramento has a longstanding history with PEVs starting in 1994 with the PEV Parking Program that provided free or discounted parking with charging for electric vehicles. In 2017, Sacramento adopted a revised PEV strategy developed through collaboration with a wide array of agencies, residents, businesses and other stakeholders. The strategy covers charging infrastructure, city fleet vehicles, ridesharing, and PEV programs run by the Sacramento Municipal Utility District (SMUD), the electric utility for the City.

An important part of Sacramento's strategy is related to multifamily residences. Sacramento has a high proportion of MFR complexes that make up 38 percent of all housing structures in the city. This proportion is expected to grow significantly in the near future due to development around the City, and multifamily units are expected to comprise over 40 percent of housing units by 2020. California legislation requires that MFR owners grant tenants the right to request and install charging installations at the tenant's expense. State code requires PEV pre-wiring in new construction and for projects with 17 or more units, and also requires three percent of parking spaces be dedicated to PEV charging. To promote PEV adoption and meet charging infrastructure demand, Sacramento

74 City of Sacramento. 2017. *Electric Vehicle Strategy*. https://www.cityofsacramento.org/-/media/Corporate/Files/Public-Works/Electric-vehicles/EVStrategy_171206_FINAL_DRAFT_CityOfSacramento.pdf?la=en

has adopted numerous policies that complement or go beyond California's state policies.

Sacramento has adopted a variety of low and no cost strategies to encourage installation of PEV charging at MFR complexes. The City has developed promotional and educational material about the City's policies and permitting procedures. The City planning department has streamlined the review process for permitting, and provides a 5-day turnaround for multifamily EVSE applications and a 24-hour turnaround for inspections. Public charging for residents without other charging options is prioritized. Sacramento has developed outreach strategies to increase awareness of PEVs, with a focus on environmental justice, disadvantaged, and low-income communities.

In addition to City efforts, SMUD provides several incentives for PEV buyers or those installing charging infrastructure. For PEV buyers, SMUD offers free electricity for two years (a $599 value) or a free residential charger. PEVs are eligible for the program, including both BEVs and PHEVs. SMUD also offers incentives to spur PEV infrastructure, including a $1,500 incentive for workplace and multi-family charging, and a $100,000 incentive to spur more DCFC in the region for qualified participants.

3.6 CONCLUSIONS AND RECOMMENDATIONS

Multifamily residential (MFR) housing poses significant challenges to accelerating PEV adoption in the United States. MFR complexes make up over 18 percent of residential units. MFR residents, however, lag single family residents in terms of PEV adoption with as few as 4 percent of PEV owners living in MFR housing. Public investment to increase PEV charging is required, making PEV ownership more accessible to larger portions of the population:

1. **Local governments could work with building code associations to institute PEV-ready building codes for new multi-family residence construction in their jurisdictions**

Many low or no cost policies are available for public officials to promote PEV charging. Examples include adopting legislation allowing tenants to request and install level 2 chargers at their own expense, streamlining permitting processes to be fast and low to no cost, and updating building code to require make-ready practices in new MFR construction.

2. **Local and state governments could require that all shared parking facilities have a minimum number of PEV parking spots allocated.**

California state code requires that all commercial or multifamily parking lots have at least 3% of parking spaces dedicated to PEV charging. Similar programs can help motivate the private owners of MFRs to provide PEV charging infrastructure without cost to the government or utility.

3. **Local governments, utilities, and state governments could utilize grants and utility rebates in the short-term to spur investment or facilitate partnerships in Level 1 and Level 2 charging infrastructure at multi-family residences and leverage intelligent charging.**

Government grants and rebates should focus on Level 2 charging infrastructure rather than level 1 EVSE. MFR owners can promote Level 2 charging as an amenity and potentially charge higher rents or command higher unit prices. As a result, public-private-partnerships can mitigate costs to the taxpayer while still providing the needed infrastructure. Furthermore, intelligent charging – like in the single-family charging situation – can save money for both the utility and the consumer.

4 | WORKPLACE CHARGING

4.1 EXECUTIVE SUMMARY

Workplace charging is an amenity that a variety of firms can offer. A workplace charging program can be as simple as providing a few wall outlets to be accessed by PEV owners to plug in their cord. It can also involve networked Level 2 chargers with features such as vehicle-to-owner communication to support a charging program on a grander scale. The scale and sophistication of a workplace charging program can vary greatly, depending on the need of the workplace and the size of the infrastructure investment.

Workplace charging is an important use case for providing the charging infrastructure necessary to support widespread PEV deployment. It increases charging convenience for current PEV drivers and increases the feasibility of owning a vehicle for potential owners. Because private companies are also incentivized to invest in this infrastructure, workplace charging provides a great lever for local and state governments to support PEV adoption with only minor investment on their part in the form of public incentives.

To summarize, this chapter makes the following recommendations:

1. **Local governments and utilities could consider offering information and technical guidance for worksites interested in EVSE deployment.**
2. **Local governments and utilities could offer rebates, tax credits, and streamline permitting for EVSE installation at workplaces to incentivize EVSE deployment.**
3. **Local governments and utilities could focus their rebate and subsidy programs on Level 1 and Level 2 EVSE charging infrastructure.**
4. **Local governments and utilities could require workplaces to survey employees for interest and demand for PEV charging infrastructure before providing subsidies for EVSE deployment. An additional requirement could mandate the release of this data to local governments and utilities.**
5. **Utilities could provide appropriate electricity discounts to workplaces deploying EVSE charging infrastructure in order to allay concerns over higher utility bills.**

4.2 INTRODUCTION

Workplace charging is a critical frontier for widespread adoption of electric vehicles and, aside from residential charging, is the second most important location for charging infrastructure in urban areas.[75] Nearly 75% of current PEV owners have expressed interest in workplace charging.[76] The availability of charging stations at worksites extends the number of electric miles per commute and could serve as a primary charging location for employees who cannot charge reliably at home. This is especially salient for employees that live in multi-unit dwellings or cannot invest in the infrastructure necessary for home charging, thus increasing the feasibility of PEV adoption for a larger segment of the population. The visibility of workplace charging can also have a network effect, further encouraging PEV adoption as employees influence their colleagues.

Companies that opt for workplace charging also benefit. Workplace charging demonstrates a commitment to social and environmental responsibility, while also helping meet sustainability goals. As consumers demand greater corporate

75 Yongxi Huang and Yan Zhou, "An optimization framework for workplace charging strategies," *Transportation Research Part C* 52 (2015): 144-155, https://doi.org/10.1016/j.trc.2015.01.022

76 "Providing Workplace Charging for Your Employees' Plug-in Electric Vehicles," Drive Electric Florida, accessed March 2019, http://www.driveelectricflorida.org/PDFs/wpc.pdf

responsibility, workplace charging can even make a company more competitive. Charging programs are also an attractive workplace benefit, which can aid employee recruitment and retention and allow a company to differentiate itself among its peers.

Cognizant of these benefits, many companies have opted to privately fund their workplace charging programs. But a 2016 Department of Energy report on the Workplace Charging Challenge, a federal program to encourage workplace charging, suggests public incentives can further promote employee PEV adoption. The report found that of the 5,000 workplace charging stations installed before June 2015 by companies across the nation, 94% are in states with existing charging station incentives.[77] Public incentives appear to promote interest in PEVs among employees, and employers respond to this demand by implementing workplace charging programs.

A variety of public incentives may be employed depending on the barriers to workplace charging adoption within a region. Such barriers may be related to cost, technical uncertainty, or permitting concerns. Incentives such as tax credits, rebates, technical assistance, and streamlined permitting processes can address these barriers. As the market share of PEVs continues to grow, the demand for workplace charging by employees alone may be strong enough to phase out the use of public incentives. But in the interim, the private sector should fund workplace charging infrastructure with the help of public incentives.

State and local governments could encourage workplace charging by offering such incentives. Increasing the number of electric miles per commute cuts down on tailpipe emissions from employee commutes, which can contribute to greenhouse gas reduction goals. Reduced air pollution also helps with ozone and particulate matter compliance as mandated under the Clean Air Act. Local utilities can also realize the potential benefits of workplace charging for grid management. Charging during the early afternoon can help smooth the demand between major peaks in use during the morning and early evening. The availability of charging at work may also alleviate the need for people to charge immediately upon returning home, particularly those that need a full night of charging to have enough charge for their daily commute, as charging will be available at work.

4.3 USE CASE CHARACTERISTICS

The availability of workplace charging can increase PEV adoption by making it a more practical and attractive option for consumers. Workplaces are one of the most common locations for vehicles to be parked for extended periods, second only to residences.[78] Workplace charging offers PEV consumers additional convenience by increasing their electric mileage per day, thus reducing range anxiety. This encourages PEV adoption both for employees with long commutes and employees who lack access to home charging. Existing research corroborates this theory that workplace charging infrastructure increases PEV adoption. The Department of Energy's 2016 report on the Workplace Charging Challenge found that employees with access to workplace charging were six times more likely than the average worker to drive an PEV.[79] The report also found that one in 73 employees in a company with worksite EVSE drove an PEV compared to the national average of one in more than 1,400 employees.[80]

Employers are also incentivized to adopt workplace charging initiatives. As consumers increasingly demand corporate responsibility, companies can cultivate an image of moral obligation and social responsibility by providing workplace charging. A corporate image of sustainability may help recruit and retain employees, and the availability of workplace charging is an attractive employee benefit and recruiting perk.

Research shows that corporate management is attempting to capitalize on the benefits that come

77 US Department of Energy, "Workplace Charging Challenge Mid-Program Review: Employees Plug In," January 2015.

78 Huang and Zhou, "An optimization framework for workplace charging strategies."

79 US Department of Energy, "Workplace Charging Challenge Progress Update 2016: A New Sustainable Commute," January 2017.

80 US Department of Energy, "Workplace Charging Challenge Progress Update."

with an image of sustainability. A 2011 study by the MIT Sloan School found that of 3,000 executives in the commercial sector, 70% place sustainability on their management agendas, and two-thirds responded that sustainability was necessary to remain competitive in today's market.[81] A second MIT study compared companies that adopted environmental and social policies with those that did not. It found that high-sustainability companies had a 4.8% higher stock market performance on a value-weighted basis than their counterparts, as well as significantly better return on assets and return on equity.[82]

4.3.1 Use Case Characteristics - Demographics

The U.S. Department of Energy encourages employers across the U.S. to participate in the Workplace Charging Challenge as part of their broader Energy EV Everywhere Grand Challenge. According to the 2016 WPCC Annual Progress Report, the Challenge has partnered with 400 employers that have a total of 757 PEV charging-equipped worksites.[83] These partners represent a variety of sectors including utilities, healthcare, higher education, and government. Participation is geographically diverse, incorporating most major areas of the country with partners represented in 45 states. The top metropolitan areas for Challenge partners are Los Angeles, San Francisco, Portland, Atlanta, and Chicago.[84]

According to the 2016 report, suburban workplaces, such as office parks, are a dominant presence in PEV workplace charging: they account for 71% of worksites and 80% of PEV-driving employees in the Challenge. Urban worksites account for less than 20% of the partners, and only 13% of partners are rural worksites.[85] It is likely that the availability of alternative sustainable commuting options like cycling or public transit result in comparatively low demand for workplace charging in urban areas. Another potential explanation for the lower rates of workplace charging in urban areas is that many companies with urban worksites do not own their own buildings or parking facilities and thus cannot easily make infrastructure improvements to benefit PEV owning employees.

Challenge partners also represent a variety of firm sizes. Small businesses account for 20% of the 400 partners, and large corporations such as Google, Coca-Cola, and 3M also participate and offer charging at their headquarters and other locations.[86]

The amount of charging infrastructure available across these worksites also varies greatly. Many worksite charging programs are small: over 50% have five or fewer PEV-driving employees and nearly 70% of the worksites have five or fewer charging stations. However, more than 60% of these worksites can accommodate future growth in the number of employees who drive PEVs to work by encouraging employees to share stations. As seen primarily in the technology, automotive, and electric utility sectors, 17 of the participating worksites have large programs that accommodate 150 or more employees who use an PEV for their commute. According to the 2016 report, the number of planned and installed charging stations has increased by nearly 40% since June 2015, suggesting steady growth in the availability of workplace charging.[87] Such growth also suggests that companies wanting to increase the amount of charging available at their workplaces face few barriers to infrastructure deployment.

4.3.2 Charging Infrastructure Requirements

Electric block heaters, used to warm vehicle engines parked in cold climates, provide a model of what a simplistic workplace charging regime could resemble: electricity routed to parking spaces with a regular 120V outlet that employees could utilize with their own Level 1 charging cable. However, even such a basic scenario is not always feasible or ideal. Ownership of the

81 Kurt Haanaes et al., "Sustainability nears a tipping point," *MIT Sloan Management Review* 2012, https://sloanreview.mit.edu/projects/sustainability-nears-a-tipping-point

82 Robert G. Eccles, Kathleen Miller Perkins, and George Serafeim, "How to Become a Sustainable Company," *MIT Sloan Management Review* 53, no. 4 (2012): 43-50, https://sloanreview.mit.edu/article/how-to-become-a-sustainable-company/

83 US Department of Energy, "Workplace Charging Challenge Progress Update."

84 Ibid.

85 Ibid.

86 Ibid.

87 Ibid.

worksite's parking facilities, availability of parking, and existing electrical infrastructure are factors that must be taken into consideration before a workplace can pursue a charging program.

When a workplace owns the parking facility, implementing PEV charging is a simple, unilateral process. However, as most commonly seen in urban areas, workplaces often lease their building and parking facilities from one or more external entities. This complicates the installation process because it requires landlord involvement, and the landlord's priorities may not align with the workplace. Companies have various levers to overcome the barriers of working with landlords. For example, they can negotiate EVSE installation as part of a lease extension. If the company shares leased space with other tenants, they can also establish an advisory committee of interested tenants to demonstrate interest in PEV charging.[88]

The ratio of available parking spots to employees is another important factor when dedicating parking spots to PEV charging. Dedicating numerous spots to Level 1 charging is likely the most effective practice for worksites with an abundance of parking. But, when parking is restricted or only adequate, it may be more efficient for worksites to install faster Level 2 chargers and impose time restrictions on employee usage. Although this may require employees to leave the worksite for a period of time to move their vehicle, it can greatly extend the amount of charging infrastructure available per-PEV.

Existing electrical infrastructure also simplifies EVSE installation. Locating EVSE close to existing electrical utility equipment is much more technologically and economically efficient than installing new circuits and conduits. This also eliminates the need to disrupt existing sidewalks or pavement for trenching. Without existing access to electrical supply, the potential EVSE installation costs could pose an insurmountable barrier to workplaces hoping to initiate PEV charging programs.

The ideal mix of EVSE will vary depending on worksite characteristics. The overall model, however, should follow the "Goldilocks approach" described by Plug In America, which minimizes employer costs while encouraging increased PEV usage.[89] The following two subsections will outline the relevant technical and economic considerations for installing workplace EVSE.

4.3.2.1 Technological Considerations

Workplaces installing EVSE can choose between Level 1, Level 2, and DC Fast Charging (DCFC). While DCFC has the ability to provide a full charge in twenty to thirty minutes,[90] this capability surpasses most workplace infrastructure requirements, as vehicles will be parked for the majority of the work day. Since DCFC installation and operation is also substantially more expensive than Level 1 and 2 charger installation and operation, most workplaces considering EVSE will choose between Level 1, Level 2, or a blend of both.

Level 1 charging is the cheapest and easiest infrastructure to implement because it only requires a 120v outlet. It can also add parking flexibility, as it does not require parking spaces to be solely dedicated to PEV charging if companies choose to make 120v outlets available to all parking spots. There are also several downsides to workplace Level 1 charging: it is the slowest charging method, providing an average of three to five miles of range per hour, and it is not usually capable of network connection.[91] However, cords come with the purchased PEV and can be brought to work, saving money on EVSE for the workplace.

Level 2 EVSE charges vehicles significantly faster than Level 1 EVSE. It can provide ten to twenty miles of charge per hour, thus allowing more than one user to utilize a station per day.[92] It also has the capacity for smart or WiFi-enabled charging that enables charge-event recording software, vehicle-to-owner communication, and the ability to implement pay-for-charge payment schemes.

88 "Providing Workplace Charging for Your Employees' Plug-in Electric Vehicles," Drive Electric Florida.

