Division 5-22

Request:

Refer to Schedule PST-1, Chapter 5, page 1 regarding public charging stations needed.

a. Please provide the number of EVs registered in Rhode Island for each of the past 5 years.

b. Has the Company estimated how many public charging stations will be necessary to support the 40-fold growth in EV adoption under the ZEV Draft Plan? If yes, please provide such estimates.

c. Please provide any data or analyses that the Company has in its possession regarding the relationship between EV adoption and charging station availability.

Response:

a. Please see the table below.

YR2013	YR2014	YR2015	YR2016	YR2017[1]
210	223	530	731	1026

b. The Company is aware of a recent estimate by the National Renewable Energy Lab in its September 2017 *National Plug-in Electric Vehicle Infrastructure Analysis* report, a copy of which is provided as Attachment DIV 5-22-1. NREL's scenario analysis suggests that more than 2,100 ports in workplaces and other public locations could be needed to support 43,000 EVs in RI (see Page 52, Appendix C). The Company has not conducted a separate analysis.

c. Lack of adequate public charging infrastructure is a major barrier to would-be EV drivers, as evidenced by automotive industry research:

- EV Consumer Study by Cox Automotive: EIA Energy Conference Washington, DC, June 27, 2017, slide 17, a copy of which is provided as Attachment DIV 5-22-2.

Furthermore, charging availability plays a significant role in enabling the driver re-purchase decision:

[1] 2017 data is through September 30, 2017.

- Nissan research shows a 2X repurchase likelihood for Leafs with added infrastructure. Peterson, David, "1700 Fast Chargers by 2016'" presentation to the California PEV Collaborative, Nissan North America, March 10, 2015, slide 6, a copy of which is provided as Attachment DIV 5-22-3.

Academic research also confirms the significance of infrastructure in consumers' purchase decisions by quantifying the "purchase price penalty" associated with lower levels of charging infrastructure:

- Malaina, M., Y.Sun, and A. Brooker, *Vehicle Attributes and Alternative Fuel Station Availability Metrics for Consumer Preference Modeling*, NREL Transportation Center, presented at Energy Commission Workshops, Sacramento, California, March 19, 2015, Page 21, a copy of which is provided as Attachment DIV 5-22-4.

The US Department of Energy's Workplace Challenge found that employers who offer workplace charging have six times the number of EV drivers in their employee base than the average employer.

- DOE's Workplace Charging Challenge, Mid-Program Review (December 2015), page 4, a copy of which is provided as Attachment DIV 5-22-5.

Recent analysis suggests that the cities with the highest proportion of EV adoption globally "use a comprehensive suite of electric vehicle promotion actions to spur the market" such as vehicle incentives, charging infrastructure, and promotional campaigns, and other policy measures.

- Dale Hall, Marissa Moultak, Nic Lutsey (2017), *Electric Vehicle Capitals of The World: Demonstrating The Path To Electric Drive*, a copy of which is provided as Attachment DIV 5-22-6.

Finally, automakers Nissan and Tesla both report a relationship between EV infrastructure development and vehicle sales, as justification for their own efforts to develop infrastructure. Nissan Leaf sales in 2013 increased in selected markets where the company supported DC Fast Charging, and Tesla indicates that their Supercharger network has helped grow sales of its Model S sedan.

- Rovito, M., *Will Nissan's No Charge to Charge Program Drive Leaf Sales?* Charged Electric Vehicles Magazine, July 3, 2014, a copy of which is provided as Attachment DIV 5-22-7.

- Baumhefner, M., Hwang, R. And Bull, P., *Driving Out Pollution: How Utilities Can Accelerate the Market for Electric Vehicles*, Natural Resources Defense Fund, June 2016 (citing Lankton, Cal, Director of EV Infrastructure, Tesla Motor Company, *Plenary Panel: Technology Marches On – The Impact of New Vehicle and Infrastructure Technologies*, EPRI Plug-in 2014 conference, San Jose, California, July 2014), a copy of which is provided as Attachment DIV 5-22-8.

(This response is identical to the Company's response to Division 1-22 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

National Plug-In Electric Vehicle Infrastructure Analysis

September 2017

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- Don MacKenzie (University of Washington)
- Susan Burke, Meredith Cleveland (U.S. Environmental Protection Agency)
- Michael Scarpino, Diane Turchetta, John Davies, Tianjia Tang (U.S. Federal Highway Administration)

List of Acronyms

BEV	battery electric vehicle
BEVxxx	battery electric vehicle with an electric range of xxx miles
DC	direct current
DCFC	direct current fast charging
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EV	electric vehicle
EVI-Pro	Electric Vehicle Infrastructure Projection Tool
eVMT	electric vehicle miles traveled
EVSE	electric vehicle supply equipment
FHWA	U.S. Federal Highway Administration
HEV	hybrid electric vehicle
HPMS	Highway Performance Monitoring System
INL	Idaho National Laboratory
L2	level 2 (charging station)
LDT	long-distance trip
LDV	light-duty vehicle
MUD	multiple-unit dwelling
NHTS	National Household Travel Survey
NREL	National Renewable Energy Laboratory
PEV	plug-in electric vehicle (BEV or PHEV)
PHEV	plug-in hybrid electric vehicle
PHEVxx	plug-in hybrid electric vehicle with an electric range of xx miles
SHRP2 NDS	Second Strategic Highway Research Program's Naturalistic Driving Study
SUV	sport utility vehicle
TAF	Traveler Analysis Framework
VMT	vehicle miles traveled
ZEV	zero-emission vehicle

Executive Summary

This report addresses the fundamental question of how much plug-in electric vehicle (PEV) charging infrastructure—also known as electric vehicle supply equipment (EVSE)—is needed in the United States to support both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). It complements ongoing EVSE initiatives by providing a comprehensive analysis of national PEV charging infrastructure requirements. The result is a quantitative estimate for a U.S. network of non-residential (public and workplace) EVSE that would be needed to support broader PEV adoption. The analysis provides guidance to public and private stakeholders who are seeking to provide nationwide charging coverage, improve the EVSE business case by maximizing station utilization, and promote effective use of private/public infrastructure investments.

The analysis is organized around the non-residential EVSE network required to meet consumer coverage expectations and to satisfy consumer demand in high-PEV-adoption scenarios. Coverage and charging demand estimates needed to serve growing PEV markets are made for the communities where people live and the highway corridors on which they travel (Figure ES-1), including four specific geographic areas:

- Cities (486 Census Urban Areas, population greater than 50,000, 71% of U.S. population)
- Towns (3,087 Census Urban Clusters, population 2,500 to 50,000, 10% of U.S. population)
- Rural Areas (regions not covered by Census Urban Areas/Clusters, 19% of U.S. population)
- Interstate Highway System Corridors (28,530 miles of highway).

Figure ES-1. Cities (yellow polygons), towns (purple points), and interstates (thick red lines) considered in this analysis.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

While this work is not intended to forecast future PEV markets, scenarios are developed to exercise the infrastructure estimation methodology and highlight sensitivities. The analysis assigns no probabilities to any PEV market or technology scenarios and considers none of the scenarios as most likely. However, a central scenario is established from which individual elements of the modeling framework are studied using parametric sensitivity analysis as shown in Table ES-1. The central scenario and bounds on the accompanying sensitivities have been developed using a combination of existing PEV market/technology data and engineering judgement to represent a set of scenarios that are illustrative of the role that key variables play in dictating PEV infrastructure requirements. The goal of this scenario development is to estimate the magnitude of PEV infrastructure requirements (relative to a growing national fleet of PEVs) and to highlight dependencies with consumer preferences and technology development.

Table ES-1. PEV Market Conditions for the Central Scenario and Sensitivities Explored

Variable	Central Scenario	Sensitivity
PEV Total	15M (linear growth to 20% of LDV sales in 2030)	9M (growth to 10% of 2030 sales) 21M (growth to 30% of 2030 sales)
PEV Mix (range preference)	Mix PHEV20 10% PHEV50 35% BEV100 15% BEV250 30% PHEV20-SUV 5% BEV250-SUV 5%	Long / Short PHEV20 0% / 40% PHEV50 50% / 0% BEV100 0% / 50% BEV250 40% / 0% PHEV20-SUV 0% / 10% BEV250-SUV 10% / 0%
Share of PEVs in Cities (w/ pop. > 50k)	83% (based on existing HEVs)	71% (based on existing LDVs) 91% (based on existing PEVs)
PHEV:BEV Ratio	1:1	4:1 to 1:4
PHEV Support	Half of full support	No PHEV support to full support (maximize PHEV eVMT)
SUV Share	10%	5% to 50%
% Home Charging	88%	88%, 85%, and 82%
Interstate Coverage	Full Interstate	Mega-regions, 80% of Long Distance Trips (Traveler Analysis Framework [TAF]), and Full Interstate
Corridor DCFC Spacing	70 miles	40 to 100 miles
DCFC Charge Time	20 minutes (150 kW)	10 to 30 minutes (400 to 100 kW)

BEVxxx = battery electric vehicle with a range of xxx miles
DCFC = direct current fast charging
eVMT = electric vehicle miles traveled
kW = kilowatt
LDV = light-duty vehicle
PHEV = plug-in hybrid electric vehicle
PHEVxxx = plug-in hybrid electric vehicle with a range of xxx miles
SUV = sport utility vehicle

The analysis relies on advanced PEV simulations using millions of miles of real-world daily driving schedules sourced from large public and commercial travel data sets. Technical considerations are made for the spatial density of PEVs concentrated in cities and towns, ambient temperature effects on electric driving range, and frequency of long distance driving days requiring non-residential EVSE. Simulations are rooted in a set of foundational assumptions which are applied across all scenarios. For example, consumers are simulated in all scenarios as preferring to perform the majority of charging at their home location. This assumption produces simulation results in the central scenario where 88% of PEV charging takes place at home locations (due to the large amount of time vehicles are parked at home and relatively short typical daily driving distances), consistent with early market findings in the EV Project. Charging at non-residential stations is simulated on an as-necessary basis such that consumers are able to maximize electric vehicle miles traveled (eVMT).

Additionally, it is assumed that future PEVs will be driven in a manner consistent with present day gasoline vehicles (e.g., 70% of daily driving under 40 miles and 95% under 100 miles). While impacts of transportation network companies (e.g., Uber, Lyft) and advances in automated driving technology are not considered in this analysis, interactions between evolving mobility patterns and refueling infrastructure supporting advanced vehicles are currently being investigated by the consortium of national laboratories participating in the U.S. Department of Energy's SMART Mobility Initiative.

Analysis results for the central scenario are summarized in Table ES-2. Results are reported as numbers of direct current fast charging (DCFC) stations required to provide an acceptable level of coverage and the number of plugs required to satisfy PEV charging demand. Figure ES-2 and Figure ES-4 highlight the sensitivities of these values to the many variables explored in the analysis.

Table ES-2. Summary of Station and Plug Count Estimates for the Central Scenario (15M PEVs in 2030)

		Cities	Towns	Rural Areas	Interstate Corridors
PEVs		12,411,000	1,848,000	642,000	—
DCFC	**Stations** (to provide coverage)	4,900	3,200	—	400
	Plugs (to meet demand)	19,000	4,000	2,000	2,500
	Plugs per station	3.9	1.3	—	6.3
	Plugs per 1,000 PEVs	1.5	2.2	3.1	—
Non-Res L2	**Plugs** (to meet demand)	451,000	99,000	51,000	—
	Plugs per 1,000 PEVs	36	54	79	—

Note: Station count estimates for providing a minimum level of coverage have been omitted for community L2 stations under the assumption that non-residential L2 is primarily used for charging within walking distance of a destination (based on the low charge power and long charge time of L2 stations) and coverage for every destination was considered unrealistic for the early PEV market (however, demand estimates for L2 plug counts are included). Similarly, coverage estimates are omitted for DCFC stations in rural areas as coverage provided by stations in cities/towns and along interstate corridors was deemed sufficient.

Non-Residential Charging for Communities

The analysis first estimates the minimum DCFC coverage requirements for dispelling range anxiety concerns by providing a safety net of DCFC stations in cities and towns for emergency situations (such as failing to overnight charge at home). To ensure that BEV drivers in cities are never more than 3 miles from a DCFC station, approximately 4,900 DCFC stations are required across the United States. Providing the same level of coverage for towns would require approximately an additional 3,200 DCFC stations.

The analysis also estimates non-residential charging stations (work and public) required to satisfy intracommunity charging demands. Figure ES-2 shows the sensitivity of total national plug requirements to several input variables. In the central scenario, a total of approximately 600,000 non-residential Level 2 (L2) plugs and 25,000 DCFC plugs are necessary to satisfy consumer charging demand (assuming 15 million PEVs are on the road in 2030).

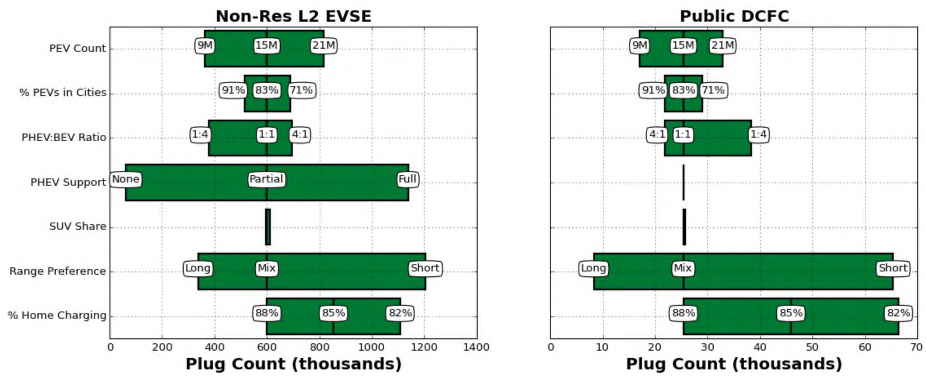

Figure ES-2. Effects of input variables on estimated total national plug requirements in communities.

Perhaps surprisingly, the national PEV total is not the most sensitive input parameter in this analysis; PEV electric range, commitment to maximizing PHEV eVMT, and percent of charging taking place at home have the largest effects. For instance, assuming a PEV market composed entirely of PHEV50s (PHEVs with a range of 50 miles) and BEV250s (BEVs with a range of 250 miles) (the long range preference scenario) drops non-residential L2 requirements to approximately 338,000 plugs and public DCFC to 8,400 plugs. The sensitivity on PHEV support reveals that non-residential L2 charging is modeled almost exclusively as supporting PHEVs, where providing full support (maximizing eVMT for all PHEV owners) results in over 1,100,000 plugs, and providing no PHEV support drops the non-residential L2 plug requirement to under 63,000. Finally, the sensitivity analysis on home charging demonstrates a strong relationship between home charging utilization and non-residential infrastructure requirements. Specifically, a decrease in the amount of charging happening at residential locations from 88% in the central scenario to 82% results in charging requirements increasing to 1,100,000 non-residential L2 EVSE plugs and over 65,000 public DCFC plugs.

Fast Charging for Long-Distance Travel Corridors

Long-distance travel has been a barrier to BEV adoption due to real vehicle range limitations, which can be exacerbated by even more restrictive perceived range anxiety. Long-range BEVs have the potential to address this issue if coupled with an extensive and convenient network of DCFC stations that enable reliable intercity travel. The analysis finds that approximately 400 corridor DCFC stations (spaced 70 miles apart on average) are required to provide convenient access to BEV drivers across the U.S. Interstate System. Approximate coverage enabled by DCFC stations in this scenario is visualized in Figure ES-3 with red buffers placed around the Interstate network, each with a radius of 70 miles.

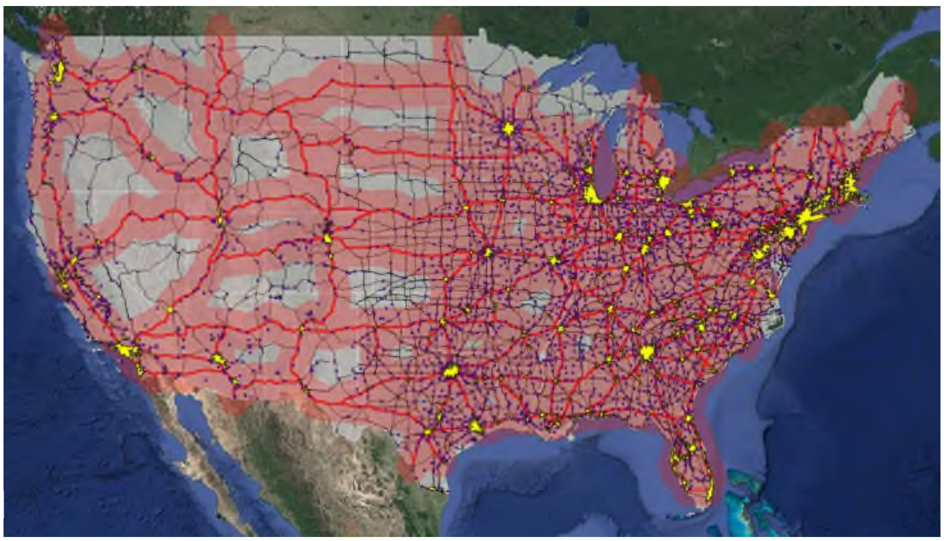

Figure ES-3. Approximate BEV driving coverage enabled by providing DCFC stations along the U.S. Interstate System. (Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

Figure ES-4 shows estimated station and plug counts for corridor fast charging supporting BEV travel along the U.S. Interstate network. Results are presented using parametric sensitivity analysis highlighting the influence of four input variables: 1) network coverage, 2) average station spacing, 3) national BEV count, and 4) average DCFC charge time. For example, 408 corridor DCFC stations are necessary in the central scenario, which assumes full Interstate coverage and 70-mile average station spacing. However, corridor DCFC station counts range from 137 to 713 depending on network and station spacing. Similarly, corridor DCFC plug counts are estimated at 2,472 in the central scenario but vary from 824 to 3,709 in the parametric sensitivity analysis depending on network coverage, size of the BEV fleet, and DCFC charge times.