89 Tom Saxton, "Workplace Charging - the Goldilocks Approach," Plug in America, January 15, 2015, https://pluginamerica.org/workplace-charging-goldilocks-approach

90 "Supercharger | Tesla." *Tesla*, Inc, www.tesla.com/supercharger

91 Plug in North Carolina, "Workplace Electric Vehicle Charging," June 2016, http://www.pluginnc.com/wp-content/uploads/2016/06/1-Employer_Workplace_EV_Charging.pdf

92 Plug in North Carolina, "Workplace Electric Vehicle Charging."

[93] Networked Level 2 EVSE also gives workplaces greater control over when vehicles charge. By controlling when vehicles charge, workplaces can avoid incurring high electricity costs due to demand charges and charging during peak hours. [94] While Level 2 charging offers many benefits, it also requires substantially more maintenance than Level 1 EVSE and is more expensive to install.

Workplaces may be able to optimize corporate and employee benefits by opting for a mix of Level 1 and Level 2 EVSE. Using this strategy, Level 1 charging can serve most employees' needs, while Level 2 stations can be made available for employees who need to charge their vehicles faster. This approach is also advantageous because installing Level 1 chargers is an effective starting point for employers that want to experiment with workplace charging. If the employer deems Level 1 EVSE to be successful, they may later decide to install more sophisticated Level 2 chargers to accommodate growth in charging program participation.

Another option for employers is to contract PEV charging systems out to third party companies. Companies like ChargePoint offer turnkey solutions for workplace charging by handling installation, maintenance, payment systems, system status monitoring, and record keeping for usage data. The downside of this option is that external contractors generally require monthly fees for their services that may exceed what workplaces are willing to spend.[95]

A more ambitious vision of workplace charging involves dedicated energy generation and storage. The end-use for the employee would be the same as other options, but this strategy would require the firm to generate its own energy for the dedicated use of workplace charging. This would require enough space for a solar or wind array to provide electricity either directly to charging stations or to a battery that supplies the designated charging ports with electricity. The benefits of this method include: no additional incurred electricity costs for charging and the reduced concerns about demand charges, reputation as a socially conscious and environmentally friendly firm, and the ability to mitigate overall costs for infrastructure by being able to charge users for time or electricity regardless of the utility structure. However, this approach also has several drawbacks. It requires on hand technical expertise and very substantial upfront investments by the firm. Since this method can only be used in areas with a large amount of free space, there are also geographical limits on where it can be implemented. Consequently, this strategy should only be considered by large firms with enough space to allow for generation and a dedicated employee base that predominately drives PEVs. As the more expensive, ambitious option for workplace charging, this type of approach would be an entirely private enterprise with no public option.

The British Columbia Institute of Technology's campus serves as an example of this workplace microgrid system. Dubbed the Energy OASIS project, its goal is to demonstrate a possible solution for mitigating grid impacts of PEV charging.[96] System components include a 500 kWh Li-ion Battery Energy Storage System, 250 kW solar photovoltaic system, two DCFC charging stations, and a sophisticated energy management system.[97] The energy management system balances energy between the solar PV system generation, PEV charging loads, battery energy storage system, and the local power distribution grid. When fully operational, the Energy OASIS PV solar system is capable of generating over 142MWh per year, with some of that energy going towards PEV charging and the rest going back into the BCIT grid to offset energy costs for the campus.[98] Details about the BCIT campus workplace charging system are further discussed in the case study section.

4.3.2.2 Equipment and Installation Costs

Workplaces can contract electricians to complete a site evaluation and determine existing site

93 Ibid.

94 Doyle, Kevin. "Level Up Your EV Charging Knowledge." ChargePoint, 23 Mar. 2017, www.chargepoint.com/blog/level-your-ev-charging-knowledge/

95 Chargepoint. *Level 1 Versus Level 2 Charging: Making the Right Choice. Level 1 Versus Level 2 Charging: Making the Right Choice*, Chargepoint, Inc., 2017.

96 British Columbia Institute of Technology, "Project Summary: Energy OASIS," accessed March 2019, https://www.bcit.ca/files/appliedresearch/pdf/energy_oasis_project_summary.pdf

97 British Columbia Institute of Technology, "Project Summary: Energy OASIS."

98 British Columbia Institute of Technology, "Project Summary: Energy OASIS."

electrical capacity, location of distribution lines, and the required capacity for the planned number and type of EVSE. The contractor will handle connecting the EVSE to an existing electrical service or to a new or upgraded electrical service, if necessary. The local electrical utility may become involved if the necessary electrical supply upgrades are considerable.

The installation process becomes complicated if one or more of the following processes are necessary: trenching to lay electrical supply conduit, upgrading the electrical service to provide sufficient electrical capacity, or locating EVSE on parking levels above or below the level with electrical service.[99] A study by the Electric Power Research Institute analyzed 385 commercial sites that installed 989 Level 2 EVSE and found that the installation cost breakdown was approximately: 55-60% labor, 30-35% materials, 5% permits, and 5% taxes.[100] The study also found that Level 2 sites that required additional work, such as trenching, were about 25% more costly than installations that did not.[101]

4.3.2.3 Operation and Maintenance Cost

Perhaps the most significant operating cost to consider when installing EVSE is the electricity cost of charging PEVs and the amount of electricity consumed. Electricity consumption is impacted by the number of vehicles charging, power output of the EVSE, vehicle power acceptance rate, climate, and the length of time vehicles charge.[102]

According the Edison Electric Institute, the national average commercial electricity rate is 10.74 cents per kWh.[103] The average commute, according to the 2017 National Household Travel Survey, is 12.71 miles.[104] For Level 1 charging at an assumed power level of 1.4kW, or four miles of range per every hour charged, it would take about 3 hours to recover the battery range from the morning's commute with an electricity cost of about 45 cents. At this rate, it would cost about $1.20 for an employee to charge their car for the entirety of an eight-hour workday. On a yearly basis, the electricity costs of Level 1 charging per employee would be between $117 and $312, depending on charging duration and the amount of workdays per-year.

For Level 2 charging at an assumed power level of 6.6kW, or twenty miles of range for every hour plugged in, it would take only about 40 minutes to recover the battery charge from the average American commute with an electricity cost of 47 cents. However, if an employee chooses to keep the car charging for half of a day, or four hours, it would cost about $2.84. In this scenario, the annual electricity cost of Level 2 charging per employee would be between $122 and $738, depending on charging duration and the amount of workdays per-year.

Demand charges are another important consideration when workplaces add the energy load of PEV charging (especially Level 2 stations). Utilities apply demand charges based on the highest amount of power drawn, typically calculated as the number of kilowatts averaged over a fifteen-minute interval in a given month. This issue can be especially pertinent for small businesses with several chargers, where the addition of workplace charging could lead to a spike in energy demand. Employers can manage PEV charging so that it occurs off peak demand by utilizing EVSE with load management systems that avoid charging during peak times or establish timing schedules that stagger charger availability.[105]

Workplaces also should budget for EVSE maintenance costs. Due to the relative newness of the PEV market, data on EVSE lifespans and maintenance costs is lacking. Regular maintenance is generally not required for basic Level 1 and 2 EVSE.[106] However, more complicated systems may need more regular maintenance, as they have more components that are more susceptible to malfunctions.

99 Ibid.

100 Ibid.

101 Ibid.

102 Ibid.

103 Rocky Mountain Power, "Commercial Price Comparison," accessed March 2019, https://www.rockymountainpower.net/about/rar/cpc.html

104 US Department of Transportation, *National Household Travel Survey 2017*, https://nhts.ornl.gov/

105 Doyle, Kevin. "Level Up Your EV Charging Knowledge." ChargePoint, 23 Mar. 2017, www.chargepoint.com/blog/level-your-ev-charging-knowledge/

106 US Department of Energy, "Costs Associated With Non-Residential Electric Vehicle Supply Equipment."

Workplaces should account for potential costs due to replacing outlets, replacements of EVSE at the end of their useful lives, and troubleshooting software issues in networked units.

Finally, additional fees will apply for networked EVSE that is connected to a charging network managed by a third-party organization. These fees cover the cost of WiFi connection and data management on the network host's computer server and vary from $100 to $900 annually depending on the manufacturer and type of EVSE.[107]

4.3.2.4 Assessing Fees

According to the 2016 DOE Workplace Charging Challenge Progress Update, 75% of Challenge partners provide free PEV charging at their worksites.[108] Free charging has advantages for employers. First, free charging can be viewed as an attractive benefit for employers to offer in order to increase recruitment and retention. Not collecting fees is the simplest model to enact, which may be especially beneficial for small firms with small workforces. Free charging also eliminates the added expense of utilizing third parties for networked charging. Based on data from the Charging Challenge partners, the additional energy load from charging stations is typically manageable, with an average use of 10 kwh of electricity per day, or less energy consumed than by four desktop computers and monitors in a 24-hour period.[109] However, free charging also has the potential to drive demand beyond the capacity of the EVSE available at a worksite. Conflict may also ensue between drivers who need to charge to make their commute and those that charge at work because it is cheaper than doing so at home. This presents a substantial challenge, but can be overcome using standardized charging etiquette and texting systems that notify employees when they need to move their vehicles.

An increasing number of employers appear to be assessing fees for EVSE use. In 2016, the number of work sites that charged fees for EVSE use increased from 20% to 25%.[110] Assessing fees is an effective means to recover equipment installation costs, cover ongoing operating costs, manage charging station use, and deter unnecessary charging. Table 4.1 below details the number

107 Ibid.

108 US Department of Energy, "2016 Update: A New Sustainable Commute."

109 Ibid.

110 Ibid.

TABLE 4.1:

Worksite Fee Regime Options

Type of Fee	Functionality	Pricing Feasibility
Fee For Power	Assesses fees based on kWh used per charging session. Directly reimburses employers for electricity costs.	Most feasible for large firms with the resources to outsource installation to third parties like ChargePoint. Also feasible for worksites where demand and EVSE availability are closely matched.
Fee for Parking	Assesses fee based on time a PEV is parked in EVSE equipped spot. Encourages drivers to move when charging is complete, helping ensure availability meets demand.	Ideal for firms of all sizes with limited parking. Potentially unfair to vehicles that draw energy at a slower rate and are thus charged more per kWh.
Variable Pricing	Use increasing fees for length of time parked. Maximizes EVSE availability by having greatest incentive for drivers to move when finished charging.	Works well for firms with not enough EVSE to meet demand. Potentially unfair to vehicles that draw energy at a slower rate and are thus charged more per kWh.
Monthly Membership Fee	EVSE management outsourced to third party companies. Employees pay monthly membership fee directly to EVSE management company. Employer avoids extra effort of collecting fees from employees	Ideal for worksites that wish to utilize networked charging.

of options worksites have for fee assessment:

Employers must also consider how to price the use of workplace EVSE. Similar to free charging, fees below the market price of electricity incentivize employees to shift their charging behavior from overnight at home to during the day at work. As adoption of PEVs increase, this shift may overburden the grid and increase energy costs as more charging occurs during peak times. Conversely, expensive charging significantly above the cost of electricity diminishes the economic benefits of commuting with PEVs and makes PEV ownership inaccessible to drivers who cannot charge at home. Thus, the ideal solution is to charge slightly above the market rate. At this cost, drivers will be less incentivized to do the majority of their charging at work, and employers can minimize the infrastructure costs of providing EVSE.

4.3.2.5 Grid Considerations

Concentrated workplace charging has the potential to be a significant concern for the grid. In a situation where all employees plug in their PEV upon arriving at work, a peak in demand would occur in the morning hours. However, daytime PEV charging also benefits grid operators. Demand typically ramps up at 4 PM and peaks at 8 PM. Charging electric vehicles during the daytime hours between 11 AM and 4 PM would help smooth the demand increase by giving grid operators more time to accommodate increasing energy demand. Midday charging can also take advantage of excess solar-generated power. To offset peak demand, employees can have designated parking times when they are permitted to charge, or Level 2 chargers could be implemented that include the ability to do networked charging where charging is controlled remotely. This has the added benefit of reducing demand charges.

4.4 POLICY CONSIDERATIONS

Employee demand for workplace charging and the desire to cultivate a company culture of sustainability may be enough incentive for workplaces to pursue onsite charging stations. However, policy levers in the form of public incentives may still be necessary to overcome certain barriers. Surveys from the DOE Workplace Charging Challenge found that of the nearly 5,000 workplace charging stations installed before June 2015, 94% were installed in states with charging station incentives.[111] A likely explanation is that workplaces are responding to interest in PEVs from their employees, who may have been influenced by the availability of PEV incentives and state efforts to promote PEVs. The following section will detail potential policy levers to encourage workplace charging and how different policy levers can be applied depending on the perceived barriers to adoption.

4.4.1 Policy Options

4.4.1.1 Emissions reduction requirements

Several governments have enacted legislation that requires employers to take strategic action toward reducing employee commute emissions. Along with subsidized public transit, compressed workweeks, and telecommuting, workplace EVSE availability is an effective way to meet these requirements. Under the Oregon Administrative Rules, for example, the Employee Commute Options (ECO) program requires employers with more than 100 employees to incentivize commuting options that reduce the number of cars driven to work in Portland and the surrounding areas.[112] In Southern California, the South Coast Air Quality Management District Rule 2202 implements a program similar to the Employee Commute Reduction Program. Rule 2202 gives employers with 500 or more employees a menu of options for emission reduction strategies that includes workplace charging.[113]

4.4.1.2 Public grants

Financial support grants for workplaces that wish to install PEV charging stations can ease the financial burden of EVSE installation. This strategy was used in Central Maine Power's 2018 Electric Vehicle Matching Grant Program. This program offered "matching grant" awards of up

111 US Department of Energy, "Workplace Charging Challenge Mid-Program Review: Employees Plug In."

112 "Employee Commute Options," Oregon Department of Environmental Quality, accessed February 2019, https://www.oregon.gov/deq/aq/programs/Pages/ECO.aspx

113 "Rule 2202 - On-Road Motor Vehicle Mitigation Options," South Coast Air Quality Management District, accessed February 2019, http://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-2202/rule-2202-employee-commute-reduction-program-guidelines-(ecrp).pdf

to $2,500 toward purchase and deployment of a Level 2 or DCFC charging station at a private host site to nonprofit and municipal Central Maine customers.[114] Similarly, the Massachusetts Department of Environmental Protection's Electric Vehicle Incentive Program provides funding to cover up to 60% of the purchase price for PEV charging stations for public, non-profit, or private employers in Massachusetts.[115]

4.4.1.3 Rebates from utilities or government entities

Like grants, rebates offered by utilities or government entities can encourage workplace charging by offsetting the initial cost of installation. In Austin, Texas, Austin Energy (the municipal utility) offers rebates of $4,000 or 50% of the cost to install approved level 2 charging stations.[116] The Pennsylvania Department of Environmental Protection offers up to $4,000 per plug for non-publicly accessible projects.[117] New Jersey's "It Pay$ to Plug in Program" offers rebates of up to $5,000 per single port and $6,000 for dual-port Level 2 stations for businesses, government entities, non-profit organizations, and educational institutions.[118]

4.4.1.4 Tax credits

Several states offer tax credits to lessen the burden of installation costs for worksite charging projects. Oklahoma's Alternative Fueling Infrastructure Tax Credit offers a one-time income tax credit available to corporations for up to 75% of the cost of an PEV charging station project.[119] New York State also provides a tax credit of up to $5,000 for the purchase and installation of an PEV charging station.[120]

4.4.1.5 Guidance

Beyond financial assistance, information and technical guidance can be useful for worksites pursuing EVSE installation. The US Department of Energy's Workplace Charging Challenge allows organizations to sign up as "partners" to gain access to informational resources, peer-to-peer networking with other worksites, and one-on-one technical assistance.[121] At the local level, the City of Rochester implemented the Rochester PEV Accelerator, a community-wide initiative to achieve widespread PEV adoption, that also includes a Workplace Charging Challenge that gives employers access to technical resources and peer-to-peer networking with other participating worksites.[122]

4.4.1.6 Building code amendments and local ordinances

State and local governments can pursue "PEV ready" building code amendments or ordinances that require a certain percentage of new commercial parking construction to be equipped for EVSE installation. Jurisdictions may pursue different degrees of PEV-readiness based on their existing needs. A basic level would require new spaces to be PEV-capable with installation of the necessary infrastructure, such as conduit, wiring, and electrical capacity. In Atlanta, via an ordinance passed in 2017, 20% of spaces in new commercial parking structures must be PEV-capable.[123] Another level would require spaces to be EVSE-ready with installation of 240-volt charging outlets, such as the NEMA 14-50 receptacle. The City of Boulder, Colorado requires 10% of new parking to have EVSE-ready outlets.[124]

114 "Take Credit for Going Green," Chargepoint, accessed February 2019, https://www.chargepoint.com/products/station-incentives/

115 "MassEVIP Workplace Charging Program Requirements," Massachusetts Department of Environmental Protection, accessed February 2019, https://www.mass.gov/files/documents/2019/01/17/massevip-wpc.pdf

116 "Plug-in Austin: Workplace Charging," Austin Energy, accessed February 2019, https://austinenergy.com/ae/green-power/plug-in-austin/workplace-charging

117 "Wolf Administration Announces Grants and Rebates for Electric Vehicle Charging Stations," Pennsylvania Pressroom, accessed February 2019, https://www.media.pa.gov/Pages/DEP_details.aspx?newsid=1073

118 "It Pay$ to Plug In: NJ's EV Charging Grant Program," State of New Jersey, accessed February 2019, https://www.drivegreen.nj.gov/PIApplication.pdf

119 "Oklahoma Laws and Incentives," Alternative Fuels Data Center, US Department of Energy, accessed February 2019, https://afdc.energy.gov/laws/all?state=OK

120 "Charging Station Programs," New York State Energy Research and Development Authority, accessed February 2019, https://www.nyserda.ny.gov/All-Programs/Programs/ChargeNY/Charge-Electric/Charging-Station-Programs

121 US Department of Energy, "Workplace Charging Challenge."

122 "Rochester EV Accelerator Workplace Charging Challenge," City of Rochester, accessed February 2019, http://rochesterevs.com/wp-content/uploads/2018/01/WorkplaceChargingPledge.pdf

123 "Cracking the Code on EV-Ready Building Codes," Southwest Energy Efficiency Project, accessed February 2019, http://www.swenergy.org/cracking-the-code-on-ev-ready-building-codes

124 Southwest Energy Efficient Project, "Cracking the Code on EV-Ready Building Codes."

The most progressive requirements may involve installation of a minimum number of Level 2 charging stations, such as in Palo Alto, California, where 5% of new commercial parking must be EVSE-equipped.[125] Forward-thinking building code requirements alleviate the need for costly retrofitting. ChargePoint used data from Dodge Data & Analytics and California Building Standards Commission to estimate that PEV charging costs $1,650 for new construction while retrofitting may cost $3,750 to $6,975 in commercial buildings. Consequently, adjustments to building codes for an PEV-ready future may lead to potential savings of $2,100 to $5,325 per charging spot.[126]

4.4.1.7 Streamlined permitting

A streamlined permitting process removes obstacles and minimizes costs for workplaces to install charging stations. In 2015, the State of California passed AB 1236 to require all local governments to have an expedited, streamlined permitting process for PEV charging stations for non-residential and residential areas as of September 30, 2017.[127]

4.4.1.8 PEV Rates

Utilities could support workplaces wishing to provide charging infrastructure for employee-owned PEVs through PEV-charging rates. For example, the Los Angeles Department of Water and Power offers an PEV discount rate of $0.025 per kilowatt-hour for electricity used to charge PEVs during off-peak times.[128]

4.4.1.9 Demonstration projects

Demonstration projects can highlight local workplace charging projects and give an example of what PEV charging at the workplace looks like. These demonstrations are also opportunities for third-party charging infrastructure providers to demonstrate their services, as workplaces may be unaware that third parties can handle the logistical and technical aspect of workplace charging. On a large scale, the US Department of Energy worked with private sector partners to deploy over 12,000 Level 2 charging stations across seventeen US regions under the EV Project.[129] In return, project participants gave consent for the EV Project researchers to collect and analyze data from the PEVs and charging units.

4.4.2 Policy Barriers

The various EVSE installation incentives will have different appeals for policy-makers, consumers, utilities, and charging infrastructure providers depending on the city or region. Which policy lever to employ depends on which barriers to broader deployment of workplace PEV charging exist. This section will describe potential barriers and the policy levers that may be most appropriate.

4.4.2.1 Economic

Costs of installation, especially if expensive retrofitting of electrical equipment is necessary, is a significant barrier for employers. In this case, subsidies such as tax credits, grants, and rebates are useful. Electricity discounts can also address the economic burden of workplace charging.

4.4.2.2 Information or technical uncertainty

If inadequate information or concern over the technical aspect of handling workplace charging is an issue, demonstration projects or guidance from government agencies, such as the DOE's Charging Challenge project, can assist.

4.4.2.3 Permitting barrier

The cost and time investment related to permitting may discourage employers from pursuing workplace charging initiatives. Streamlining the permitting process and "EV-ready" building codes address this barrier.

125 Ibid.

126 "The Contractor's Guide to EV Ready Building Codes," ChargePoint, accessed February 2019, https://www.chargepoint.com/blog/contractors-guide-ev-ready-building-codes/

127 "AB 1236 Tool Kit: EV Charging Stations Ordinance," California Building Officials, accessed February 2019, https://www.calbo.org/sites/main/files/file-attachments/calboab1236toolkitlargejurisdiction.pdf

128 "Plug-In Electric Vehicle (PEV) Charging Rate Reduction - LADWP," US Department of Energy Alternative Fuels Center, accessed February 2019, https://afdc.energy.gov/laws/6142

129 "AVTA: The EV Project," US Department of Energy Office of Energy Efficiency and Renewable Energy, accessed February 2019, https://www.energy.gov/eere/vehicles/avta-ev-project

4.5 POLICY CASE STUDY

The following case studies represent examples of workplace charging programs in three different sectors: higher education, government, and technology. These examples function as real-world models for the points discussed in this chapter. These organizations responded to demand from employees to implement charging infrastructure, determined the best system of EVSE to meet their charging needs, including the type of charging stations installed and a payment system to manage demand, and took advantage of incentives to fund the installation.

4.5.1 Higher Education

British Columbia Institute of Technology (BCIT) is one of British Columbia's largest universities with more than 48,000 students enrolled annually.[130] Composed of five campuses across Vancouver, the institution employs 1,800 staff members. BCIT offers charging station for employees, students, and the general public in paid parking lots. The charging infrastructure available uses solar and battery to provide two DCFC stations, six Level 2 stations, and two Level 1 outlets. All parking spots are metered and managed by a third-party company. On average the chargers are used 20-30 times per day. In order to manage the stations, BCIT implemented a four-hour maximum for parking that is enforced by smart chargers to ensure adequate parking space turnover. Staff use RFID chips to activate the chargers, and students and the general public can login into a kiosk and register their vehicles to access the chargers. The availability of government funding was a key motivator for the project, and the funding seeded development of the school's entire Workplace Charging Program.

4.5.2 Public Agency

The California Environmental Protection Agency offers sixteen Level 1 and twenty Level 2 chargers in an eight-story public parking garage operated by the City of Sacramento. The organization installed workplace charging to support the agency's mission, help achieve the building's LEED Platinum certification, and encourage PEV adoption among employees.

The charging stations are available to anyone who utilizes the garage for parking, which includes employees, agency fleet vehicles, and members of the public. Stations are available on a first-come, first-served basis, and the number of PEVs exceeds the number of chargers. To meet the demand, the PEV drivers adopted an informal charger sharing protocol, including an email list for communication between drivers and with the ability to request charging access. The City of Sacramento is considering other methods to facilitate sharing, a four-hour time limit for charging or a requirement that vehicles must be actively charging to park at the stations.

The California Air Resources Board administered an electric vehicle loan program that financed the project's EVSE installation costs. A US Department of Energy/California Energy Commission grant further funded a replacement of the stations to meet the current SAE J1772 standard. The City of Sacramento pays for the cost of electricity and maintenance out of its operating budget.[131]

4.5.3 Private Company

At its Mountain View, California headquarters, Google has one of the world's most extensive networks of workplace charging stations. The parking area features 227 Level 2 charging stations managed by ChargePoint, 160 Level 1 charging spots, a pilot project to test a wireless charging system, and a DCFC station for their fleet vehicles. Google does not charge employees or guests for use of the charging stations. More than 200 employees and 50 PEV fleet vehicles utilize the chargers daily with usage continuing to grow.[132]

130 "Workplace Charging Case Study: BCIT," Metro Vancouver, accessed February 2019, http://www.metrovancouver.org/services/air-quality/climate-action/transportation-programs/ev-workplace/Documents/Workplace_Case_Study_BCIT.pdf

131 "Amping Up California Workplaces," California PEV Collaborative, accessed February 2019, http://www.ct.gov/deep/lib/deep/air/electric_vehicle/CAPEV_-_Amping_Up_California_Workplaces.pdf

132 "Charging While You Work," Minnesota Pollution Control Agency, accessed February 2019, https://www.pca.state.mn.us/sites/default/files/charging-while-you-work-guide.pdf

4.6 CONCLUSION AND RECOMMENDATIONS

Provision of PEV charging at worksites not only encourages PEV adoption, but also works in the interests of companies wishing to demonstrate corporate sustainability and social responsibility. Therefore, this report recommends that the private sector be the main source of funding for PEV charging infrastructure in the workplace. Municipalities, states, and utilities can utilize a number of public incentives to encourage workplaces to consider PEV adoption, including grants, tax credits, and building code amendments, depending on the needs of the jurisdiction. Furthermore, municipalities, states, and utilities could require worksites to conduct a survey for potential interest in EVSE use. They could also require the worksite provide anonymized survey response data to the subsidy program coordinators. This will allow both the worksite as well as the subsidy program coordinators to determine and estimate future increases to demand. Due to the long dwell time, worksite charging is essential to supporting widespread PEV adoption and has the potential to solve the infrastructure challenges of other locations, particularly multi-family residential. PEV owners who live in multi-unit dwellings without EVSE access can utilize their workplace as their primary charging location. The strategies and considerations outlined in this chapter could be used to grow workplace charging.

The following steps could be taken to further encourage workplace charging infrastructure installation:

1. **Local governments and utilities could consider offering information and technical guidance for worksites interested in EVSE deployment.**

Breaking down information asymmetries between workplaces that may not have the expertise to adequately assess their charging infrastructure needs will make public and private investments more efficient in the long-run.

2. **Local governments and utilities could offer rebates, tax credits, and streamline permitting for EVSE installation at workplaces to incentivize EVSE deployment.**

Workplaces are second to residences for PEV charging opportunities. The majority of workers in the US drive to work, and providing workplace infrastructure will alleviate range anxiety.

3. **Local governments and utilities could focus their rebate and subsidy programs on Level 1 and Level 2 EVSE charging infrastructure.**

Level 1 and Level 2 EVSE will provide plenty of charge for PEV owners parking on-site. DCFC may be cost prohibitive to be effectively deployed at workplaces given the need for high asset utilization: quick charge times mean that DCFC may be underutilized as workers leave their cars parked in spaces after a full charge.

4. **Local governments and utilities could require workplaces to survey employees for interest and demand for PEV charging infrastructure before providing subsidies for EVSE deployment. An additional requirement could mandate the release of this data to local governments and utilities.**

Survey requirements will allow workplaces to understand their own PEV charging infrastructure needs, allowing them make a more informed choice as to how to invest. Furthermore, requiring survey data be given to subsidy program providers will allow utilities and local governments to gain insight into local workplace trends and how their future need for EVSE may change.

5. **Utilities could provide appropriate electricity discounts for adopting intelligent charging PEV charging infrastructure.**

Workplaces may be concerned with higher electric utility bills caused by increasing PEV adoption and electricity usage on-site. Discounting the cost of electricity for PEVs will incentivize workplaces to make investments or take part in subsidy programs by lowering the cost of ownership. Combining this with intelligent charging can save both consumers and utilities money in the long run.

5 | DIRECT-CURRENT FAST-CHARGING

5.1 EXECUTIVE SUMMARY

DCFC infrastructure is a relatively small but critical piece of the overall EVSE infrastructure puzzle. It is required to relieve range anxiety for BEV owners on long trips, and as a convenience in urban areas. However, this technology is not critical for PHEV owners. Direct current fast charging (DCFC) is a faster charging alternative to Levels 1 and 2, and can charge some PEV batteries to 80% capacity in as little as 20-30 minutes. Urban DCFC stations provide fast and convenient charging to people living in multi-family residences without access to home or workplace charging. DCFC stations on interstates between metropolitan areas make long distance PEV travel substantially easier by eliminating the possibility of BEVs running out of power while travelling between cities. Because of the convenience DCFC provides, increasing urban and rural DCFC infrastructure will likely encourage more widespread PEV adoption.

The scenarios in which DCFC have already been developed are not reproducible models that would be viable in most areas. However, these cases have been critical to the wide rollout of DCFC across the country. As a result, in most cases, DCFC does not require significant public investment. If municipalities or states feel that public investment in PEV charging infrastructure is critical to meeting public health and climate initiatives, the recommendations below provide a few ways that a government could fund DCFC infrastructure.

5.1.1 Research Methods

This chapter utilized pricing data from charging company websites. It determined market factors for charging technology by referencing a series of reports on DCFC rollout. Additionally, a review of government programs provided an indication of how much funding is necessary to improve DCFC financial feasibility.

5.1.2 Recommendations

1) **In general, public funds are not necessary to fund DCFC infrastructure.**

2) **If a government decides to use taxpayer funds to help fund DCFC, local governments and utilities could do the following:**

    a. **Rebates, Incentives, Tax Credits**

    b. **Direct ownership of charging stations**

    c. **Station Specification Requirements**

    d. **Public-Private Partnerships**

5.2 INTRODUCTION

Consumer range anxiety makes charging speed and convenience a major challenge to PEV adoption among drivers who travel between cities, or drivers who live in dense urban areas without access to home charging. DC fast charging can charge PEV batteries to 80% capacity much faster than other charging types, in some cases within 30 minutes. This allows drivers to charge PEVs with speed and convenience approaching that of ICE vehicles. Consumer range anxiety will decrease substantially as inter-city and urban DCFC infrastructure proliferates. However, it is not clear who should make the upfront investment in DCFC.

DCFC is proving to be a compelling option for some private firms, with several making investments in DCFC charging networks. Companies like Blink, Tesla, ChargePoint, VW, and ChargeHub have started installing DCFC infrastructure in many areas of the U.S. The largest of these projects, Tesla's SuperCharger Network and VW's Electrify America are beginning to cover large swaths of America's interstate highways. However, the motivation behind both these projects is unrelated to the financial feasibility of installing DCFC stations. In the case of Electrify America, the funds were raised through Volkswagen's Dieselgate settlement. Additionally, Tesla has made investment in DCFC technology to promote the sales of their vehicles.

Although it shows promising technological growth, DCFC has several significant drawbacks. DCFC technology is expensive, and full installation of a DCFC station can cost between $10,000 and $50,000. Combined with installation costs charges and utility fees for peak electricity demand can make DCFC infrastructure unaffordable for many businesses. This could indicate a need for public or utility construction and maintenance of DCFC stations, particularly in geographic locations where utilization of electric charging is low.

Another drawback to DCFC is that it currently lacks a universal charging standard, and many car manufacturers and charging networks use different DCFC equipment. The most popular charging equipment includes Combined Charging Standard (CCS), Tesla's Supercharger, and CHAdeMo. Though these different equipment standards can be placed at the same station, they are in competition with each other.

DCFC is a promising technology that allows PEV drivers to charge quickly and conveniently, and will be particularly useful to urban residents without home charging and PEV drivers traveling between cities. This chapter will describe the implications of emerging DCFC technology for EVSE owners, customers, and the grid, as well as how DCFC will be integrated in the public and private spheres. We begin with a discussion of the DCFC market. We then analyze public sector investment, primarily utility investment. We then review private business models including colocation and exclusive charging networks. We finish with a discussion of the impact of transportation network companies on DCFC charging infrastructure.

5.3 USE CASE CHARACTERISTICS

DC fast charging infrastructure is a relatively small but critical piece of the overall EVSE infrastructure puzzle. DCFC is critical in that it is required to relieve range anxiety for BEVs on long trips, and as an important convenience in urban areas. The DCFC need is relatively small when compared the need for Level 1 and Level 2 charging infrastructure. A recent report from the Edison Electric Institute used the National Renewable Energy Laboratory's Electric Vehicle Projection tool to model the need for charging infrastructure.[133] The study projected by 2030 there would be 18.7 million PEVs on the road requiring 9.6 million total charging ports. Of these charging ports, 100,000 (1%) were DCFC ports.

As of February 2019, there are 2,714 publicly or privately owned DCFC stations in the United States with 9,925 charging outlets.[134] The states with the most DCFC stations are California, where 29% are located, followed by Florida (5%), Texas (5%), New York (4%) and Washington (3%). The U.S. Department of Energy's Alternative Fuels Data Center categorizes these stations by ownership status. 6,714 outlets are privately-owned, 3,396 have an unknown ownership status, 102 are government-owned, and 10 are directly owned by utilities.