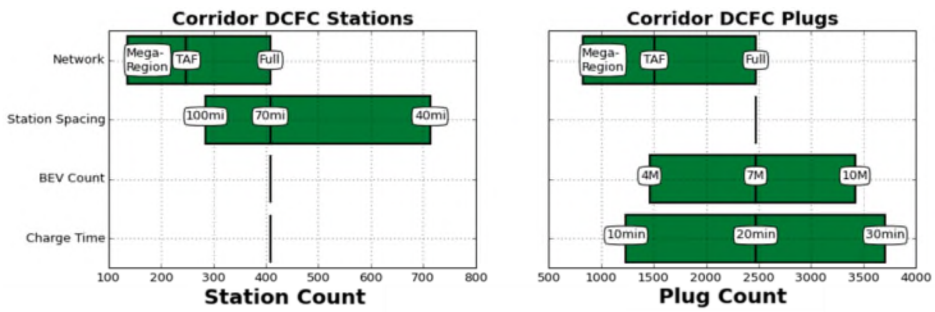

Figure ES-4. Sensitivity of corridor DCFC station (left) and plug (right) counts to selected networks, station spacings, BEV counts, and DCFC charge times.

As described above, the U.S. Interstate System provides a basis for DCFC infrastructure that can efficiently satisfy long-distance driving demands in the near term. The Interstate System is not, however, entirely isolated from community-based DCFC infrastructure. Although full community-based infrastructure may take longer to establish, it could provide travel corridors with charging backup options, route flexibility, and additional coverage along U.S. highways and state routes. Figure ES-5 shows the national DCFC station coverage enabled by providing the community-based charging station coverage previously discussed. Each covered city and town has a 70-mile radius buffer around it, approximating station coverage.

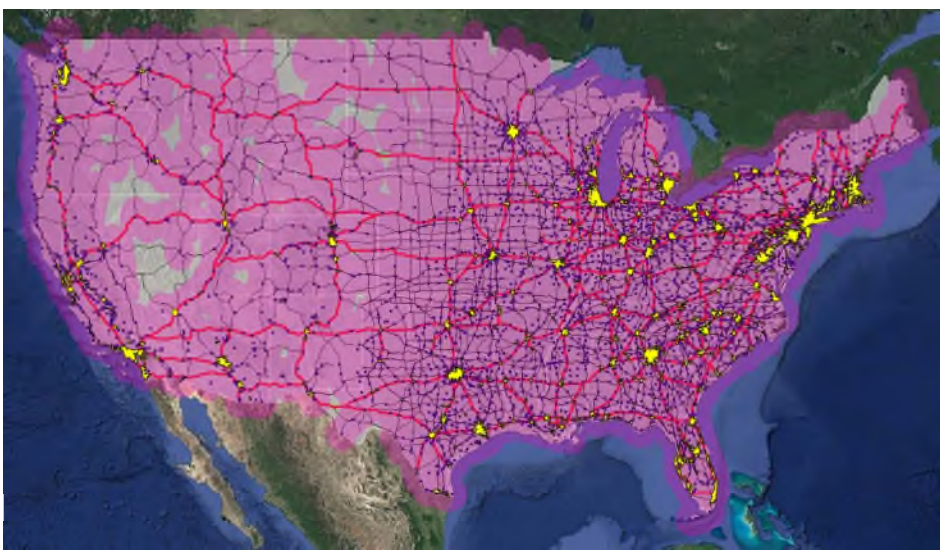

Figure ES-5. Approximate BEV driving coverage enabled by providing DCFC stations in all cities and towns in the United States.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

Major Conclusions

This report categorizes PEV charging infrastructure requirements by area served (cities, towns, rural areas, and Interstate corridors) and role during early PEV market growth (providing coverage to early PEVs and satisfying demand due to increased PEV adoption). The analysis makes no assumptions about the likelihood of particular PEV market or technology scenarios. Rather, a range of plausible scenarios explores the relationship between the evolution of the PEV fleet and charging infrastructure.

Communities are expected to have significantly larger charging infrastructure requirements than Interstate corridors under both the coverage and demand assessments. About 4,900 DCFC stations are required across cities with an additional 3,200 DCFC stations required in towns to provide a minimum level of nationwide coverage in the communities where 81% of people live. Such a network would dampen range anxiety concerns by providing drivers with a safety net for emergency charging situations.

Intracommunity charging demand analysis demonstrates how utilization of the DCFC coverage network would be expected to grow in increased PEV adoption scenarios based on a home-dominant charging assumption. Results for a 15-million PEV market estimate a DCFC plug requirement of 25,000 in communities (approximately 3.1 plugs per average DCFC station and 3.4 plugs required to support 1,000 BEVs). Demand for non-residential L2 EVSE (including work and public charging) is estimated as 600,000 plugs necessary to support 15 million PEVs (approximately 40 plugs per 1,000 PEVs).

Sensitivity analysis of the community results for consumer charging demand indicates a strong relationship between the evolution of the PEV and EVSE markets. As this analysis attempts to arrive at charging infrastructure solutions that fill the eVMT gaps between consumer travel patterns and PEV electric ranges, infrastructure requirements are not only proportional to the total number of PEVs in the system, but also inversely proportional to PEV electric range. Manufacturer and consumer preferences with respect to electric range, charging power, and utilization of residential EVSE have direct and dramatic consequences on the level of charging demand calculated in this analysis.

Results suggest that approximately 400 corridor DCFC stations are needed to enable long-distance BEV travel along Interstate highways between cities (where the majority of BEVs are likely to be concentrated). Understanding driving patterns, vehicle characteristics, and charging behavior and then prioritizing corridors and setting station spacing accordingly—as illustrated in the network scenarios—could help optimize the utility and economics of early-market corridor charging stations.

Regardless of geographic scope, the analysis suggests that organizations planning for charging infrastructure to support consumer adoption of PEVs need to be aware of the importance of consumer preferences with respect to electric range and charging behavior. Furthermore, planners should focus on providing consumers with adequate charging coverage (particularly DCFC supporting adoption of BEVs) while monitoring station utilization over time and increasing charging capacity (both in terms of rated power and number of plugs) as the PEV market continues to grow.

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1 Introduction

Plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs)—collectively known as plug-in electric vehicles (PEVs)—provide various benefits to the United States. They reduce reliance on petroleum, which accounts for over 90% of total U.S. transportation energy consumption (U.S. Energy Information Administration [EIA] 2017) and is characterized by an extremely volatile market. Substituting electricity for gasoline and diesel could significantly improve U.S. energy security, providing greater fuel diversity in a market currently dominated by a single energy source. PEVs also produce zero tailpipe emissions and potentially low or zero greenhouse gas emissions, depending on the electricity generation mix (Orsi et al. 2016).

PEV sales in the United States increased by 40% in 2016, reaching a total stock of over 500,000 vehicles (IHS Markit 2017). This rapid market growth is the result of significant advances in PEV technologies, most notably the rapidly falling cost of lithium-ion batteries used in automotive applications (U. S. Department of Energy [DOE] 2017a, Nykvist and Nilsson 2015), as well as policy support. Policy support includes government research and development support (which also enabled battery technology advancements); technical and cost targets, mandates, and regulations (*e.g.*, corporate average fuel economy [CAFE] standards and zero emission vehicle [ZEV] mandates); financial incentives for PEV purchase and charging station installations; and other measures increasing the value proposition of alternative fuel vehicles (*e.g.*, preferential parking or access to high-occupancy vehicle lanes) (International Energy Agency [IEA] 2017). Still, widespread market adoption of PEVs remains hindered by many factors, including limited availability of models and styles, higher cost compared with conventional vehicles, and the lack of a convenient and ubiquitous network of charging stations.

Understanding the barriers to and benefits of deploying a widespread and effective network of PEV charging stations, also known as electric vehicle supply equipment (EVSE), is particularly important. Such a network would promote PEV consumer acceptance and market growth, enable long-distance travel for BEVs (alleviating the range anxiety concerns of many consumers), and potentially increase the share of electric miles driven by PHEVs. Infrastructure planning must anticipate PEV adoption while remaining cost-effective so low station utilization does not severely undermine the business case for building and operating stations (Melaina et al. 2017). Sufficient revenue is required to build and continue operating the EVSE network as the PEV market grows over time.

This report presents an approach for developing a U.S. network of non-residential EVSE that enables broader PEV adoption and maximizes PEV use. This analysis can help inform various public and private stakeholders who are seeking to provide nationwide charging coverage and improve the business case for building stations by maximizing station utilization.