5.3.1 Financial Considerations

The major barrier to DCFC infrastructure development is cost. DCFC charging stations are significantly more expensive than Level 2 chargers. Installation costs for DCFC stations vary by wattage size, location, the number of ports, and availability of electricity infrastructure, among other factors. It is difficult to find peer reviewed estimates of DCFC charging station installation, but the U.S. DOE Alternative Fuels Data Center estimates that individual DCFC units can cost between $10,000 and $40,000, depending on the power level and features. Installation costs are largely dependent on electrical capacity at the site so costs can vary widely from $4,000-$51,000, depending on how close the DCFC is to the electrical service and if

133 Cooper, Adam, and Kellen Schefter. 2018. "Electric Vehicle Sales Forecast and the Charging Infrastructure Required Through 2030." Eei, no. November. http://www.edisonfoundation.net/iei/publications/Documents/IEI_EEI PEV Sales and Infrastruc

134 U.S. Department of Energy (DOE), "Alternative Fueling Station Locator" https://afdc.energy.gov/stations/#/analyze?fuel=ELEC&ev_levels=dc_fast&country=US&access=public&access=private (accessed on February 10, 2019)

there is sufficient electrical capacity for the DCFC's high power needs.[135] For a private business looking to capitalize on high electric vehicle adoption, this cost may be prohibitive without financial assistance. Even in the event of high electric vehicle utilization and a subsequent increase in revenue at private businesses offering DCFC, these capital costs and additional operating costs can mean many years until the investment pays off.

Financial viability for the private sector of DCFC fast charging infrastructure is one of the most important questions regarding PEV charging infrastructure in general. It is difficult to estimate the profitability of DCFC infrastructure as data are proprietary and closely guarded by DCFC charging companies. We can, however, make some general estimates. If we consider a DCFC station costs $60,000 with annual operating expenses of $5,000 utilized for four hours of charging per day, at EVGo's current per minute charge of $0.30 cents and an assumed discount rate of 7% discount, the charger would break even in approximately four years. The Canadian Council of Ministers for the Environment commissioned more detailed analysis.[136] Based on estimates of PEV adoption and EVSE infrastructure in an urban area, this report estimated that urban DCFCs would break even during the 6th year of usage, with full payback occurring in the 8th year. Inter-city chargers would break even during the 4th year and achieve full payback during the 7th year. Larger investors may accept these returns, particularly if they believe early entry into the market will have benefits in the future, however, these longer payback periods suggest the need for some public funding in the near term.

5.3.2 Technological Considerations

Long payback periods also increase the impact of other risk factors, in particular the risk that the rapidly advancing state of charging infrastructure will make present day infrastructure obsolete, or at least substandard. Most DCFC stations currently operate in the 50kW to 120kW range offering charging speeds of between 20 and 60 minutes for 100 miles of range. As batteries grow in capacity to take charge and charging stations improve, they will deliver charge at increasingly efficient rates. For example, Swiss company ABB recently launched a 350kW charger which can provide 100 miles of range in less than 8 minutes. If battery technology improves to allow this rate of charging – many batteries are currently limited to 100kW or below to preserve battery life – current charging technology may be less desirable. The installation of charging networks will require a multi-year payback period, so prospective host sites will want to consider whether charging infrastructure is likely to become outdated before they break even on their investment. The host site will then want to consider the opportunity costs: whether outdated infrastructure will occupy space and interrupt consumer behavior patterns.

DCFC success also depends on long-term consumer usage. DCFC must offer a comparative advantage to Level 1 and Level 2 charging, which can be done at low cost at home. In most cases, electric car users are only likely to use DCFC if it can effectively save charging time at a low enough premium. There are specific cases, however, where DCFC is critical, particularly on long distance travel. Although charge times vary by vehicle and charging infrastructure technology, one can use standard kW output at Level 1, Level 2, and DCFC to determine effectiveness relative to internal combustion engine vehicles. In particular, at a standard, lower-end output of 50 kW for DCFC, a 2019 Chevy Bolt with a battery capacity of 60 kWh and max mileage of 238 miles can fill its entire battery in roughly an hour and a half. Although the charging cost can vary depending on the charging location and associated fees, a full battery charge can cost up to $20. Compared to a similar internal combustion vehicle with closer to 350 miles on a full tank, the cost of filling a tank hovers closer to $30 after a few minutes at the gas station. At these prices and charging times, the prospect of DCFC to drivers is unattractive in both the urban and intercity settings. This issue could be partially offset by intelligent colocation of charging stations.

135 US DOE. Alternative Fuels Data Center. https://afdc.energy.gov/case/2832. Accessed April 11 2019

136 "Business Case for Investing in Electric Vehicle Direct Current Fast Charge Station Infrastructure," Canadian Council of Ministers of the Environment, 2016

The role of PHEVs in a growing PEV market will also determine the utilization of publicly available DCFC. With smaller batteries and engines, PHEV drivers will not need DCFC charging than BEV drivers. The portion of the PEV market that each PHEVs and BEVs make up will need to correlate with the portfolio of Level 2 and DCFC stations available. Per the National Plug-In Electric Vehicle Infrastructure Analysis put together by the Department of Energy in 2017, utilization of electric infrastructure is highly dependent on the type of electric vehicles present in the market. Since PHEVs do not need DCFC infrastructure, an increased adoption of PHEVs will diminish the need for new DCFC infrastructure. BEVs with lower ranges (less than 100 miles) will also take advantage of publicly available Level 2 in conjunction with DCFC. Consumer preferences may also drive whether or not the adoption of PEVs increased with PHEVs vs BEVs. Consumers may determine that they prefer the flexibility of PHEVs especially with larger vehicles such as SUVs and minivans.

Although it seems that battery charging is currently the best way to refuel electric vehicles, investments by companies around the globe suggest that this paradigm could change in the future. Chinese electric vehicle car manufacturer, NIO, has recently begun building battery swapping stations along Chinese highways. Battery swapping could also get drivers back on the road much faster than DCFC. Although battery swapping has failed previously, those looking to invest in DCFC should consider the possibility of other refueling technologies. In Europe, the Automotive Association in Ireland has developed Europe's first fast charging mobile van which can be deployed to charge vehicles that run out of charge mid-trip. These vans would provide enough charge to empty vehicles so that drivers can proceed to their home or charging station. With options like these available to consumers, the need for large amounts of permanent PEV infrastructure might be greatly diminished. Charging companies may need to understand if these technologies will continue to permeate the market before rolling out more public charging stations.

5.3.3 DCFC Investment Strategies

While DCFC is a small piece of the puzzle, there is an infrastructure gap to make up by 2030, and potentially lucrative private business opportunities. In the relatively nascent DCFC market there are a variety of strategies that market actors are testing. The market actors include automakers, charging network companies, electric utilities, and state and local governments and agencies. It is a complex and fastmoving space, with market actors at times competing and at times collaborating with one another. Generally, strategies have taken the following forms:

- *Public: Government* – While typically not actively installing and managing charging stations, state and local governments are investing public funds in DCFC charging infrastructure in the form of rebates, incentives, and tax credits. At least thirteen states have some type of incentive (e.g., grant or tax credit) to support the deployment of DCFC charging stations.[137] In some cases these are very generous, for example the Minnesota Pollution Control offers a rebate of 80% of DCFC costs, and the Pennsylvania Department of Environmental Protection offers a rebate of 75% of DCFC costs. Lastly, electrify America, a Volkswagen subsidiary was established as part of the diesel emissions settlement, and is required to spend $2 billion over 10 years (2017-2027) to deploy charging infrastructure.

- *Public: Public utilities and regulated investor owned utilities* – Utilities in California gained regulatory approval on January 11, 2018 to install, own and manage DCFC as well as other charging infrastructure in a series of pilot projects.[138] Generally, however, utilities provide incentives and

137 US DOE. Alternative Fuels Data Center. https://afdc.energy.gov/case/2832. Accessed April 11 2019.

138 California Public Utilities Commission. 2018. "Decision on the Transportation Electrification Priority Review Projects. D-18-01-024". http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M204/K670/204670548.PDF

rebates to subsidize DCFC with ratepayer funds. There are nine states in which utilities provide assistance for DCFC.

- *Private: Colocation* - Companies like ChargePoint and Blink serve as an umbrella network, allowing the provider of each charging station to set the rates. Many providers in this type of network install chargers in shopping center parking lots that are free to use by subscribers to their respective networks. This is a creative co-location strategy, as DCFC stations can be used as amenities to attract customers.
- *Private: Exclusive Charging* - Tesla offers convenient and exclusive charging as an incentive to purchase their vehicles. Other automakers such as BMW and VW have also invested in DCFC partnering with charging network companies.
- *Private: End-to-End*– Charging network companies that operate public DCFC networks, for example EVgo. These companies solely own and operate DCFC stations. These companies may also seek colocation opportunities, but typically do not allow the host to set rates or receive revenue. A potential drawback of this strategy is that private third parties are generally not allowed to sell electricity by the kWh.

The following sections will review public and private strategies more closely, focused on utility investment and private business models.

5.3.4 Utility Investment

Although many utilities are not directly investing in DCFC infrastructure, they can enter this market under certain conditions. A more common way for public utilities to invest in EVSE is to offer public incentives. For example, the Sacramento Municipal Utility District (SMUD) does this by offering a rebate of up to $120,000 per qualified DCFC site.

5.3.4.1 Financial considerations

IOUs and IPPs that operate in retail choice markets are able to make capital investment decisions based on the firm's goals. IOUs attempt to meet the demands of their shareholders, while IPPs seek to maximize payouts for private investors. Utilities that do not fall into these categories must determine if financial investment in DCFC infrastructure will better serve customers, if so, the appropriate investment levels and instruments.

A primary benefit of publicly-financed utility investment is the public sector's comparative access to lower capital costs. According to data from NYU, utilities have the second lowest cost-of-capital at 3.61% as of January 2019. In comparison, the total market's average cost of capital is 7.00%. Lowering the financing costs of meeting a target level of investment or deployment of DCFC infrastructure provides benefits to consumers that are specific to utility financing. Utilities possess institutional knowledge about capital-intensive investment and long payback period projects that plays a role in their decision to finance DCFC. Utilities are generally comfortable with investments that take decades to payback, and investors are willing to accept these investments' reduced liquidity.

Utility experience is also relevant when coordinating site locations with the distribution grid. The need for system upgrades to support a DCFC site is a primary driver of capital cost increases. Trenching enhancements and upgrades to transformers or conduits may be necessary to ensure the system can handle demand spikes caused by DCFC clusters. However, utility involvement in identifying siting locations can reduce information asymmetries between the utility and host that might otherwise occur.

Utilities can account for distributional or social inequities in electricity delivery by utilizing pricing design, such as low and middle-income exemptions. For example, while rebates for new electric vehicle ownership tend to be regressive in nature, utilities could expand their existing low-income exemptions or rebates when rate-basing the capital costs of DCFC infrastructure and thereby change the distributional effects of the investment. Similarly, the benefits of policies targeted to achieve further electrification of the transportation sector in order to reduce greenhouse gas emissions could be internalized through DCFC infrastructure investment.

5.3.4.2 Technological considerations

Advancing smart meter technology will play a substantial role in DCFC energy pricing. As of 2017, there were over 19 million commercial and industrial (C&I) electricity meters in the United States and just under 50% were capable of Advanced Meter Infrastructure (AMI) technology while 76% were capable of either Automated Meter Reading (AMR) or AMI technologies. AMR, or "one-way smart" meters allow utilities to automatically read customers' meters for billing purposes and AMI, or "two-way smart" meters, allow utilities to measure and record electricity usage and a minimum of hourly intervals but can range to real-time reading with built-in two-way communication.

Another technological consideration is the impact declining battery costs are having on the market for behind-the-fence storage. This allows customers to avoid or reduce high utility demand charges. In an analysis done by the National Renewable Energy Laboratory (NREL) found that demand charges typically range from 30-70% of a customer's electricity bill. These high demand charges are often attributed as a critical factor in battery price economics and were found to be a significant predictor of an economically viable battery. Similar economic analysis conducted by Greentech Media Research as well as by McKinsey & Company have found that currently battery storage can breakeven with demand charges as low as $9-$15/kW.

As battery costs continue to decline, consumers can choose to utilize batteries behind-the-fence, on their side of the meter, in order to increase predictability of demand charges on their bills. While batteries can smooth spikes in hourly demand, their usage behind-the-fence reduces the utility's visibility into its customers' loads. From the utilities' perspective, it may be more cost effective to manage these peaks in demand without batteries, especially if these consumer peaks do not coincide with broader system or localized peak demand or if the utility has excess spare capacity. Declining battery costs could in this case, reduce a utilities' ability to cost-effectively optimize its assets in tandem with consumer decisions to minimize their individual electricity bills.

5.3.4.3 Grid considerations

Energy consumption is a significant consideration for DCFC installation. With the exception of 2008-2010, electricity consumption in the U.S. has been relatively flat for the past decade. Though consumption varies by state, utilities are finding themselves in a difficult and changing business environment where increasing vehicle electrification could bring a new source of demand to the grid.

Unlike Level 1 or 2 chargers that can function as load management tools, DCFC is more comparable to a traditional grid load. DCFC users are willing to pay a premium price, whether through a fast-charging network membership or wrapped into the price of the vehicle, to charge their vehicles quickly and on demand. Due to these characteristics, DCFC provides a new source of revenue for utilities facing declining or flat electricity demand. This usage is business-as-usual model for the utility, where their involvement ends at the distribution of electricity at the meter.

The three utility business models that offer different levels of involvement beyond the business-as-usual model are

- *Make-Ready* – The make-ready model includes the necessary trenching and wiring to connect the meter to charging infrastructure.
- *Owner-Operator* – The owner-operator model expands on the make-ready model's utility investment to include PEV charger capital and operations costs.
- *Utility Incentive* – The Utility Incentives model allows for utility involvement in the traditional business-as-usual setting while providing financial incentives to host. These incentives generally take the form of rebates, which encourage accelerated EVSE deployment.

There are several advantages that arise when a utility steps beyond the business-as-usual business model to either build and operate a DCFC charger (Owner-Operator) or work directly with a third-party host (Make-Ready) from the perspective of minimizing distribution system grid impacts. The major drivers of DCFC cost are as follows:

- *Hardware*: DCFC supply equipment
- *Installation*: contractor labor and materials, electrical services, permitting and inspection, engineering review and design
- *Other capital*: hardware warranty, repair labor warrant, land
- *Operation and maintenance*: electricity consumption and demand charges, network subscriptions, transaction costs, maintenance and repairs

Due to the high variability in these costs across a relatively small sample of installations, the U.S. DOE estimates that dual-port non-residential infrastructure installation can cost between $4,000-$51,000. However, these estimates are from data collected from 100 installations between 2011-2013 and other studies have estimated even larger ranges. The DOE found that the most expensive DCFC installations were at sites that were unable to utilize existing electrical services. These sites required distribution line and transformer upgrading or installation to ensure the utility could safely deliver adequate voltage to the site. In planning where to site DCFC stations, utilities have greater visibility into the existing distribution network, including its current bottlenecks or potential to better utilize existing excess capacity. For this reason, the Make-Ready or Owner-Operator business models allow the utility to be more involved in the siting decision. This can potentially minimize the costs of necessary distribution system upgrades. While utility involvement could be limited to data-sharing with third-party site hosts, bringing the investment decision in-house would reduce data confidentiality concerns and reduce informational asymmetries between stakeholders.

Another insight into the economics of DCFC stations can be gleaned from the growing literature on the effects of utility demand charges on cost predictability. While demand charges have been driving the market for behind-the-fence batteries in industries across the economy, they also represent a significant and unnecessary barrier to DCFC station deployment. According to Rocky Mountain Institute (RMI) analysis done on 230 stations in California, demand charges can represent upwards of 90% of a station's electricity bill. While California has some of the highest demand charges in the country, managing these charges is critical to the profitability of DCFC stations across the U.S. In fact, NREL found that some of the highest demand charges it identified were actually in states such as Colorado, Nebraska, Arizona and Georgia. Figure 5.1 (page 60) identifies the range of maximum demand charges in the U.S. as of 2017.

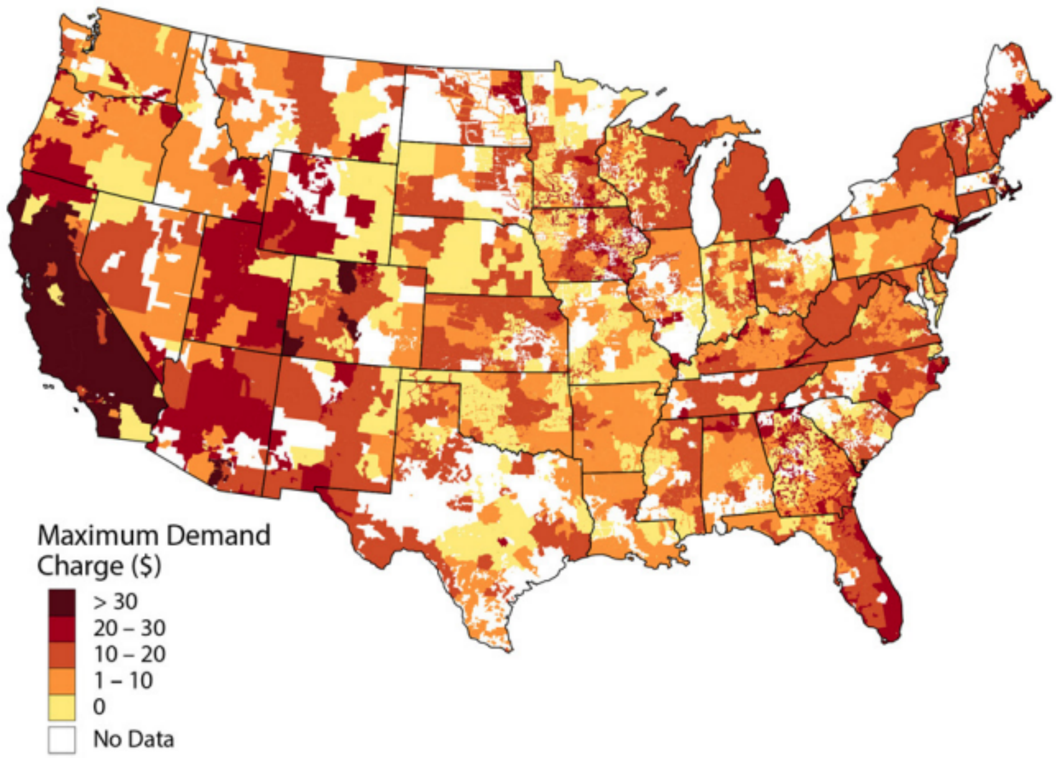
Though demand charges are a mechanism for utilities to recover the cost of ensuring sufficient electricity distribution capacity, there is a growing body of literature on the inefficiency of this tariff mechanism. Research by the RMI, the Regulatory Assistance Project (RAP) and the Berkley Energy Institute at Haas have identified more efficient tariff design structures that minimize demand charges. These structures allow utilities to recover the fixed costs associated with maintaining electricity system capacity and ensuring peak demand can be met.

In its analysis of EVgo tariffs in California, RMI asserted several rate design theory best practices worth considering for public DCFC infrastructure. Though this report does not endorse these designs, it utilizes them in its assumptions. These designs suggest that demand charge structures are not always reflective of cost causation and can allow off-peak loads to free-ride while being paid for by on-peak users. Thus, PEV demand charges should be time varying and reflect actual system costs.

The adoption of advanced metering infrastructure allows for utilities to more accurately understand their customers load profiles and enables them to offer dynamic pricing models such as time-of-use (TOU) pricing. Furthermore, replacing demand charges with fixed monthly charges and TOU pricing, which would benefit DCFC station economics, would additionally assist the utilities themselves in managing existing

FIGURE 5.1:

Maximum Demand Charge Rates by Utility Service Area, 2017



Source: National Renewable Energy Laboratory (NREL) "Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges" http://www.nrel.gov/docs/fy17osti/68963.pdf (accessed on February 17, 2019)

assets and planning infrastructure investments. These conclusions are supported by further analysis conducted by RAP, which suggests that smart meters and AMI can facilitate a movement away from demand charges toward more granular time-varying energy rates.

As the utility business model changes, research on cost recovery for utilities can shape the methods utilities use to secure and update their role in the electricity system. Understanding the possibilities for utilities to enter the market for DCFC infrastructure, or PEV supply equipment infrastructure more broadly, could provide a growing source of revenue in the future. Alternatively, improving rate design will enable the market to function more efficiently when deciding to invest in DCFC infrastructure privately.

5.3.5 Private Investment

Charging network companies follow a variety of business strategies, and there is not clear frontrunner. Where each company differs is in its handling of the hardware, software, maintenance, and operation of the charging infrastructure. Based on research of existing charging infrastructure companies in the United States we identify four main business models in the DCFC infrastructure sector:

- *Colocation – Hardware and software*
- *End-to-End – Hardware and software*
- *Software as a Service*
- *Automaker Exclusive Charging*

ChargePoint, EVGo, Greenlots, and Tesla are considered exemplars of these strategies, and their business models provide important insights into consumer behavior around electric vehicle charging.

5.3.5.1 ChargePoint - Hardware and Software

Chargepoint is the largest of the charging network companies, with 320 of its North American charging locations offering DCFC. Chargepoint is responsible for installing charging hardware and software, handing control of its stations to the private business host site. Electric vehicle users simply connect their free Chargepoint card to their credit card, which is charged with each electric vehicle charge. Whether or not the charging is free is determined entirely by the host site, not Chargepoint.

Given Chargepoint's business model, it is difficult to estimate Chargepoint's overall revenue stream. And with over 60,000 charging locations around the world, it is reasonable to conclude that Chargepoint has made large upfront investments to become the world leader in charging infrastructure. Chargepoint appears to largely depend on money earned from selling licenses and maintaining stations for private business or utility host sites to use their hardware and software.

5.3.5.2 EVgo – Hardware and Software

EVgo maintains the largest public DCFC charging network with over 1,000 charging stations in 34 states. EVgo chargers provide charging services for all connection types so are available to drivers of all makes and models of PEVs. EVgo solely owns and operates all its DCFC chargers, and markets itself as a premium, seamless charging experience. The company offers both pay-as-you-go charging and monthly membership charging.

5.3.5.3 Greenlots - Software

Greenlots sells software to charging station installers including utilities, car companies like BMW and VW, and municipalities. Greenlots has chosen not to be in the business of building infrastructure, largely due to the fact that other businesses, like utilities, already own and operate a significant amount of charging infrastructure. Rather than building infrastructure, which entails large up-front investment with long payback periods, Greenlots has positioned itself to adapt to an ever-changing market, ceding the responsibility of installing charging infrastructure to others.

Because Greenlots advocates selling non-proprietary software that can easily merge with any charging station, it is hard to estimate the extent to which Greenlots makes money. Even with an understanding of where Greenlots charging software is used, this financial data is kept private for best business practice.

5.3.5.4 Tesla Superchargers - Complementary to Tesla Car Ownership

Tesla's Supercharger network began free for all Tesla users, although the cost of the charging stations was initially rolled into the price of all Tesla vehicles. Tesla announced in 2018 that it would start requiring owners of new Teslas to pay for charging.

The Supercharger network is expansive, with nearly 13,000 individual charging ports in 1440 stations on the network. Although the cost to build each station is private data, even a low estimate of $40,000 per station means Tesla invested over $50,000,000 to build the network. It is not clear to what extent Tesla accounted for this investment through car sales; however, Tesla clearly believes that a charging network is vital to secure electric vehicle adoption.

5.3.5.5 Co-location

Two goals that DCFC infrastructure development should strive for are cost effectiveness and positive driver experience. As noted previously, often the largest cost in installing DCFC is not the charging unit, but power and installation costs. One of the challenges for PEV owners is the relatively slow speed of charging compared with ICE vehicles. Co-location of DCFC infrastructure with other amenities or businesses can help achieve both goals. DCFC infrastructure developers can work with utilities to select suitable locations with nearby power infrastructure and identify appropriate amenities that can occupy PEV owners while their vehicles are charging. A recent survey conducted by Nicholas and Tal[139], drivers participate in the following activities while charging:

- Walk around until charging is done
- Walk around part of the time
- Stay in vehicle
- Shopping – Reason for visit
- Shopping – Incidental

Forty-three percent of drivers surveyed participated in incidental shopping while charging their vehicle. This behavior is important to highlight as it provides potential motivation for retail businesses to invest in PEV infrastructure. Nicholas and Tal also reported that drivers spent an average of $29.33 on incidental shopping, compared to $45.94 for intentional shopping.[140] These figures indicate the opportunity for retail businesses to monetize the revenue potential of investing in charging infrastructure.

The study conducted by Nicholas and Tal also determined that many drivers will opt for public charging options that are close to their homes regardless of whether home charging is available to them. This phenomenon could contribute to higher utilization of available DCFC infrastructure. Of those surveyed, many drivers stated that adequate Level 2 charging did not exist in convenient locations. Additionally, there was a sentiment that Level 2 charging required longer parking time than what was available at metered parking spots to achieve the desired range. Though Level 2 charging may have been sufficient for the surveyed drivers, due to its absence, they concluded that DCFC played a vital role in areas where Level 2 charging was lacking. Charging companies will need to understand driver behavior to determine whether Level 2 or DCFC is adequate for driver needs in a specific area. This will be dependent on characteristics of trips to charging stations such as, origination point, next destination, and number of charges a day/week.

139 Nicholas, Michael A., and Gil Tal. Survey and Data Observation on Consumer Motivations to DC Fast Charge. Report no. UCD-ITS-RR-17-21. Institute of Transportation Studies, University of California - Davis. 10-12.

140 Ibid.

PEV adoption will be highly dependent on the public's view regarding range anxiety. This is particularly true for intercity trips and as a result, intercity DCFC is clearly necessary. Where to site DCFC charging stations on inter-city corridors is a particularly salient question. One potentially beneficial option is colocation with existing businesses on inter-city corridors. A 2017 study by the Idaho National Laboratory noted that "DCFCs are most useful when they are sited within a half mile of major transportation corridors where they can support both intra and inter-urban travel".[141] This opens opportunities for colocation with fast-food chains, shopping malls, and truck-stops where captured consumers will increase revenue.

Another colocation opportunity for inter-city travel is hotels. Many hotels have begun to make investments in Level 2 charging infrastructure for their guests which will allow them to recharge their vehicles overnight. For example, Marriott advertises that they have installed more than 2516 charging stations at their properties around the globe. Additionally, Tesla has partnered with Hilton Hotels to expand their charging network. With major hotel chains investing in Level 2 charging, they see the benefits of attracting travelers who are embarking on long journeys with their electric vehicles. As PEV adoption increases, there may be need for additional overnight charging infrastructure that could charge multiple vehicles overnight, opening the opportunity for DCFC.

While inter-city charging is necessary, the volume of chargers required is debated. The need for publicly available DCFC stations is dependent on the rollout of charging infrastructure to multi-family residences and workplaces. If drivers have access to charging at home and the workplace, there will be less demand for public charging infrastructure, urban DCFC or otherwise. Workplace charging and home charging provide an alternative to fast charging because of the amount of time individuals spend at those locations. However, if workplaces or apartment complexes decide the investment in charging infrastructure is too high for them, there will be opportunities

141 Francfort, Jim, Shawn Salisbury, John Smart, Thomas Garetson, and Donald Karner. 2017. "Considerations for Corridor and Community DC Fast Charging Complex System Design." Inl, no. May.

for charging companies to expand public charging infrastructure to supplement the needs of those who do not have access to home charging.

5.4 POLICY CONSIDERATIONS

The role of policy in DCFC infrastructure development is largely dependent on social goals for PEV adoption. At current costs and utilization rates, DCFC can take anywhere from four to eight years to recoup the initial capital costs. While the two most notable examples of DCFC rollouts, the Tesla Supercharger Network and Electrify America, appear to have been relatively successful, in these cases, each organization had very specific reasons to put forth the capital costs to build DCFC stations. There is still an infrastructure gap to fill, however, and other investors will be needed. For other charging network companies without other core businesses (Tesla) or dedicated resources (Electrify America), the proposition of building DCFC stations is challenging. At this nascent stage, there is a need for intelligent public policy to build out DCFC infrastructure efficiently which will involve investment of public funds, either through state and local governments, or electric utilities.

5.4.1 Geographic Considerations

To ensure effective DCFC infrastructure implementation, different approaches are necessary for urban and rural markets. Organizations like Electrify America that fund DCFC infrastructure are currently investing most heavily in metropolitan areas, where PEV ownership tends to be concentrated. This market will face inherently different challenges than rural markets, where most DCFC infrastructure is most necessary on highways for PEV owners to utilize for intercity travel, but where local residents are unlikely to own PEVs.

5.4.2 Urban Infrastructure

As urban centers consider publicly funding the DCFC infrastructure market, policymakers will inevitably consider questions of equitable access and how to properly manage the risk of this infrastructure. For governments or utilities that operate in a natural monopoly or regulated retail market structure, the public interest should be concerned not just with how DCFC is being funded, but for whom. Public intervention, through utility funding, can enable utilities to expand the scope of their equity mandate to serve all customers. Utilities can provide incentives for locating chargers in underserved locations and cross-subsidize utilization through their broader asset portfolio while the market is developing.

Although the utilities' ability to rate-base capital costs could lead to criticisms of this implementation method's regressive nature, most utilities already engage in re-distributional efforts aimed at reducing the effects of higher prices on low- and middle-income communities. Separating the income effects from the price signal used to dynamically and efficiently allocate resources, such as through an income-based rebate, allows the public to encourage efficient allocation decisions while accounting for distributional consequences.

While three levels of utility intervention have been introduced – the Make-Ready model, the Owner-Operator model and the Utility Incentives model – each come with their own potential for increased risk to the public from a pace of deployment perspective. Because the private market is in its infancy, there is relatively little information for public officials to base decisions on when it comes to choosing technologies and understanding future market operations. Utilities appear to be mitigating this risk by engaging in the Utility Incentives model, where the rebate cost is fixed and can be based on either the utilities' private benefits or the public's evaluation of the social benefits not currently captured in the private market. However, other methods such as the phasing of deployment or funding pilot projects, through either the Make-Ready or Owner-Operator models, could be alternatively implemented.

Due to the variety of charging options available in urban environments, public investment in charging infrastructure should be diversified. DCFC is not the only option for public charging. Level 2 public charging will frequently be more cost effective depending on the application and wider proliferation of Level 2 charging will acts as a signal to consumers that charging options are widespread. In particular, jurisdictions attempting to increase PEV adoption in urban areas should focus on providing rebates for Level 2 chargers in public parking, workplaces, and multi-family dwelling units. In the cases where DCFC stations are viable in urban areas, stations should be located near corridors to serve a dual purpose. With Level 2 stations ubiquitously located at workplaces and multi-family dwellings, the need for DCFC could be reduced.

While other policy mechanisms for achieving of the energy transport sector remain infeasible, utility investment in DCFC infrastructure could alleviate some of these green market failures in an indirect way. Utilities have numerous advantages for reducing the overall cost of infrastructure investment, not limited to a lower cost of capital, patient capital and institutional knowledge. There also exist opportunities for utilities to improve market outcomes regardless as to whether they invest themselves more directly in DCFC charging, including data sharing and tariff design. In conclusion, these recommendations are a starting point for utilities looking at DCFC infrastructure investment as a potential source of new and growing electricity demand going forward.

5.4.3 Intercity Infrastructure

A comprehensive rural DCFC infrastructure network is crucial for widespread PEV adoption. Though PEV electric ranges are increasing dramatically, range anxiety is still a significant barrier to BEV adoption. Increasing DCFC infrastructure in rural areas on interstate highways will abate this concern for most drivers and will make BEVs more competitive with ICE vehicles.

But unlike urban markets, rural DCFC infrastructure should not be funded by local utilities. Rural co-ops generally have far fewer financial resources than urban utilities, and most PEV drivers live in urban areas. Thus, rural co-ops should not be obligated to finance DCFC infrastructure that will primarily be used for intercity travel by urban-dwelling PEV drivers.

Electrify America is planning to invest $65-85 million in highway DCFC infrastructure despite substantial installation costs. Private companies are already making significant strides in highway DCFC installation, and this process should be primarily left to the private market so rural co-ops are not overburdened. If governments wish to further incentivize rural DCFC installation, state-level incentives will be more effective and equitable than pressuring rural co-ops to fund the process.

5.4.4 Public Rebate Programs

Since public funds are being utilized, rebate programs should set clearly defined eligibility requirements to ensure that funds are being utilized in the most effective manner possible. For example, rebate programs focused on intercity DCFC stations could set requirements such as:

- Station located along U.S. Highways
- No two stations can be located within 50 miles of each other
- Minimum charging rate of 120 kW[142]

In an urban setting, government priorities should focus on equity issues as there are a greater variety of charging options available to consumers. As a result, governments can scale rebates depending on the average household income of a neighborhood where a charging station is being installed and ensure that any subsidized station provides access to the whole population.

- Regardless of geography, rebates should be tiered based on the following factors:
- Necessary grid upgrades for installation
- Type of plugs available on station
- Number of stations at a site
- Public accessibility
- Proximity to inter-city corridors

By defining these requirements, governments can reduce the risk of taxpayer money being mismanaged or ineffectively utilized.