1.1 Recent EVSE Initiatives and Analysis Studies

Several recent public and private initiatives and pilot projects are promoting EVSE growth across the United States as a way to increase PEV adoption by enhancing consumer familiarity and acceptance of this technology as well as providing a more convenient network of charging stations. In particular, direct current fast charging (DCFC) is receiving significant attention as the fastest PEV charging system currently available. Tesla's Supercharger, CHAdeMO, and SAE's combined charging system (CCS) are the currently available standards for DCFC. The landscape of DCFC in the United States is expected to change significantly with the penetration of longer-range BEVs (with over 200 miles of driving range), which likely will rely on DCFC to make long-distance trips (LDTs). While fast charging currently ranges between 50 and 120 kilowatts (kW), power levels up to 400 kW are currently being explored to reduce charging time and provide a more convenient consumer experience.

Over the past five years, Tesla has established a network of 357 fast-charging stations, supporting 2,478 individual fast chargers rated at up to 120 kW (DOE 2017b). Each supercharger station has between one and 12 120-kW plugs, with an average of seven plugs per station. As the only automaker selling long-range BEVs in the United States during this period, Tesla started addressing the circular dilemma between alternative fuel vehicle adoption and refueling infrastructure availability by deploying a national network of proprietary charging stations to enable long-distance travel for Tesla vehicles. Tesla recently announced the goal of doubling the number of superchargers both nationally and globally. As of June 2017, the average distance between Tesla supercharger stations is approximately 67 miles (based on data from DOE [2017b]).

Electrify America—a project funded in December 2016 by Volkswagen Group of America as required by Appendix C to the 2.0-Liter Partial Consent Decree—has committed to investing $2 billion over the next 10 years in ZEV infrastructure and education programs, including $800 million in California alone (Electrify America 2017, Green Car Reports 2017). In its first national ZEV investment cycle (30 months, through mid-2019), Electrify America plans to develop a large network of community-based PEV charging stations as well as approximately 300 fast-charging stations along high-traffic corridors between metropolitan areas in 39 states. Each corridor DCFC station will include four to ten plugs with an average of five plugs per station. Individual plugs will be rated at 150 kW with the ability to be upgraded to up to 350 kW for future vehicles that can accept higher power charging. Corridor DCFC stations will be spaced on average 70 miles apart with a maximum distance of 120 miles between consecutive stations. The Electrify America network will be non-proprietary by providing both CHAdeMO and SAE CCS plug types, allowing any BEV to charge.

Nissan and BMW are partnering to double the EVgo network of fast charging stations across the United States. As of January 2017, an additional 174 EVgo 50-kW fast charging stations across 33 states have been installed, with an additional 50 stations planned for 2017 (Nissan 2017).

The U.S. Department of Transportation (DOT) recently designated several highways as alternative fuel corridors (including 48 PEV charging corridors) with the intent of establishing a comprehensive national network of refueling stations to promote the continued adoption of alternative fuel vehicles (DOT 2017a). This network will include nationally consistent signage and is intended to encourage multi-state collaborations of public/private stakeholders.

Launched in 2009, the EV Project partnered with city, regional, and state governments; utilities; and other organizations in 18 cities to deploy about 14,000 Level 2 PEV chargers and 300 direct current (DC) fast chargers (DOE 2014). The EV Project was the first large-scale data-collection effort for PEVs and related infrastructure in the United States (Idaho National Laboratory [INL] 2013).

In parallel to these initiatives, several analytical studies have explored the opportunities and implications related to EVSE development. In this early market phase for PEV adoption, vehicle configurations, styles, and all-electric ranges are changing rapidly in response to evolving consumer preferences and technology improvements (particularly battery cost). Future vehicle attributes and requirements remain uncertain, and the most effective EVSE strategy to support PEV adoption will depend on how these trends evolve over time. Still, various stakeholders must anticipate a range of possible future trends to develop cost- and market-effective EVSE plans. In this context, scenario analysis and market simulation studies can inform different stakeholders during the EVSE planning process, including federal and local governments, private investors, vehicle manufacturers, and infrastructure developers.

In the 18th edition of the *Automotive Executive Survey,* an annual international assessment of the current state and future prospects of the worldwide automotive industry, KPMG focused on the role of vehicle electrification and its connection with infrastructure (KPMG 2017). Although 50% of the 953 executives who participated in the KPMG survey identified BEVs as the industry's key near-term (2017 to 2025) trend, most respondents (62% of executives) also absolutely or partly agreed that BEVs "will fail" owing to infrastructure challenges. This pessimistic long-term view of the industry's ability to overcome infrastructure challenges was more pronounced from respondents in Organisation for Economic Co-operation and Development countries, whereas respondents in China were more optimistic. KPMG concluded that significant investments in a ubiquitous and user-friendly PEV charging infrastructure are crucial for supporting long-term PEV adoption and that overcoming the range anxiety issue for BEV users is critical for the long-term survival of BEVs.

INL recently leveraged information from previous data collection activities to assess criteria for designing and upgrading DCFC complexes that provide fast-charging opportunities for BEV drivers in urban communities and on corridors (Francfort et al. 2017). Findings and lessons learned suggest 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" and that "there is a greater likelihood that a DCFC will be highly utilized if it is located at or near a workplace where employees are likely to own PEVs" (Francfort et al. 2017).

Navigant Research has published several studies about opportunities for global PEV and related infrastructure markets. Its *DC Charging Map for the United States* explores fast-charging opportunities that enable intercity, interstate, and cross-country travel in response to market trends that are promoting long-range BEV adoption (such as battery capacities of ~60 kilowatt-hours) (Navigant Research 2016). The report maps the progression of fast-charging stations needed to meet the demands of light-duty BEVs through a phased rollout, focusing on the needs of long-range BEVs. The analysis shows that 95 fast charging stations would provide basic long-distance coverage for BEV travel. It also shows that sufficient coverage for BEVs in the top 100 metropolitan areas could be achieved with 408 stations.

The California Energy Commission's *Statewide PEV Infrastructure Assessment* is an example of scenario analysis developed at the state level (Melaina and Eichman 2015, Melaina and Helwig 2014). In this study, PEV sales are estimated based on compliance with the ZEV mandate, and PEV travel simulations are performed to assess the role of public infrastructure in future PEV market growth, focusing on the degree to which increased public charging may increase e-miles. Results show that 225 to 775 fast-charging stations will be required to support 1 million PEVs in California, depending on charging preference. One conclusion of the report is that insights from analytical studies are required to guide the development of effective near-term fast-charger installation strategies.

A 2013 National Academy of Sciences report explored alternative scenarios that would radically transform the U.S. passenger vehicle sector, including enabling technologies and adoption barriers (National Research Council 2013). The report identifies charging infrastructure availability as a major barrier to consumer adoption of PEVs.

1.2 Analytic Approach

This PEV charging study complements the existing literature by providing updated and comprehensive analysis of the national PEV charging infrastructure requirements within cities, towns, and rural areas and along corridors connecting them. It provides guidance to regional and national stakeholders on non-residential EVSE strategies and plans, both to reduce range anxiety as a barrier to increased PEV sales and to promote effective use of private/public infrastructure investments.

1.2.1 Conceptual Representation of PEV Charging Infrastructure Requirements

PEV charging infrastructure requirements—the number of stations and plugs required to provide a convenient and ubiquitous network of PEV charging opportunities—will evolve as PEV adoption increases. In particular, two driving forces characterize the charging infrastructure required to support a growing fleet of PEVs:

1. A basic level of geographic **coverage** is required to guarantee nationwide charging opportunities and enable long-distance travel for BEVs.
2. Over time, a larger network of stations will be required to satisfy growing **charging demand**. The requirement increases non-linearly with PEV market share. At low market shares, the requirement increases quickly because PEVs are clustered in particular areas and charging is concentrated during

specific times such as after commuting periods and on weekends (for long-distance travel). As PEV market share increases, the infrastructure requirements increase less aggressively owing to the natural stochastic features of driving behavior—not all drivers will require charging in the same location and at the same time. In a fully developed market, each additional PEV leads to lower incremental requirements for PEV charging infrastructure.

Figure 1 illustrates coverage (blue line) and demand (black line) infrastructure requirements for different PEV market shares. The coverage requirement is independent of PEV adoption: even if few PEVs are deployed, a ubiquitous network of stations is required to enable long-distance travel, prevent range anxiety, and promote PEV adoption. Therefore, a "utilization gap" exists at low PEV market shares, which is characterized by a market demand for charging infrastructure that is lower than the required coverage infrastructure; the infrastructure is underutilized, which negatively impacts station financial performance and makes it difficult to justify investment in new stations (Melaina et al. 2017). As PEV adoption increases, the demand for charging infrastructure exceeds the coverage infrastructure, creating "market pull" for the installation of additional charging stations or the addition of plugs to existing stations.