142 "Comments of The Texas Electric Transportation Resources Alliance to the Texas Commission on Environmental Quality Regarding the Texas VW Settlement Funding Plan." *TxETRA*, October 8, 2018. https://www.tceq.texas.gov/assets/public/implementation/air/terp/VW/VW Comments/VW-03-193_TxETRA.pdf

5.4.5 Automaker Investment in PEV Charging to Promote Core Business

Automakers have a vested interest in establishing a comprehensive EVSE infrastructure network, including DCFC. Tesla has long operated under the model that in order to promote sales of its primary product, electric vehicles, customers needed access to DCFC stations. Thus, Tesla used a proprietary model, building out a network of DCFC stations where only Tesla drivers could charge their PEV for free. Recently, Tesla has begun charging for use of a DCFC station, presumably to begin to recoup some of the capital costs. As other car manufacturers try to increase the sales of their electric vehicles, they might also consider building out a DCFC network to reduce buyers range anxiety. They might also consider approaching Tesla with the request to buy into the Supercharger network. To support this, states could legislate that all DCFC charging have interoperability and access for all vehicle types and customers, but require automakers compensate Tesla appropriately.

5.4.6 Sunsetting Policies

Once adoption of PEVs has reached a level where utilization of DCFCs has made them financially viable, public investment should phase out and allow a competitive private sector emerge. Governments could still maintain control of how networks are built out by using zoning laws to restrict where they can be built, how many, in what range of closeness, etc. It may be that utilization would reach such a rate that chargers would need to be placed closer than 50 miles to prevent lines at chargers. However, as technology increases the range of PEVs will also increase so building out more charging stations at already existing locations may suffice. And it is not impossible that PEV range would increase to such a point that intercity chargers would only be needed for extra long-distance trips. But as this is a way off, to increase adoption, 50-120 miles is still the optimal distance. as time goes on it is not a foregone conclusion that more DCFCs will be needed.[143]

143 "Comments of The Texas Electric Transportation Resources Alliance to the Texas Commission on Environmental Quality Regarding the Texas VW Settlement Funding Plan." *TxETRA*, October 8, 2018. https://www.tceq.texas.gov/assets/public/implementation/air/terp/VW/VW Comments/VW-03-193_TxETRA.pdf

5.5 CONCLUSIONS AND RECOMMENDATIONS

DCFC infrastructure is a relatively small but critical piece of the overall EVSE infrastructure puzzle. It is required to relieve range anxiety for BEVs on long trips, and as an important convenience in urban areas. At present there is an infrastructure gap in DCFC charging that will increase as PEV adoption increases. To fill this gap, investment is needed, however, DCFC infrastructure cost is prohibitive for purely private investment. As a result, public policy and investment are needed. There are a range of policy options available for the public sector to use to support DCFC infrastructure development, primarily well managed planning supported by incentives and rebates.

This report makes the following recommendations for DCFC infrastructure funding:

1. **Local governments and utilities should not use public funds to invest in DCFC infrastructure, unless the installation of these charging stations would benefit a large percentage of the population and address policy goals.**

Due to the high cost of DCFC, public investment in these charging stations for the sole reason of increasing availability of charging infrastructure would be an inefficient use of taxpayer dollars. However, if a government has broad public health or climate initiatives that would benefit from an increase in PEV adoption, there may be a justification for the use of public funds for this expensive technology. In most cases, public funds could be more efficiently spent in other types of charging infrastructure (e.g. MFR Level 2 and Public Level 2).

2. **If a government decides to use taxpayer funds to help fund DCFC, local governments and utilities could do the following:**
    a. **Rebates, Incentives, Tax Credits**
    b. **Direct ownership of charging stations**

c. **Station Specification Requirements**

d. **Public-Private Partnerships**

If a government has significant cause to spend public funds on DCFC infrastructure, there are a few financial and regulatory approaches that could improve the efficiency and equity of that expenditure.

a. Rebates, Incentives and Tax Credits: DCFC infrastructure may help supplement limited charging infrastructure at workplaces and multi-family dwellings in urban areas. As a result, public investment, in the form of rebates, incentives or tax credits, could help increase the rollout of privately managed charging stations. These funds should be scaled to account for the revenue generation potential of these private assets.

b. Direct ownership of charging stations: Urban utilities can install DCFC infrastructure more effectively because they have substantial expertise on local grid infrastructure. By installing DCFC more efficiently, this may provide the most socially equitable allocation, especially in high need areas where rates can be regulated.

c. Station Specification Requirements: In order to ensure the effectiveness of the rollout of DCFC infrastructure, local governments or utilities could specify sites and power capacity of these units to help ensure utilization. These sites could often be along highway corridors so that they can serve as urban and intercity charging options.

d. Public-Private Partnerships: Through formal partnerships with private companies, local governments and utilities could ensure the rollout of DCFC infrastructure meets their broader policy goals. This could also provide means for governments to recoup their investment in infrastructure through user fees, similar to tolls roads. More broadly, this form of partnership would allow governments or utilities to help complete the rollout of existing networks (e.g. Electrify America).

6 | POTENTIAL TECHNOLOGICAL IMPACTS

Previously, this project detailed background information regarding electric vehicles, their charging infrastructure, and the factors that affect them. It discussed the different use cases for electric vehicle charging infrastructure – single-family residences, multifamily residences, workplaces, and DCFC – and gave recommendations for policymakers regarding strategies for investment in such infrastructure. As one read through the project, they may have recognized that this report does not consider some potentially highly disruptive factors to the PEV infrastructure market. Transportation network companies, autonomous vehicles, changes in battery storage and cost, and hydrogen fuel cell vehicles are four technologies or factors that may heavily influence how EVSE is both used and deployed. This chapter details these four factors and notes trends in current technology. Its purpose is to inform policymakers as to how they should consider these technologies when deploying EVSE.

6.1 TRANSPORTATION NETWORK COMPANIES (TNCS)

6.1.1 Introduction

Although electric vehicle adoption is typically viewed in terms of individual ownership, the vastly expanding scale of Transportation Network Companies (TNC) such as Uber and Lyft form a crucial decision point for the topic of public versus private support for battery charging infrastructure. As a result of rapidly-evolving consumer transit preferences within urban metro areas, electric vehicle adoption for ride sharing services provides a unique platform for advancing eco-centric initiatives. However, policy makers also face challenging realities concerning the collective lack of incentives for TNCs to invest in green-friendly operations.

While it is true that electric vehicles (EVs) offer the long-term benefit of minimal costs for maintenance and upkeep, the nature of TNC workforces inhibits the value of a large-scale company-owned “fleet” of automobiles. Since the majority of TNC drivers are independent contractors seeking to leverage the use of vehicles they already own, the incremental cost of new EV purchases as opposed to continuing to utilize fuel-efficient (but conventionally designed) internal combustion (ICE) vehicles is rarely advantageous. As a result of these constraints for embracing electric vehicles as a monetary value-add, tangible and impactful public regulations must be strongly considered to facilitate TNC migration away from internal combustion engines.

As of 2016, vehicle transportation has overtaken power generation as the USA’s largest source of CO2 emissions.[144] Following recent year over year increases near 2%, vehicle greenhouse gases also exceed 2.0 billion tons of CO2 on an annual basis.[145] Even in the presence of heightened industry standards for fuel efficiency, cars and trucks of less than three years of age currently comprise over 80% of transportation emissions.[146] Given the steady decline in fuel prices, reduced financial support for public rail transportation, and proliferation of low-cost ride sharing services, it is commonly cheaper and more convenient for urban Americans of all ages and income levels to travel by personal automobile. Given these market conditions, sales of electric vehicles continue to lag heavily behind traditional cars and trucks. Even in the presence of robust federal and state tax benefits and extensive marketing efforts, electric vehicles have yet to eclipse more than 1% of new car purchases within the United States.[147] While it is reasonable to assume that expansion of car model options, reduced retail prices, and more robust charging infrastructure will gradually facilitate EV integration, the

144 “Overview of Greenhouse Gases.” EPA. April 11, 2019. Accessed May 03, 2019. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

145 Ibid.

146 Ibid.

147 “EV Market Share.” EVAdoption. Accessed May 03, 2019. https://evadoption.com/ev-market-share/

purchase of these vehicles in lieu of entry-level ICE alternatives (i.e. Nissan Versa, Hyundai Accent, Toyota Yaris) will continue to occur at a short-term cost premium for the foreseeable future.

Within the realm of TNC services, the core nature of ride share drivers as independent contractors places substantial emphasis on seeking the lowest possible operating cost per mile. Based upon these constraints, there is almost zero direct benefit for cost-conscious TNC drivers to pay a premium to obtain a new or gently used electric vehicle purely for environmental purposes in the place of lower priced gasoline options. Unless the TNC market evolves to the degree where customers seek 'for-hire' ridership for long distance journeys that exceed hundreds of miles, the fuel savings and reduced maintenance costs linked with higher-priced EVs will not prevail over generally cheaper-to-buy ICEs in terms of pure dollars and cents.

6.1.2 Key Facts & Figures

Uber and Lyft currently comprise an overall customer base that exceeds 40 million riders within the United States, the majority of whom reside in dense urban areas.[148] On the operator side, ride sharing services boast more than 3 million drivers with several key metros witnessing exponential growth in contractor-based participation. Within the New York City region, the fleet of independent for-hire vehicles increased by over 120% from 2013 to 2017 and now exceeds 100,000 separate trips per day within the city limits.[149] With respect to typical routes and ride duration, the average TNC journey is approximately 6.5 miles which further underscores its natural foothold within dense communities.[150]

Despite this massive influx of TNC-driven CO2 emissions, there are very few substantive taxes or surcharges implemented with the aim of boosting electric vehicle utilization or disincentivizing car pollution among ride share providers. Although TNC-specific regulatory fees and safety inspections have been enacted by major cities such as Portland and Seattle, any legitimate "Uber tax" has yet to advance beyond basic discussion points even in highly eco-minded regions.[151] With the exception of several short-lived experimental programs, there have been also very few deliberate attempts to establish DCFC charging infrastructure with the aim of subsidizing or even facilitating electric vehicle ownership among urban TNC operators.

The city of New York implemented a pilot program to explore EV viability among taxi services in the year 2016, but limited testing to the Nissan Leaf which requires robust charging infrastructure due to its limited driving range of approximately 75 miles. As part of the city's initiative, taxi-focused charging stations were successfully built in the Midtown and Lower East Side neighborhoods through coordination with the local utility provider, Con Edison. In addition to frustrations raised by taxi drivers that the Leaf's limited range was insufficient to support entire 8-12 hour driving shifts without charging, the city's final report also raised concerns that "Level III charging requires extensive and complicated land, technical, and user requirements not typically found in Manhattan."[152] Given these commonly-voiced themes of range anxiety and infrastructure limitations, it is clear that the impetus for EV integration among TNC providers is much better positioned as a publicly-sponsored environmental imperative than a business-friendly enhancement.

6.1.3 Financial & Technological Considerations

Given the current market conditions, deliberate policy action is necessary in order to stem the tide of rapidly expanding ride share services that

148 Iqbal, Mansoor. "Uber Revenue and Usage Statistics (2018)." Business of Apps. May 02, 2019. Accessed May 03, 2019. http://www.businessofapps.com/data/uber-statistics/#1

149 Ben-Shahar, Omri. "The Many Wrong Reasons To Fear Uber (And The One Unnoticed Über-Threat)." Forbes. March 13, 2017. Accessed May 03, 2019. https://www.forbes.com/sites/omribenshahar/2017/03/13/the-many-wrong-reasons-to-fear-uber-and-the-one-unnoticed-uber-threat/#653868505729

150 SherpaShare. "Uber Trips Are Becoming Longer and Faster, but Are They More Profitable?" SherpaShare Blog. February 2, 2016. Accessed May 3, 2019. https://www.sherpashareblog.com/2016/02/uber-trips-are-becoming-longer-and-faster-but-are-they-more-profitable/

151 Carver, Jack. "An Uber Tax Is a Great Idea in New York. In Austin, It's Not Quite as Great." Medium. December 29, 2017. Accessed May 03, 2019. https://medium.com/jackcraver/an-uber-tax-is-a-great-idea-in-new-york-in-austin-less-so-2f9a48731efe

152 City of New York. *Electric Vehicle Pilot: Final Report*. Report. New York City, New York: NYC Online, 2016.

generate extreme emissions risks without any degree of regulatory constraint. As such, it is reasonable for government agencies to actively evaluate a multi-tiered policy that requires TNC companies to shoulder greater responsibility for their environmental footprint while also paving the way for corresponding adoption of electric vehicles. With that said, regulatory precedent has already proven that political action viewed by TNCs as punitive or non-competitive can frequently lead to swift repercussions with limited capacity for negotiation. As demonstrated through nearly 12 months of total withdrawal for both Uber and Lyft in response to fingerprinting requirements by the city of Austin in 2016, impact of TNC losses upon tourism, airport parking, and special event access can be painfully inhibited in the absence of robust ride sharing options.[153] When assessing options for promoting electric vehicle integration, another difficult calculus appears in the form of determining how much urban charging infrastructure is adequate to accommodate long-term TNC fleet totals, and at what cost to the operators.

In the spirit of public-private collaboration, cases can be made for offering DCFC charging access free of charge to TNC operators during a specified integration period, and at reduced costs thereafter. Consideration can also be given to additional tax rebates or subsidy grants to TNC drivers (based on documented proof of high-volume driving services rendered during the previous calendar year) to help offset the short-term expense of replacing their ICE vehicles with higher priced EVs. By softening the cost of purchase and essentially eliminating fuel expenses for ride share drivers via subsidized battery charging, policy makers can stride toward controlling the narrative for seeking a collective public good rather than punishing citizens serving as ride share drivers who often already live under financial duress. In addition to the existing issue of TNC expansion, constantly evolving technology with respect to autonomous vehicles presents another distinct consideration. If TNC providers establish the ability to conduct continuous 24-hour ride share operations, battery charging requirements and logistical constraints are vastly different than the current framework that requires human participation to manually connect electric vehicles.

153 Lien, Tracey. "Uber and Lyft Return to Austin after Texas Law Kills the City's Fingerprint Rule." Los Angeles Times. May 29, 2017. Accessed May 03, 2019. https://www.latimes.com/business/technology/la-fi-tn-uber-austin-20170529-story.html

6.1.4 Grid Considerations

If political will and financial viability enables urban DCFC charging initiatives to accommodate TNC providers, careful analysis should be devoted to ensuring that high impact vehicle charging does not create grid disruptions. In addition to tailoring charging cost reductions to correspond with off-peak hours, charging portals must be equipped to recognize and validate authorized subsidized consumers (i.e. ride-share drivers, low income residents) as opposed to general citizens or out of town visitors. As driving range for EVs continues to increase, it is realistic to expect that autonomous vehicle recharging configurations can be programmed in a manner that combines the optimal balance between minimal grid impact and maximum rideshare availability at all hours.

In the absence of this specialized technology, host cities could establish a rebate system that could simply reimburse eligible participants via mail or electronic submission upon receipt of verified charging transactions. Alongside sophisticated charging equipment, the balance between prioritizing portal locations between commonly utilized TNC route paths (i.e. airports, large shopping districts) and centrally placed sites that accommodate the largest total of overall citizens. Furthermore, how vital are large-scale charging sites (with 10+ portals) if TNCs ultimately migrate toward autonomous vehicles, which could therefore be programmed to travel outside the city limits for cheap and convenient charging without feeling constrained by extra time away from home.

6.1.5 Policy Considerations and Levers

From a policy perspective, the most effective way to leverage urban DCFC charging as a means of reducing carbon emissions would occur in gradual and well-articulated stages. First, an initial foundation of charging portals must be established in proximity of the most common ride share roadways, with immediate short-term incentives offered to both TNC companies and independent contracts who take swift advantage of the offer. In sequence with this first time, a 18- to 24-month grace period should be considered with the expectation that TNCs must meet or exceed an defined percentage composition of ride-share vehicles within their driving network by a certain deadline to allow ample time for reaction and refinement by TNC providers. Once the transition period concludes, the presiding municipalities could then levy penalties for non-compliant combustion drivers on a per-ride basis and then assess a separate cumulative penalty to the overall TNC company. In addition to transactional components, an effective policy lever may occur in the form of specialized access to highly desirable parking areas or premium passenger drop-off sites for TNC drivers who operate an electric vehicle. Given the recent relocation of TNCs to an entirely separate terminal facility near Austin Bergstrom International Airport, providing tangible incentives for immediate compliance is central to maintaining positive momentum away from internal combustion engines.

Although these initiatives may deliver desired eco-friendly outcomes in principle, frequent obstacles may occur across the political spectrum in relation to financing and implementation. Given the array of state laws that often heavily restrict the ability to collect taxes and surcharges at the local laws, non-compliance penalties assessed to individual drivers may be viewed as unduly punitive against a small segment of the contractor population without regard for similar environmental transgressions that frequently occur in many different industries. Even if the surcharge or reduced cost model proves effective in facilitating electric vehicle adoption, the issue of how incremental charging revenue should be spent or reallocated in certain to present yet another heavily-contested topic of debate.

6.1.6 Recommendations and Conclusion

When it comes to reducing carbon emissions and pursuing eco-conscious policy, lawmakers cannot justifiably overlook the effect that TNCs place upon the environment in the form of increased congestion and CO2 pollution. In order to make meaningful steps toward improvement, TNCs must be central components of any effort to reducing greenhouse gases and establishing a robust infrastructure of DCFC stations. Although the most effective DCFC implementations will naturally occur in high density, heavily trafficked urban areas with limited public transportation where TNCs tend to thrive, there are general themes that apply to cities of all sizes across the United States. By establishing a deliberate policy balance between tangible incentives for electric vehicle integration and discernible consequences for non-compliance, ride-sharing can serve as an extremely valuable platform for leveraging public and private resources to achieve collectively positive outcomes.

6.2 AUTONOMOUS VEHICLE TECHNOLOGY

Headlines abound with news of autonomous vehicle (AV) technology. As this technology progresses, it will have the potential to disrupt transportation networks, changing the need for PEV charging infrastructure and how drivers utilize their vehicles. This section will detail the current state of AVs in the market, types of AVs and levels of automation, AV benefits, and the potential for AVs to disrupt transportation systems.

6.2.1 Development of AV Technology

AVs operate using a combination of different technologies. They utilize radar, cameras, and motion sensors to map distances between vehicles and instrument vast amounts of data. Such data is then utilized by software packages both on- and off-board the vehicle to create machine learning models – statistical and mathematical models that provide insights from vast amounts of instrumented data – that determine how the vehicle should appropriately drive and navigate its surroundings. Although these technologies are relatively old, recent advances in computing power have made them cost-effectively deployable for use in vehicles.

The motivation for self-driving vehicles is not new. The DARPA Grand Challenges in 2004, 2005, and 2007 catalyzed innovation in AV technology in an attempt to reduce casualties from driving supplies to soldiers stationed in dangerous areas. Two competitions first took place in the Nevada desert and required robots to navigate a 132-

mile course. No team completed the course in 2004, with the best performing robot traveling only 7.5 miles. By 2005, five robots completed the course, with the best performing finishing in under 7 hours. The 2007 challenge took place in a simulated urban environment where robots had to navigate traffic and obey traffic laws. Of eleven competing teams, six completed the course. Having encouraged substantial growth in AV technology, these competitions played an essential role in allowing AVs to become a competitive market force.[154] Today's AV prototypes have progressed such that many of them could navigate successfully the DARPA Grand Challenge courses that were so challenging fifteen years ago.

6.2.2 Current State of AVs

While the DARPA challenges laid the groundwork for AV technology, public interest in AVs spiked when Google's self-driving AVs were first used on public roads in 2015. These vehicles showed promising results. As of July 2015, Google's self-driving fleet had logged one million miles and only 14 minor accidents. It was later determined that these accidents were caused by human error, not faulty operating systems. There has been at least one collision where the Google system was at fault, which took place in 2016 when a Google vehicle struck a bus.[155]

In the four years since these incidents and publication of this report, AV technology has progressed significantly. Waymo, a subsidiary of Alphabet (of which Google is also a subsidiary) began testing their AVs on public roads in Phoenix, Arizona in 2018.[156] Elon Musk, CEO of PEV manufacturer Tesla, in 2015 predicted fully autonomous versions of his company's vehicles by 2018; as of writing, a number of these vehicles include some form of operational AV technology.[157] Uber, a transportation network company, has begun to use AVs in their operations but has also witnessed horrific accidents as a result.[158] Several additional firms, such as BMW, Mercedes Benz, Nissan, and General Motors, have already begun to prototype AVs and are predicting their vehicles to be driving by 2020.

6.2.3 Levels of Automation

There are 6 levels of automation and 4 levels with the potential to augment both ICEVs and PEVs and disrupt the EVSE market:

- Level 0: vehicles have no AV technology whatsoever and drivers are in complete control of the vehicles at all times.
- Level 1: vehicles may operate by themselves in singular instances mostly with driver assistance. Drivers have the option to use adaptive cruise control, which uses a combination of radar, sonar, and cameras to measure the distance between the AV and the vehicle in front of it.
- Level 2: partial automation. These vehicles have the ability to control speed and steering *simultaneously* for under one minute. These vehicles can react to warning signals by staying in a lane and braking to avoid accidents.
- Level 3: conditional automation. Unlike the previous level of AV technology, this level allows vehicles to self-drive in certain conditions for extended periods of time, notifying drivers when they need to intervene.
- Level 4: high automation. These AVs can operate in traffic without a human driving them. They can self-drive in most scenarios, maintaining safety-

154 DARPA, *The DARPA Grand Challenge: 10 Years Later*, 2014.

155 Bagolee, S, Tavana, M, Asadi, M, and Oliver, T. *Autonomous Vehicles: Challenges, Opportunities, and Future Implications for Transportation Policies*, 2016.

156 Hawkins, Andrew J. "Inside the Lab Where Waymo Is Building the Brains for Its Driverless Cars." The Verge. May 09, 2018. Accessed April 22, 2019. https://www.theverge.com/2018/5/9/17307156/google-waymo-driverless-cars-deep-learning-neural-net-interview

157 Korosec, Kirsten. "Elon Musk Says Tesla Vehicles Will Drive Themselves in Two Years." Fortune. December 21, 2015. Accessed April 22, 2019. http://fortune.com/2015/12/21/elon-musk-interview/; "A Tragic Loss." Tesla, Inc. June 30, 2016. Accessed April 22, 2019. https://www.tesla.com/blog/tragic-loss.

158 Hawkins, Andrew J. "Uber "likely" Not at Fault in Deadly Self-driving Car Crash, Police Chief Says." The Verge. March 20, 2018. Accessed April 22, 2019. https://www.theverge.com/2018/3/20/17142672/uber-deadly-self-driving-car-crash-fault-police

critical functions and monitoring road conditions. Drivers need to control the vehicle only when driving during certain roads or in specific areas.

- Level 5: full automation. These vehicles self-drive as effectively as a human on any road in any situation without human involvement.[159]

6.2.4 AV Benefits

As AVs become more widespread, they will likely provide substantial societal benefits. Road accidents are an incredibly common phenomenon that impose both a large financial and human cost on society. In 2010 alone, over 32 thousand people were killed in automobile accidents in the U.S. and 3.9 million were injured; automobile crashes in 2010 had a total cost burden of $277 billion. Human error is blamed for 90 percent of crashes by reducing human error as a factor, automobile accidents are likely to decrease. In addition to reducing human casualties and the financial burden of automobile accidents, fewer accidents will likely lead to less traffic congestion.[160]

AVs are also likely to provide benefits to the elderly or people with disabilities who cannot drive, as they will be able to rely on their own form of transportation, rather than being dependent on caretakers, public transit, taxis, or ride-sharing services.

It is also likely that AVs will reduce the cost of ride-sharing services, making transportation more accessible to low-income people. If companies like Uber and Lyft invest in AV fleets, they will no longer need to pay drivers and it is possible their rates will decrease. If ride-sharing rates decrease enough, it is possible utilizing AV ride-sharing services will be cost-effective enough to reduce the demand for individual vehicle ownership.

6.2.5 Disrupting Potential

It is possible that widespread autonomous vehicle adoption will disrupt existing transportation systems and change the need for PEV charging infrastructure. Tony Seba, of Stanford University, argues that the existing model of Transportation as a Service (TaaS) that ridesharing companies like Uber and Lyft have spearheaded will utilize AV technology to reduce individual vehicle ownership and lower costs for both the company and the consumer. According to a 2017 report, Seba argues that AVs will make TaaS increasingly affordable, especially if coupled with PEV technology that lowers the overall variable costs associated with fossil fuel use. He projects that the decreasing cost of TaaS will compel more people to abandon individual vehicle ownership and projects that by 2030 95% of U.S. passenger miles will be served by TaaS.[161] Such assertions have led to significant debate about the true trajectory of this technology's progress and subsequent adoption rates.

Widespread adoption of AVs significantly changes what PEV charging infrastructure will be needed. The majority of the recommendations in this report for single-family, multifamily, and workplace charging infrastructure hinges on the fact that vehicles sit idle for large amounts of time in-between use. Paul Barter, a transportation adviser under Karl Popham, Manager of Electric Vehicles and Emerging Technologies at Austin Energy, estimated contemporary vehicle usage rates: 3% of a vehicle's time is spent driving or in otherwise productive use; 0.5% is spent sitting in traffic; 0.5% if spent looking for parking, and; 96% of a vehicle's time is spent parked. This long dwell-time allows consumers to utilize low-cost, low-power charging infrastructure such as Level 1 and Level 2 EVSE and thus means that utilities and local governments need not make large investments in charging infrastructure. Widespread adoption of AVs will decrease this percentage of dwell-time and shift charging needs away from Level 1 and Level 2 EVSE towards DCFC as vehicles increase their daily mileage and battery use.

However, while AV technology may expand rapidly, such predictions are highly uncertain and subject to a high degree of variability in environmental conditions. Furthermore, it is unlikely that vehicle

159 Fortuna, C. *Autonomous Driving Levels 0-5 + Implications*, 2017.

160 Bagolee, S, Tavana, M, Asadi, M, and Oliver, T. *Autonomous Vehicles: Challenges, Opportunities, and Future Implications for Transportation Policies*, 2016.

161 Arbib, J, Seba, T. Rethinking Transportation 2020-2030: *The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries*, 2017

ownership will decrease substantially by 2030. As of 2016, the average LDV on the road in the U.S. was 11.6 years-old.[162] Tony Seba projects that AVs will be available for widespread use on public roads by 2021: assuming no growth in vehicle durability – which is itself a highly uncertain assumption – it is likely that non-AVs purchased in the years leading up to 2021 will last well into the 2030s. Having already paid the up-front cost for a vehicle, the incentive to utilize AV TaaS will be substantially lower throughout the 2020s and 2030s. Assuming PEV ownership increases, vehicles are likely to last even longer, thus further delaying the widespread adoption of individual vehicle ownership. These conclusions led the authors of this report to discount concerns over AV technology adoption as a deterrent for PEV charging infrastructure investment and deployment.

6.3 BATTERY TECHNOLOGY

Batteries represent one of the main challenges to both PHEVs and BEV adoption. This component interlinks with all current adoption issues. Larger batteries help solve range-anxiety in BEVs and increase the miles electrified in PHEVs. Because batteries makeup a large percentage of total PEV costs, cheaper battery packs will result in cheaper PEVs. Different battery pack sizes and components also result in different charging times and requirements, thus shifting consumer demand for specific PEV charging infrastructure. Finding the sweet spot between cost, size, and usability is an important part of PEV forecasts. Previous estimates found battery pack costs to be around $300 per kWh.[163] Current estimates show that battery packs have reached a price level of $200 per kWh in 2017 real terms, with prices expected to continue to decline over time and reaching a price level of $96 per kWh in 2025.[164] This section will describe current trends in battery pack development, potential future issues, and concludes how these factors affect PEV charging infrastructure.

162 IHS Markit, *2016 U.S. Light Duty Vehicle Market At-A-Glance*, 2016

163 Björn Nykvist, Frances Sprei, and Måns Nilsson, "Assessing the Progress toward Lower Priced Long Range Battery Electric Vehicles," *Energy Policy* 124, no. September 2018 (2019): 144–55, https://doi.org/10.1016/j.enpol.2018.09.035.

164 BloombergNEF, "New Energy Outlook 2018," Bloomberg New Energy Finance, 2018, https://about.bnef.com/new-energy-outlook/.

6.3.1 Current Trends

Technological development in the electric vehicle industry space has accelerated after the development of modern Lithium batteries, embedded computers, and power electronics. Even using year-old studies leads to great uncertainty with forecasting costs. The most recent study from the Vehicle Technology Office (VTO) in the Energy Efficiency and Renewable Energy department of the U.S. Department of Energy is from February 2017, utilizing data as recent as 2016. Their study finds market prices for battery packs at between $399 and $480 per kWh, of which the battery cell is between $234 and $282.[165] The VTO explains future price reductions as a process between manufacturing learning, oversupply driven by market expectations, and also subsidization by multinational corporations with diversified product lines.[166] Using VTO lab-proven costs, the US DOE expects to achieve lab-costs of around $130 by the year 2022.[167] They note that actual manufacturing costs lag behind VTO modeled costs by about 4 years. From these estimates, then, the VTO expects manufacturing costs to achieve sub $200/kWh by 2022.[168]

Nykvist, Sprei, and Nilsson present the most recent findings for PHEV and BEV battery costs. Published in February 2019, they utilize a number of different studies to find future potential cost structures. They note how learning rates in manufacturing (presuming as suppliers gain experience in the process costs will decline) have been estimated between 15 and 20% per year. Various forecasts put battery pack costs for a 200-mile BEV between $100 and $200 per kWh by 2025. Higher learning rates could result in lower prices by that timeframe. Using an estimated learning rate of 16+- 3% per year for the industry as a whole, their analysis "confirms that estimates are converging to a current level of around 210 USD/kWh (market leaders) to 230 USD/kWh (all estimates) in 2017."

165 Vehicle Technologies Office, "FY 2017 Annual Progress Report - Batteries," 2016, https://www.energy.gov/sites/prod/files/2018/06/f52/Batteries_FY2017_APR_Final_FullReport-webopt.pdf

166 Ibid.

167 Ibid.

168 Ibid.

Using an assumption of 60 million BEVs in stock by 2030, they estimate battery pack costs to reach $150 USD in 2020 and $100 USD in 2025.[169]

Bloomberg's New Energy Outlook for 2018 also has estimates for battery pack costs. Using industry data, they note that battery prices have decreased by 79% since 2010, and current trends for 2017 place battery pack costs for lithium-ion batteries at roughly $200 USD/kWh.[170] They forecast prices to decrease to sub $100/kWh by 2025 at $96/kWh, and $70/kWh by 2030.[171] These estimates give evidence to the notion that PEV deployment will not only increase, but increase in such a way as to further drive down battery pack costs significantly over time.

6.3.2 Disruptive Factors

As PEV batteries become less expensive, Lithium battery technology will also become increasingly attractive for electric grid applications. The market opportunity for grid storage solutions could eventually be much larger than automotive applications. Increasing market demand for batteries will likely increase costs in the short-term until new firms enter the market to meet this higher level of demand, at which point one can expect consumer costs to decrease. This can help further decrease the cost of PEVs, thus increasing the potential adoption rate of PEVs as they become not only cost-comparable with conventional ICEVs, but even lower in cost.

There are a number of potential issues with projecting this far out with battery packs. First, the learning curve assumptions demonstrated in the previous paragraph and by the VTO assume stable macroeconomic conditions, increasing market demand for BEVs, and stable prices. Although market demand for BEVs is certainly increasing, stable macroeconomic conditions and prices provide a great deal of uncertainty. Increasing protectionist policies can disrupt current supply chains and increase the price of battery packs as a result. Furthermore, battery packs rely on lithium and cobalt for manufacture: resource shortages, caused by political strife or geological lacking, can also increase the price of battery packs in the short term. Long-term uncertainty for resources is difficult to model: geopolitical issues in the Democratic Republic of Congo, a key source of Cobalt, have inherent uncertainty,[172] while new technologies allowing batteries to not require cobalt may change the dynamic in the opposite direction.[173]

Of most important for policymakers and decisionmakers, however, is market support. Nykvist, Sprei, and Nilsson note that "the observed decline in battery pack costs which followed from the surge in BEV sales was closely related to subsidies and mandates. ZEV mandates might have had a dampening effect on the market prices of BEV if the manufacturers have sold the vehicles with a loss. Our estimates presume a continuous growth in sales of BEV that is still linked to continued policy support on both purchases and charging infrastructure." With current policies maintained for subsidizing PEV adoption this report expects battery pack costs to decline in such a way that continues to increase BEV adoption. However, the federal tax credits for PEVs have begun to phase out for a number of the larger manufacturers – Tesla, General Motors, and soon Nissan – leading this report to conclude that PEV prices may rise in the short-term. But, policy support for PEV sales from China and the EU can increase the demand for PEVs and, given constant supply, reduce the cost despite the lack of federal tax credits. This also affects the supply chain for batteries: increasing demand for PEVs pushes PEV manufacturers to lower costs. Since the majority of an PEV's cost comes from the battery pack, improving battery technology remains a sure-fire way of decreasing costs for consumers.