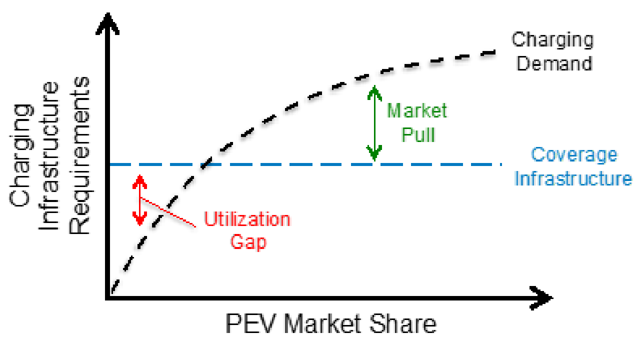

Figure 1. PEV charging requirements evolution as a function of PEV market share.

This report quantifies non-residential EVSE requirements necessary to meet consumer coverage expectations independent of PEV adoption level and to meet consumer demand in high PEV adoption scenarios. Coverage and demand estimates are made for:

- Cities (486 Census Urban Areas, population greater than 50,000, 71% of U.S. population)
- Towns (3,087 Census Urban Clusters, population 2,500 to 50,000, 10% of U.S. population)
- Rural Areas (regions not covered by Census Urban Areas/Clusters, 19% of U.S. population)
- Interstate Highway System Corridors (28,530 miles of highway).

1.2.2 Scenario Discussion

The majority of this report describes an analytic process for estimating PEV non-residential charging requirements within communities (cities, towns, and rural areas) and along Interstate corridors, assuming home charging is the dominant behavior. While it is not the intention of this work to forecast the future PEV market, PEV market scenarios are developed to exercise the infrastructure estimation methodology and highlight sensitivities. The analysis assigns no probabilities to any PEV market scenarios and considers none of the scenarios as most likely. However, a central scenario is established from which individual elements of the modeling framework are studied using parametric sensitivity analysis. PEV market conditions for the central scenario and sensitivities explored are shown in Table 1.

Table 1. PEV Market Conditions for the Central Scenario and Sensitivities Explored

Variable	Central Scenario		Sensitivity	
PEV Total	15M (linear growth to 20% of LDV sales in 2030)		9M (growth to 10% of 2030 sales) 21M (growth to 30% of 2030 sales)	
PEV Mix (range preference)		Mix		Long / Short
	PHEV20	10%	PHEV20	0% / 40%
	PHEV50	35%	PHEV50	50% / 0%
	BEV100	15%	BEV100	0% / 50%
	BEV250	30%	BEV250	40% / 0%
	PHEV20-SUV	5%	PHEV20-SUV	0% / 10%
	BEV250-SUV	5%	BEV250-SUV	10% / 0%
Share of PEVs in Cities (w/ pop. > 50k)	83% (based on existing HEVs)		71% (based on existing LDVs) 91% (based on existing PEVs)	
PHEV:BEV Ratio	1:1		4:1 to 1:4	
PHEV Support	Half of full support		No PHEV support to full support (maximize PHEV eVMT)	
SUV Share	10%		5% to 50%	
% Home Charging	88%		88%, 85%, and 82%	
Interstate Coverage	Full Interstate		Mega-regions, 80% of Long Distance Trips (Traveler Analysis Framework [TAF]), and Full Interstate	
Corridor DCFC Spacing	70 miles		40 to 100 miles	
DCFC Charge Time	20 minutes (150 kW)		10 to 30 minutes (400 to 100 kW)	

eVMT = miles achieved on electric power
SUV = sport utility vehicle

The central scenario arbitrarily assumes a linear growth in the sale of new PEVs, climbing to 20% of all light-duty vehicle (LDV) sales in 2030. This sales rate would result in a total of 15 million PEVs on U.S. roads in 2030 (approximately 5% of the total U.S. LDV stock in 2030). Sensitivities around PEV sales are explored between 9 and 21 million PEVs (10% to 30% of U.S. LDV sales in 2030).

The range preference variable is meant to reflect relative adoption of the short- and long-range PHEVs and BEVs. For example, the central scenario features a preference for PHEVs with longer electric driving ranges, resulting in greater shares for PHEV50s and BEV250s (relative to PHEV20s and BEV100s, respectively). During the sensitivity analysis, a short-range preference is explored in which PEVs are exclusively comprised of PHEV20 and BEV100 vehicles (the long-range sensitivity shifts all PEVs to PHEV50 and BEV250 vehicles).

PEVs clustered in cities versus widespread adoption across the United States directly affects the degree to which infrastructure can be regionally concentrated. Three PEV dispersion scenarios are evaluated, each informed by the spatial dispersion of existing LDVs across the United States. The central scenario assumes 15 million PEVs are dispersed among cities, towns, and rural areas proportional to existing registrations of hybrid electric vehicles (HEVs). HEVs are considered a useful proxy for the spatial dispersion of an evolving PEV market based on their status as an advanced technology powertrain that predates the introduction of modern PEVs by approximately a decade. Allocating future PEVs using existing HEV registrations results in 83% of PEVs being located in cities (population greater than 50,000). Sensitivities on the spatial dispersion of future PEVs are developed based on the existing dispersion of all LDVs (71% in cities) and existing PEVs (91% in cities). Registration data used to develop these estimates are discussed in Section 2.1.

The central scenario assumes a 1:1 ratio between future PHEVs and BEVs (similar to existing PEV registrations, see Section 2.1). Arbitrary sensitivities around this parameter are explored, from 4:1 (80% PHEV) to 1:4 (80% BEV).

PHEVs feature internal combustion engines for backup power and consequently have no hard requirements for non-residential charging infrastructure. PHEVs can however utilize work and public Level 2 (L2) EVSE to improve the percent of miles achieved on electric power (eVMT); however, PHEVs are restricted from using DCFC in this analysis. Providing full PHEV support in this model implies enough charging plugs to enable consumers to maximize eVMT (but not necessarily reach 100% eVMT as individual trips may exceed the PHEV single charge range and L2 EVSE is restricted to destination charging in this project). Conversely, providing no PHEV support implies that no L2 EVSE is allocated on behalf of PHEVs in the model. Partial PHEV support is implemented in the central scenario reflecting 50% of full support.

The central scenario arbitrarily assumes a 10% sport utility vehicle (SUV) share within the PEV segment. While relatively modest given the increasing popularity of SUVs in the context of all LDVs (including conventional vehicles), existing PEV registrations reflect a mere 5% market share for electric SUVs (see Section 3.2.2). SUV market shares within the PEV segment are explored between 5% and 50% during sensitivity analysis.

All scenarios assume the majority of consumers prefer to do most of their charging at their home location. In the central scenario, 100% of PEVs are simulated as having a home-dominant charging preference (resulting in 88% of charging taking place at home locations). Sensitivity analysis explores scenarios where 90% and 80% of PEVs are simulated with home-dominant charging behavior, with the remainder having work- and public-dominant charging behavior. This sensitivity results in PEVs performing 85% and 82% of charging at home locations.

Central scenario analysis of the interstate corridor network considers full coverage with average DCFC station spacing of 70 miles and a typical DCFC charge time of 20 minutes. DCFC coverage along the interstate network, station spacing, and average charge time are explored using the sensitivity analysis shown in Table 1.

1.2.3 Report Structure

The remainder of this report is structured as follows. Section 2 reviews the current status of the PEV market and EVSE infrastructure. Section 3 presents methods and results for non-residential community charging requirements, including L2 charging and fast-charging stations. Section 4 presents methods and results for fast-charging stations along interstate corridors. Finally, Section 5 summarizes the report's findings and offers insights to decision makers who are working to deploy an effective charging infrastructure network in the United States.

2 Existing Vehicle and Infrastructure Status

This section reviews the current status of the U.S. PEV market and EVSE infrastructure.

2.1 Plug-in Electric Vehicle Market Analysis

The PEV market has experienced significant growth over the last few years, with more than 2 million PEVs on the road globally and more than 500,000 in the United States alone (IEA 2017). IHS Markit (formerly R.L. Polk & Co.) LDV registration data are used in this report to inform geographical disaggregation of PEV adoption in the United States (IHS Markit 2017). This rich data set yields numerous insights into the composition of the PEV stock, its geographical distribution, and its temporal evolution. Out of the approximate 266 million light-duty vehicles registered in the United States in 2016, 239,000 were BEVs and 261,000 were PHEVs (IHS Markit 2017).

Policy support has been a strong driver for PEV adoption in the United States, as shown in Figure 2 by the significantly higher share of PEVs in the "ZEV states" (California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont), which require automakers to sell a certain proportion of ZEVs (PEVs and fuel-cell electric vehicles) (California Air Resources Board 2017).