169 Nykvist, Sprei, and Nilsson, "Assessing the Progress toward Lower Priced Long Range Battery Electric Vehicles."

170 BloombergNEF, "New Energy Outlook 2018."

171 Ibid.

172 "Can the World Produce Enough Cobalt for Electric Vehicles?" The Economist. November 29, 2018. Accessed April 22, 2019. https://www.economist.com/business/2018/12/01/can-the-world-produce-enough-cobalt-for-electric-vehicles

173 "John Goodenough." The Economist. November 29, 2018. Accessed April 22, 2019. https://www.economist.com/technology-quarterly/2018/11/29/john-goodenough

6.4 HYDROGEN FUEL CELL VEHICLES

Investing public money always entails a certain degree of risk: doubly so for investing in advanced technology undergoing constant research and development. Although this report focuses on plug-in electric vehicles (PEVs) and the charging infrastructure needed to maintain larger numbers of PEVs on the road, this section discusses one alternative technology that may impact investment decisions: hydrogen-powered fuel cell electric vehicles (FCEVs). FCEVs require different energy carriers, different infrastructure, and different policy mechanisms compared to PEVs. This chapter outlines (1) production systems for hydrogen fuel; (2) consumption of hydrogen; (3) the advantages and disadvantages of using hydrogen-powered FCEVs; and (4) current and future impediments to FCEV adoption. It concludes that hydrogen systems and FCEVs are at too early a stage to consider in contrast to PEV infrastructure deployment, especially given the high rate of PEV adoption compared against FCEVs.

6.4.1 Hydrogen Production Systems

Hydrogen is one of the most abundant elements. Despite this, it cannot be found and extracted like other elements. Instead it must be isolated from other compounds. The two most common methods for isolating hydrogen, gasification and electrolysis, require a number of production steps before hydrogen can be used as an energy carrier. Worldwide, these methods account for more than 99% of all hydrogen produced annually.

Of the 50 million metric tons of hydrogen produced annually today, 95% of it is produced through the gasification of fossil fuels. The vast majority, 68%, is produced from natural gas while 16% and 11% are produced from oil and coal respectively.[174] Isolating hydrogen through gasification can be done by one of two processes: steam-methane reforming or partial oxidation. The former is an endothermic process that requires heat to begin the reaction, and the latter is an exothermic process that gives off heat.

Steam-methane reforming uses steam at temperatures between 700°C and 1000°C to react with methane, producing hydrogen, carbon monoxide, and carbon dioxide. Following this, a second reaction called a "water-gas shift reaction" changes carbon monoxide and steam to produce carbon dioxide and more hydrogen. A final process called "pressure-swing absorption" then removes carbon dioxide and other impurities to leave hydrogen available for use as an energy carrier.[175] Partial oxidation uses a small amount of oxygen to react methane and other hydrocarbons in natural gas to create hydrogen and carbon monoxide. Similar to steam-methane reforming, hydrogen producers then utilize a "water-gas shift reaction" and a "pressure-swing absorption" to produce more hydrogen.

While hydrogen (specifically H2) is a secondary form of energy similar to electricity, its production is heavily coupled with fossil fuels. As a result, although tailpipe emissions from using hydrogen in vehicles may be zero, they are not net-zero carbon emissions as the production of the hydrogen used is based upon the use of fossil fuels. If fossil fuel demand decreases due to an increase in net-zero carbon emission energy carriers – namely electricity – then hydrogen production would fall alongside fossil fuel use. – there are scenarios however where current fossil fuel use currently used for oil production could be transferred to hydrogen production assuming that this latter system would be economical for companies to undergo.

The other process for extracting hydrogen from other compounds, and a process that can be net-zero carbon emissions, is electrolysis. This process uses electricity to split water into hydrogen and oxygen. So long as the electricity used is generated without atmospheric emissions, then it will account for net-zero carbon emissions at both the tailpipe and in the production of hydrogen. Although the technical process has been demonstrated

174 Amela Ajanovic and Reinhard Haas, "Economic Prospects and Policy Framework for Hydrogen as Fuel in the Transport Sector," *Energy Policy* 123, no. March (2018): 282, https://doi.org/10.1016/j.enpol.2018.08.063

175 "Hydrogen Production: Natural Gas Reforming," U.S. Department of Energy Fuel Cell Technologies Office, 2018, https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

thoroughly by a number of researchers throughout the world, it is more expensive to produce hydrogen through electrolysis than gasification.

Using data from the Eurozone, Ajanovic and Hass demonstrate how capital costs, electricity costs, and production size affects the production of hydrogen via electrolysis for electricity on the grid. A 500kW electric plant would have investment costs of 2900 Euros per kW of hydrogen produced and 1800 Euros per kW of electricity produced, a 63% difference due to energy efficiency.[176] A 10MW plant would have costs of 1550 Euros per kW of hydrogen and 1150 Euros per kW of electricity, 74% difference due to efficiency.[177] When including the conversion of electricity, compression, and storage of hydrogen, these costs go up to 3800 Euros and 2400 Euros for the 500kW plant and 2050 Euros and 1550 Euros for the 10MW plant.[178] This Power-to-Gas system (P2G) is increasingly becoming of interest for its use in renewable energy storage. Although their work focuses on the European Union and the cost structurers there, the paper describes how a similar cost premium might be associated with hydrogen production for electricity in the United States.

6.4.2 Hydrogen Consumption

Since producing hydrogen via electrolysis has high capital costs relative to gasification, fossil fuel refiners produce – and then use – the vast majority of hydrogen today. Of the 50 million mega tons produced annually, 55% goes toward the production of ammonia, 25% toward refining, 10% toward methanol production, and the final 10% goes toward a variety of other end-uses, including electricity as well as use in FCEVs.[179]

Three methods exist for the distribution of hydrogen: pipelines, high-pressure tube trailers, and liquefied hydrogen tankers. The first of these methods, pipelines, is the least expensive method of transporting hydrogen but is severely limited. The majority of hydrogen pipelines today are located near fossil fuel refiners and plants – production of more hydrogen pipelines would entail significant capital costs similar to any other pipeline. High-pressure tube trailers transport compressed hydrogen at barometric pressures of 700PSI and are capable for short-distance transport. Liquefied hydrogen tankers are the most expensive method of transporting hydrogen and entail high capital costs. Because of the limited number of methods, the high costs associated with hydrogen production, and the high capital costs of electrolysis, the majority of hydrogen produced today is consumed locally.[180]

Consumption of hydrogen is locally based additionally because of its energy density. Davis et al. shows that hydrogen's volumetric energy density is between 2.5 and 10 MJ/L depending on the barometric pressure used to contain it.[181] This is greater than that of lithium-ion batteries used in PEVs. While much worse than conventional fuels for internal combustion engines (ICEVs) such as oil and gasoline, its specific energy (energy per unit weight) is greater than any other energy carrier currently available at roughly 120 MJ/kg.[182] However, hydrogen's volumetric energy density makes it more expensive to transport on a per gasoline gallon equivalent (gge) basis, thus making it inefficient and expensive to utilize as an energy carrier for transport unless produced at point-of-sale for light-duty vehicles.

6.4.3 Advantages and Disadvantages of FCEVs

Fuel cell electric vehicles (FCEVs) use hydrogen as the main energy carrier. When mixed with oxygen inside of a fuel cell, hydrogen generates electricity through an electrochemical process, electricity that then is used to operate the electric motor and powertrain of the vehicle. The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy lists a number of advantages to using fuel cells: high quality, reliable power; flexible generation from a number

176 Ajanovic and Haas, "Economic Prospects and Policy Framework for Hydrogen as Fuel in the Transport Sector," 282.

177 Ibid.

178 Ibid.

179 Ibid.

180 "Hydrogen Production and Distribution," Alternative Fuels Data Center, U.S. Department of Energy Vehicle Technologies Office, accessed October 1, 2019, https://afdc.energy.gov/fuels/hydrogen_production.html

181 Steven J. Davis et al., "Net-Zero Emissions Energy Systems," *Science* 360, no. 6396 (2018), https://doi.org/10.1126/science.aas9793

182 Ibid.

of domestic sources; scalable to fit any power need with diverse applications; can offer combined heat and power options; 50% electric efficiency and 90% electric and thermal efficiency; quiet; durable and rugged; exceptionally low/zero emissions; and it can produce drinkable water.[183]

Specific to using fuel cells in transportation, Curtin and Gangi note that FCEVs "replicates today's driving experience: range of 300+ miles per hydrogen fueling, refuel at a pump in 3-5 minutes".[184] Compared to current PEVs (average of less than 200 miles per charge, charging can take up to 10 hours on a level 1 charge), FCEVs have a clear advantage. However, in addition to the high cost of producing zero-carbon emission hydrogen and transporting it to refueling stations, the high cost of FCEV production limits its marketability currently.

Current as of 2015, FCEV costs breakdown as 39% from the vehicle body, 7% from the hydrogen tank, 1% from the battery, 3% from the electric motor and power control, and 50% from the fuel cell system itself.[185] Fuel cell systems require a number of fuel cells, in what is known as a stack, in order to provide the electrical output necessary to power the FCEV drivetrain. When compared against PEVs, FCEVs have a significant cost premium attached to the hydrogen tank and fuel cell system in addition to the particular vehicle body that has to be customized for fuel cell technology. The battery and electric motor and power control, which would be similar to, if not the same for, a PEV is insignificant compared to these capital costs.

Compared to conventional ICEVs, fuel cell vehicles are twice as expensive in total and four times as expensive in capital costs alone.[186] Compared to BEVs, FCEVs are roughly 1.7 times as expensive in total and 1.8 times as expensive in capital costs.[187] As Ajanovic and Hass state in their 2018 assessment of the hydrogen-based transport sector, "the prospects of hydrogen in transport are not very convincing today. It is clear that the major economic barriers are the investment costs of the car".[188]

These costs become magnified when conducting a net present value (NPV) analysis of current trends given certain discount rates and kilometers driven per year. Such analysis, assuming a certain set of electricity costs, maintenance and operating costs, illustrates how FCEVs may fall short of BEVs. Harvey (2018) provides an excellent analysis of such information. The NPV of different vehicles, namely fuel cell plug-in hybrid electric vehicles, battery electric vehicles (BEVs), among others varies against the price of gasoline in dollars per liter. 2010 light-duty vehicles all have a negative net present value with hybrid electric vehicles rising to near 0 NPV at around $2/liter of gasoline. Future LDVs at 2030 have similar characteristics, but advanced ICEVs and HEVs rise above 0 NPV at 7500kilometers/year while all vehicles analyzed have a NPV above 2000 for 15000kilometer/year and $2/liter gasoline. A significant takeaway from this analysis is that "doubling the distance [driven in a single year] has a far larger effect in improving the economics of advanced vehicles than either of the other changes shown".[189] This leads the author to conclude that "car-sharing systems could boost the distance travelled per vehicle" and thus improve the economics of purchasing a vehicle, particularly BEVs and FCEVs.[190]

The most significant result from Harvey's analysis, however, is that a discount rate of 3% used in the NPV analysis provides a substantial improvement on the economics. The prior assessments were conducted with discount rates of 10% — far higher than how most LDVs would be financed. A 3% rate makes the NPV greater than 0 for all drive trains

183 Sandra Curtin and Jennifer Gangi, "State of the States: Fuel Cells in America 2017," *U.S. Department of Energy*, no. January (2018): 1–46, https://doi.org/10.1021/jp512235t

184 Ibid.

185 Ajanovic and Haas, "Economic Prospects and Policy Framework for Hydrogen as Fuel in the Transport Sector."

186 Ibid.

187 Ibid.

188 Ibid.

189 L. D. Danny Harvey, "Cost and Energy Performance of Advanced Light Duty Vehicles: Implications for Standards and Subsidies," *Energy Policy* 114, no. August 2017 (2018): 7, https://doi.org/10.1016/j.enpol.2017.11.063.hybrid electric vehicles (HEVs

190 Ibid.

in 2030 for gasoline prices higher than $0.80/liter. However, this is in comparison to 2010 LDVs and not compared to advanced, conventionally-fueled LDVs.[191] However, under these scenarios BEVs have a higher NPV than FCEVs, demonstrating that they may be the more economical choice in the future.

6.4.4 Current and Future Impediments to FCEV Adoption

A number of current impediments to FCEV adoption have been explored throughout this essay already. The cost and system structure of hydrogen production increases the fuel cost of any FCEV relative to conventional ICEVs and contemporary PEVs. High capital costs for fuel cell systems further increase the cost of FCEVs relative to conventional and contemporary electric vehicles. To bring these costs down, R&D departments of car manufacturers will have to spend a significant amount of time and money investing in FCEV production. Currently only three car manufacturers worldwide have an FCEV available for purchase or lease: Toyota, Honda, and Hyundai. Until more manufacturers invest in hydrogen-based fuel cell electric vehicles, their adoption will likely continue to be eclipsed by plug-in electric vehicles.

Another major impediment to FCEV adoption, however, is that lack of infrastructure currently available. Little infrastructure exists for customers to refuel FCEVs. Nearly all hydrogen fueling stations that exist in the United States currently exist in the state of California. According to the International Energy Agency (IEA) report, as of mid-2017 only 200 fueling stations exist worldwide for hydrogen fuel cell vehicles.[192] These fueling stations cost between $2.1 and $3 million in California currently, with other estimates from the U.S. Department of Energy placing their cost at least greater than $1 million.[193] Compared to electric vehicles, these costs are exorbitant: plug-in electric vehicles can be charged – albeit slowly – anywhere a 120v outlet is available. Although this report explores the infrastructure needs for a future PEV-dominant market, this ubiquity gives PEVs an extensive advantage over FCEVs.

6.4.5 Conclusion

Hydrogen presents one alternative technology for policy- and decision-makers to consider when investing in light-duty vehicle transport infrastructure. Despite a number of studies and reports demonstrating the vast potential for hydrogen in a future energy economy, the current impediments to FCEV adoption should give infrastructure investors little reason to consider deploying hydrogen infrastructure over EV charging infrastructure. Ajanovic and Hass demonstrate that, given technological learning and continued economies of scale from car manufacturers, FCEVs should be at cost-parity with conventional ICEVs and contemporary PEVs by the year 2050.[194] Such a long time-horizon means that any infrastructure deployed today for electric vehicle charging can be reconsidered by the time FCEVs gain a significant percentage of the light duty vehicle market. Finally, the high rate of BEV adoption compared against FCEV adoption rates may mean that BEVs will acquire market scale long before FCEVs, resulting in positive feedback loops where increasing demand pushes producers to lower the cost of production and making BEVs even more competitive against conventional ICEVs than FCEVs. For LDVs, FCEVs will not play a competitive role in the market.

191 Ibid, 7-9.

192 Mary-Rose de Valldares, "Global Trends and Outlook for Hydrogen," 2017.

193 Ibid.

194 Ajanovic and Haas, "Economic Prospects and Policy Framework for Hydrogen as Fuel in the Transport Sector."

7 | CONCLUSIONS

Electric vehicles are a central part of the transportation future. The question is no longer if EVs will be widely adopted, but when. With major auto manufacturers poised to release a multitude of new PEV models, and battery technology improving, the answer to that question is likely sooner than we expect. The main concern among drivers, however, remains anxiety about vehicle range. Development of a robust, convenient charging infrastructure is of critical importance to the transition to PEVs. The question asked in this report was, is this charging infrastructure a public necessity requiring public investment, or a private convenience needing only private investment?

The answer, as with many complicated questions is — it depends. In many ways, PEV charging infrastructure is largely already in place; it is hard to think of many resources as far reaching and ubiquitous as electricity. There are, however, significant infrastructure investments needed. Most charging does and will take place were vehicles spend the most time idle, at homes and workplaces. Single family homes will need electrical upgrades and charging equipment. Multifamily residences and workplaces will need charging infrastructure in shared parking areas. There is a need for public charging stations in urban areas, and intercity charging for vehicles making long distance trips. In each of these use cases there are multiple stakeholders beyond the vehicle owner including electric utilities, car manufacturers, property owners, to name a few. We also have pressing social goals around climate change and reduced emissions. All these questions and more, make the answer to who should invest in charging infrastructure complicated.

In this report we aimed to provide a comprehensive review of the complexities related to the overarching question across four use cases: single-family residential charging, multifamily residential charging, workplace charging, DC fast charging. The different considerations across use cases led us to different conclusions and recommendations for each which we detail below. Despite this, across use cases, we conclude that in general, PEV charging infrastructure will not be built at the pace required to support the foreseeable fast adoption of PEVs without some public investment. This investment, however must be strategic and equitable. In the long run, PEV charging will be a lucrative business for charging network operators, and an important revenue stream for electric utilities, and public investment will not be required.

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