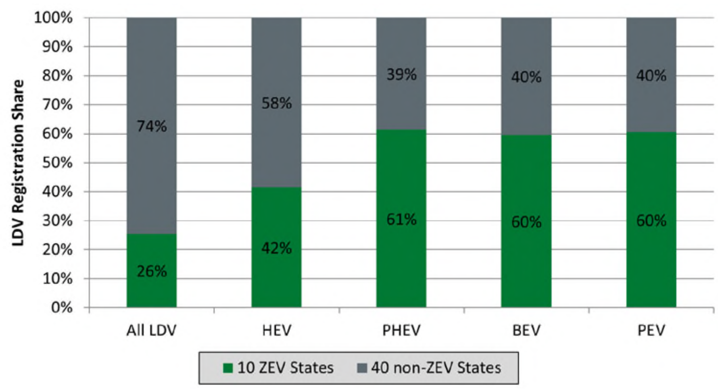

Figure 2. Distribution of all 2016 registrations of LDVs, HEVs, and PEVs in the United States by state ZEV status

(IHS Markit 2017)

While PEV model availability is still limited compared to conventional gasoline vehicles, 30 PEV models were available in the U.S. market at the end of 2016, covering a range of body styles and sizes. Although early PEVs were mainly small hatchbacks and sedans, such as the Nissan Leaf and the Chevrolet Volt, SUVs such as the Tesla Model X and BMW X5—and even vans such as the Chrysler Pacifica—are now available. This trend will help make PEVs more attractive to customers across several segments. Likewise, longer-range BEVs such as the Chevrolet Bolt (with 238 miles of battery-only range) will appeal to consumers who were previously deterred by the limited range of BEVs. Figure 3 shows the composition of the existing U.S. PEV stock. The Chevrolet Volt and Nissan Leaf are the most popular models in the PHEV and BEV segments, respectively, but several other models account for significant market shares.

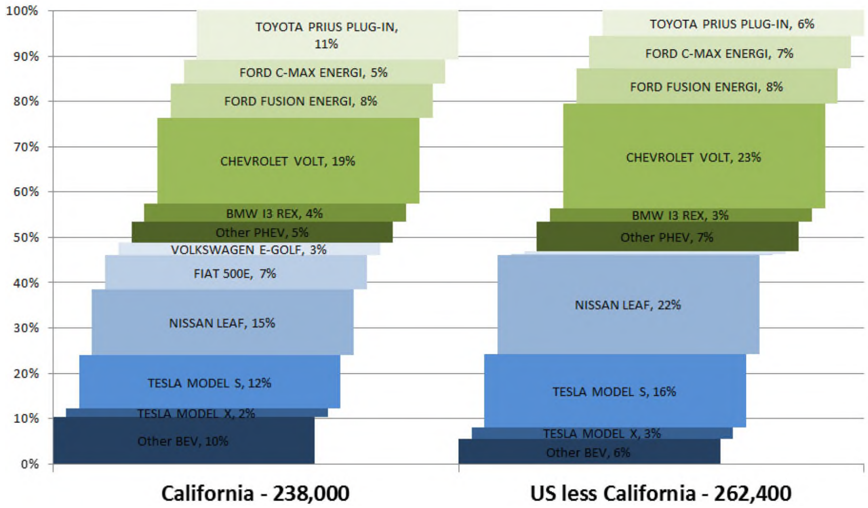

Figure 3. Composition of 2016 U.S. PEV stock

(IHS Markit 2017)

PEV registrations, shown in Figure 4, appear to be concentrated in cities (91% of existing PEV registrations are located in cities) with the remainder distributed in towns and rural areas. This disparity is partially driven by a larger population in urban areas (71% of Americans live in cities with populations of 50,000 people or more), but lower PEV adoption in towns and rural areas is also the result of a lack of charging infrastructure combined with lower consumer awareness, lower availability of PEV models, and higher requirements for longer-distance trips.

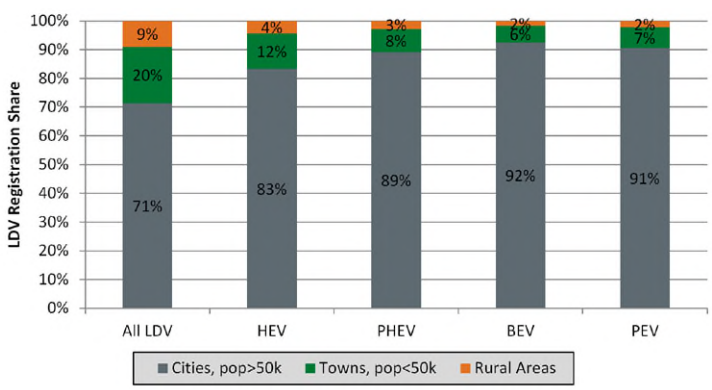

Figure 4. Distribution of all 2016 registrations of LDVs, HEVs, and PEVs in the United States by area

(IHS Markit 2017).

Table 2 reports the number of LDV registrations aggregated by urban area for the top 10 U.S. PEV markets. California leads the nation, with six of the top 10 PEV urban area markets. Yet, the overall PEV penetration remains modest, with only four major urban areas exceeding 1% LDV market share. Two of the top 10 urban areas, Concord, California, and Mission Viejo – Lake Forest – San Clemente, California, have populations under 1 million, but have a higher number of PEVs registered than Chicago, which is 10 times larger in terms of population. This may be explained by the demographics of these areas (including high average income) and significant policy support in California, including the ZEV mandate and financial incentives offered by the state—$2,500 for BEVs and $1,500 for PHEVs—on top of the $7,500 federal tax rebate (Clean Vehicle Rebate Project 2017). These numbers also highlight the clustering effect, or neighbor effect, in PEV adoption, where a high existing concentration of PEVs and EVSE increases the awareness and attractiveness of PEVs in the surrounding area (Kahn and Vaughn 2009). Atlanta stands out as the most BEV-leaning market in the country, which can be traced back to a generous state incentive of $5,000, which ended in the summer of 2015. Elimination of this incentive (and introduction of a $200 road tax) may help explain the 8% year-on-year drop in PEV stock in Atlanta.

Table 2. Top 10 U.S. Urban Areas by PEV Stock, 2016 (IHS Markit 2017)

Urban Area	All LDV Registrations	PHEV	BEV	PEV Share	BEV/PEV Ratio	2015 to 2016 PEV Stock Change
Los Angeles-Long Beach-Anaheim, CA	9,851,000	48,800	36,700	0.9%	43%	32%
San Francisco-Oakland, CA	2,500,000	15,800	23,600	1.6%	60%	27%
San Jose, CA	1,504,000	14,700	22,100	2.4%	60%	22%
New York-Newark, NY-NJ-CT	10,652,000	11,800	7,300	0.2%	38%	30%
Atlanta, GA	4,459,000	3,100	15,700	0.4%	83%	-8%
San Diego, CA	2,548,000	7,900	9,000	0.7%	53%	28%
Seattle, WA	2,874,000	4,800	10,100	0.5%	68%	25%
Concord, CA	636,000	5,400	5,800	1.8%	52%	25%
Mission Viejo-Lake Forest-San Clemente, CA	572,000	5,400	3,900	1.6%	42%	28%
Chicago, IL-IN	6,769,000	4,700	4,400	0.1%	48%	30%

2.2 Electric Vehicle Supply Equipment Availability

According to the DOE's Alternative Fuels Data Center Station Locator, as of June 2017 there were approximately 16,000 PEV charging stations with 43,000 charging plugs nationwide (DOE 2017b), where a station is defined as a location with one or more individual plugs for PEV charging. L2 chargers are the most commonly installed type, accounting for approximately 80% of the installed plugs (DOE 2017b). Table 3 summarizes the public EVSE characteristics of the top 10 urban PEV markets including the number of plugs per 1,000 PEVs (existing public charging capacity) and stations per 1,000 square miles (existing public charging coverage). Although these top 10 urban areas typically feature public charging capacity and coverage above the national average, significant variability exists. For example, the Mission Viejo–Lake Forest–San Clemente urban area in California currently supports the nation's ninth largest PEV market with relatively low public charging capacity and coverage. Additional summaries of public EVSE networks are included in Appendix A.

Table 3. EVSE Characteristic of the Top 10 U.S. Urban PEV Markets, 2017 (DOE 2017b)

Urban Area	L2 Plugs	DCFC Plugs	L2 Stations	DCFC Stations	L2 Plugs per 1,000 PEVs	DCFC Plugs per 1,000 PEVs	DCFC Stations per 1,000 sq.mi.
Los Angeles-Long Beach-Anaheim, CA	4,543	357	1,229	152	53.2	4.2	87.5
San Francisco-Oakland, CA	1,786	200	535	81	45.4	5.1	154.7
San Jose, CA	1,592	88	382	37	43.3	2.4	129.5
New York-Newark, NY-NJ-CT	1,087	130	603	54	56.9	6.8	15.7
Atlanta, GA	1,140	150	433	75	60.7	8.0	28.4
San Diego, CA	1,224	102	363	39	72.4	6.0	53.2
Seattle, WA	1,102	78	448	39	74.4	5.3	38.6
Concord, CA	265	50	113	20	23.7	4.5	98.1
Mission Viejo-Lake Forest-San Clemente, CA	76	14	31	4	8.2	1.5	26.6
Chicago, IL-IN	785	80	382	41	86.1	8.8	16.8

3 Non-Residential L2 and DCFC for Community Charging

Most driving in the United States consists of habitual trips in and around the communities where people live, making convenient access to charging in these communities crucial to widespread PEV adoption. Although the majority of PEV charging currently takes place at home, access to charging away from home at long dwell time locations, commercial entities, and along freeways is highly valued by drivers as it dispels range anxiety and enables a greater share of electric miles. The analysis in this section estimates charging requirements in cities, towns, and rural areas to support the growing PEV market. First, coverage estimates are made for a minimum level of DCFC stations within cities and towns to support BEV intra-city long distance travel and emergency situations such as failing to charge overnight at home. Next, the National Renewable Energy Laboratory's (NREL's) Electric Vehicle Infrastructure Projection (EVI-Pro) tool is used to estimate non-residential charging requirements for a baseline scenario of 15 million PEVs on U.S. roads in 2030. Finally, a sensitivity analysis is presented to document model uncertainty with respect to key factors such as technology development, PEV market evolution, and consumer charging behavior.

3.1 DCFC Coverage Estimates

This section presents a straightforward approach to estimating the number of DCFC stations required to provide minimum coverage for PEVs in cities and towns. L2 station coverage is not considered, assuming that non-residential L2 is primarily used for charging within walking distance of a destination (based on the low charge power and long charge time of L2 stations), and coverage for every destination is unrealistic for the early PEV market. Coverage estimates are also omitted for DCFC stations in rural areas, because coverage provided by stations in cities/towns and along interstate corridors (see Section 4) is deemed to be sufficient. Given that PHEVs are assumed to perform most charging at home and can use an internal combustion engine for backup power, they are naturally excluded from this calculation of a minimum charging coverage requirement. Consequently, attention is paid to DCFC stations supporting BEVs in cities and towns.

As a simplifying assumption, coverage estimates assume DCFC stations are spaced uniformly on a square grid across a two-dimensional area within each community. For BEV drivers to never be more than 3 linear miles from a DCFC station in a given city, 56 stations per 1,000 square miles would be required (for reference, there are currently 960 gasoline stations per 1,000 square miles in U.S. cities). This station density is applied to the 108,246 square miles occupied by cities and towns in the United States, resulting in a national DCFC station count of 8,072 (4,861 in cities and 3,211 in towns).

For comparison, the public DCFC station density per 1,000 square miles in major PEV markets ranges from 16 in New York and 17 in Chicago to 130 in San Jose and 155 in San Francisco (as of June 2017). The average DCFC density per 1,000 square miles in the top 10 U.S. PEV markets is 65. This number drops to 18 across all cities and towns nationwide.

3.2 Non-Residential EVSE Community Demand Estimates

This section describes methods for estimating non-residential EVSE (work L2, public L2, and public DCFC) demand requirements for community charging. NREL has developed three regional models using EVI-Pro—for California, Massachusetts (Wood et al. 2017), and the Columbus, Ohio, area (Wood et al. forthcoming). The findings from those models are extended to estimate nominal ratios of EVSE per 1,000 PEVs for the national study. These nominal ratios are adjusted for the various communities across the United States. Adjustments to the nominal EVSE/PEV ratios are based on population density, PEV concentration, and local ambient temperature.

PEV stock for all communities (486 cities, 3,087 towns, and 50 rural areas with state-level aggregation) is calculated by disaggregating a national PEV count (15 million in the baseline 2030 scenario) proportionally to existing registration data from IHS Markit. Three variations on PEV disaggregation are considered based on: 1) all existing LDV registrations, 2) existing HEV registrations, and 3) existing PEV registrations. Among these three options, basing disaggregation on existing PEV registrations maximizes the number of PEVs in cities and ZEV states, whereas basing it on existing LDV registrations places a comparatively larger share of PEVs in towns, rural areas, and non-ZEV states (see Section 2). Basing disaggregation on existing HEV registrations produces results that are in between the results of the other two approaches in terms of geographic PEV distribution. The central scenario uses the HEV-based disaggregation approach, and the other approaches are used for sensitivity analysis.

After individual EVSE/PEV ratios and PEV stocks for each geography are calculated, the ratio and stock values are simply multiplied to generate a localized estimate of consumer demand for non-residential charging. A schematic of this approach is shown in Figure 5.

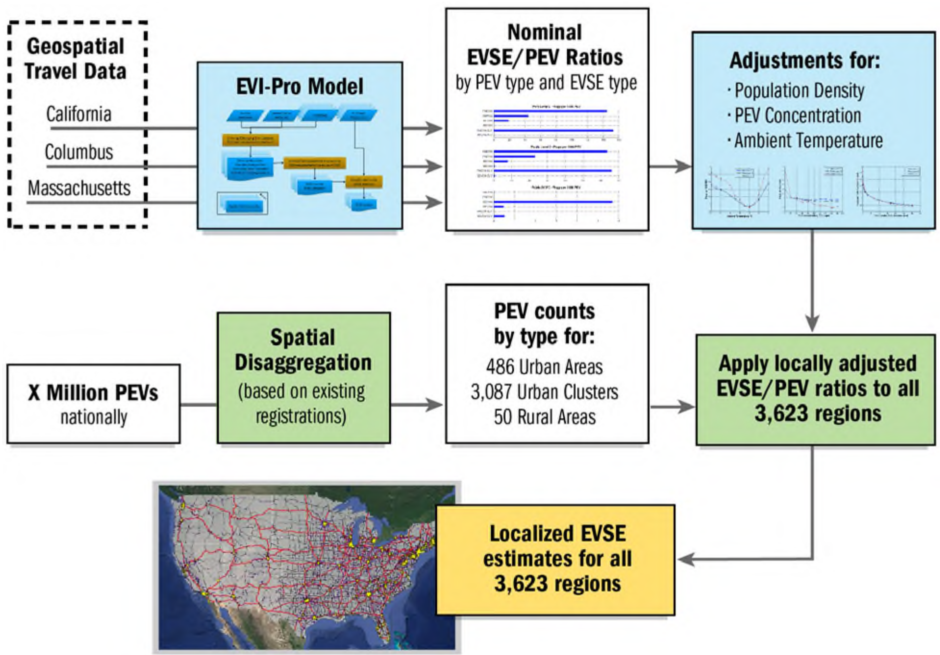

Figure 5. Schematic for estimating community charging requirements.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

3.2.1 Electric Vehicle Infrastructure Projection (EVI-Pro) Tool

Consumer demand for non-residential L2 and DCFC is estimated using EVI-Pro. NREL developed EVI-Pro in partnership with the California Energy Commission to estimate regional requirements for charging infrastructure that supports consumer adoption of light-duty PEVs. EVI-Pro uses real-world travel data to simulate spatially and temporally resolved demand for PEV charging at homes, workplaces, and public destinations. It anticipates consumer charging behavior while capturing variations with respect to housing type (single- versus multi-unit dwellings [MUDs]), travel period (weekdays versus weekends), and regional differences in travel behavior and vehicle adoption. Its fundamental assumption is that consumers prefer charging scenarios that enable them to complete all their existing travel with maximum eVMT and minimum operating cost. For more information about EVI-Pro's functionality, see the methodology section of Wood et al. (2017).

3.2.2 Estimating Non-Residential EVSE/PEV Nominal Ratios

A mix of PEVs selected to emulate the 2030 PEV market is shown in Table 4. EVSE attributes assumed for charging infrastructure are summarized in Table 5.

Table 4. Modeled Vehicles

Modeled PEVs	PHEV20	PHEV50	BEV100	BEV250	PHEV20 SUV	BEV250 SUV
Chassis Type	Sedan	Sedan	Sedan	Sedan	SUV	SUV
Nominal Electric Driving Range, mi	20	50	100	250	20	250
Nominal Efficiency, Wh/mi (excludes charger efficiency)	225	225	225	230	315	330
Assumed 2030 PEV Registration Shares (central scenario)	10%	35%	15%	30%	5%	5%
Existing Registration Shares	25%	21%	34%	14%	2%	3%
Existing Example PEVs	Ford Fusion Energi, Toyota Prius Prime	Chevrolet Volt	Nissan Leaf, Fiat 500e	Tesla Model S, Chevrolet Bolt	BMW X5 xDrive40e, Volvo XC90 T8	Tesla Model X

Table 5. Modeled Charging Infrastructure

Location	Level	Power	Comment
Home	L1	1.4 kW	
	L2	3.6 kW	BEVs simulated with L2 power above 3.6 kW to enable full overnight charge
Work	L2	6.2 kW	PHEV on-board charger limits max power to 3.6 kW in model
Public	L2	6.2 kW	PHEV on-board charger limits max power to 3.6 kW in model
	DCFC	150 kW	BEVs only; charge rate tapers at high state of charge; BEV100 limited to 50 kW max

L1 = level 1 charging station

Global positioning system travel trajectories for the Columbus area from commercial traffic/mapping provider INRIX were used as the input data set to the EVI-Pro model (Wood et al. forthcoming). Results from the Columbus model were harmonized with PEV/EVSE ratios from the California model (based on the 2012 California Household Travel Survey) and Massachusetts model (based on the 2011 Massachusetts Travel Survey). This process yields a nominal set of EVSE/PEV ratios for each charger location and power level. Figure 6 shows the nominal EVSE/PEV ratios in terms of plugs per 1,000 PEVs for work L2, public L2, and public DCFC infrastructure. These estimates assume a home-dominant charging pattern in which consumers have access to home charging and prefer to do most charging at home owing to their electricity rate structures and the perceived level of convenience.

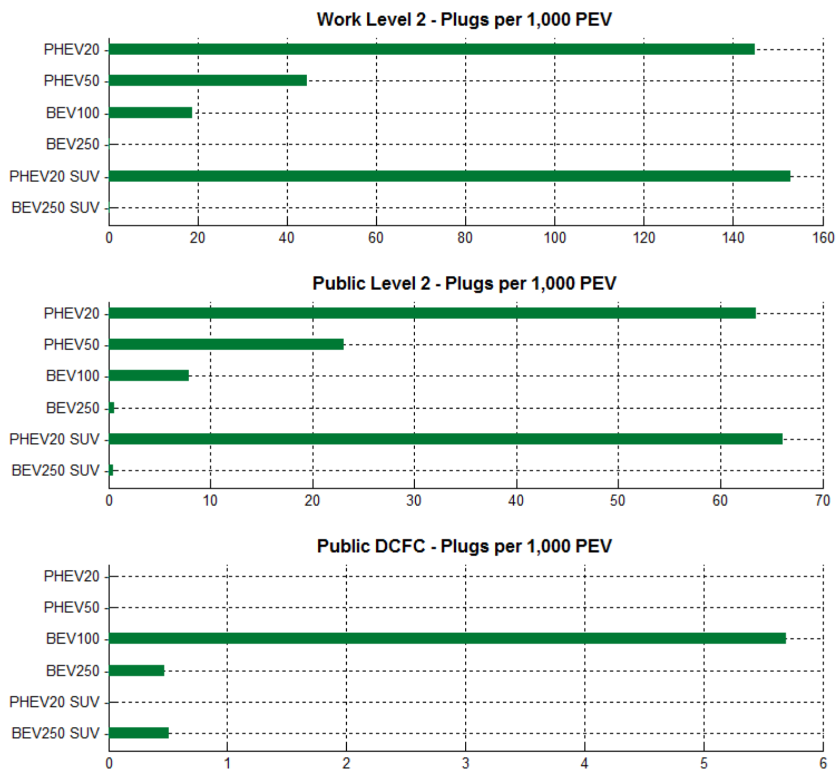

Figure 6. Nominal non-residential EVSE/PEV ratios (home dominant charging behavior).

The relationship between electric range and estimated infrastructure requirements is clear in these results. PEVs with longer electric ranges are less dependent on work and public charging to maximize eVMT (e.g., the BEV250 results in almost non-existent L2 charging requirements at work and public locations). Because PHEVs are incompatible with fast charging in this analysis, by definition they have no DCFC requirements.

The resulting charging load profile from home-dominant EVI-Pro simulations is shown in Figure 7. Note that 88% of charging in the EVI-Pro simulations is from residential EVSE (either L1 or L2). The simulations do not account for electricity pricing mechanisms or consumer incentives (such as time-of-use pricing) designed to shift load from the early evening into overnight hours. These effects have significant impacts on the operation of the electricity grid, but do not impact the non-residential EVSE/PEV ratios estimated in this report.

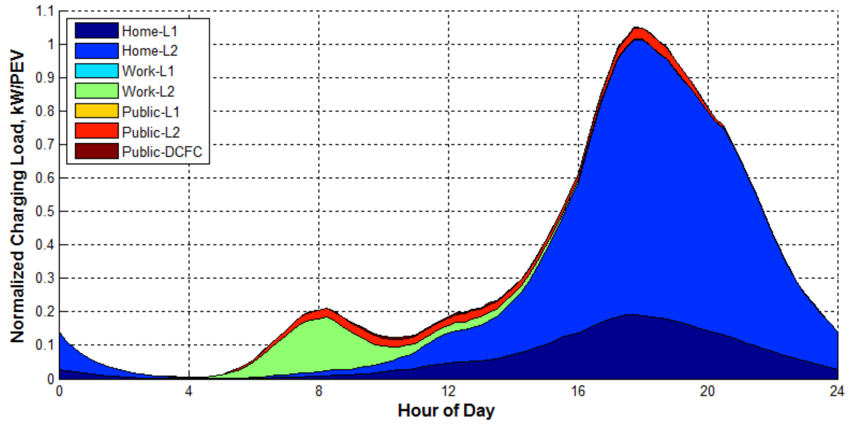

Figure 7. Nominal charging load profile from EVI-Pro simulations (home dominant charging behavior).

The nominal set of EVSE/PEV ratios is adjusted to account for the unique characteristics of all U.S. geographies based on population density, PEV concentration, and ambient temperature, as discussed in Appendix .

3.2.3 National Results in the Central Scenario

A set of national simulations is run using the settings from the central scenario (discussed in Section 1.2.2). Table 6 shows the modeled estimates for PEVs and EVSE for the top 10 urban areas from simulation of the central scenario. Results by community type and national totals are shown in Table 7, and state-level results are shown in Appendix . In 2030, approximately 600,000 L2 plugs (work and public) and 25,000 DCFC plugs are projected to serve 15 million PEVs across the United States. These estimates normalize to 40 L2 plugs per 1,000 PEVs and 1.7 DCFC plugs per 1,000 PEVs.

Present day public charging infrastructure represents approximately 13% of the plug count estimates modeled for 2030 (under PEV market assumptions in the central scenario). However, cities such as San Jose, California (73%), San Francisco, California (43%), and Seattle, Washington (41%) are much closer to the estimated requirements for the 15 million PEVs simulated in the central scenario.

Table 6. Central Scenario PEV and Non-Residential EVSE Estimates in 2030, Top 10 Urban Areas

Urban Area	PEV Total	Work L2 Plugs	Public L2 Plugs	Public DCFC Plugs
Los Angeles-Long Beach-Anaheim, CA	1,213,000	22,000	13,000	700
New York-Newark, NY-NJ-CT	553,000	13,000	7,000	600
San Francisco-Oakland, CA	497,000	7,000	4,000	400
Washington, DC-VA--MD	407,000	9,000	5,000	400
Chicago, IL-IN	399,000	8,000	5,000	500
Seattle, WA	316,000	5,000	3,000	500
San Diego, CA	297,000	5,000	3,000	300
Boston, MA-NH-RI	266,000	7,000	4,000	300
San Jose, CA	260,000	4,000	2,000	200
Philadelphia, PA-NJ-DE-MD	235,000	6,000	4,000	300

Table 7. Central Scenario PEV and Non-Residential EVSE Estimates in 2030, by Community Type (with National Total)

	PEV Total	Work L2 Plugs	Public L2 Plugs	Public DCFC Plugs
Cities	12,411,000	278,000	173,000	19,000
Towns	1,848,000	56,000	43,000	4,000
Rural Areas	642,000	28,000	23,000	2,000
National Total	15,000,000	362,000	239,000	25,000

3.2.4 Sensitivities of National Results to Various Assumptions

This section illustrates the sensitivity of the national results to potentially important assumptions. Figure 8 shows the results in terms of total national plug requirements, whereas Figure 9 shows the results in terms of normalized requirements (EVSE/PEV ratios). For example, increasing the number of PEVs from the central value of about 15 million to 21 million increases the number of non-residential L2 plugs from 600,000 to 820,000, and it increases the number of DCFC plugs from 25,000 to 33,000 (Figure 8). The effects of changing PEV penetration are smaller on a normalized basis, especially for non-residential L2 plugs. Otherwise, the ranking of influential variables is similar for total and normalized non-residential L2 plugs: 1) PHEV support, 2) range preference, 3) percent home charging, 4) PHEV:BEV ratio, 5) percent of PEVs cities, and 6) SUV share. For DCFC plugs, PHEV support has no impact as PHEVs are not modeled as supporting DCFC. Range preference has the largest impact, followed—on a normalized basis—by percent home charging, PHEV:BEV ratio, PEV count, and percent of PEVs in cities.

This analysis also enables comparison of the input variables' impacts on the L2 and DCFC total plug counts. Supporting PHEVs boosts L2 plug counts significantly since PHEVs are modeled as using non-residential L2 EVSE at significantly higher rates than BEVs, whereas it has no effect on DCFC plug counts as PHEVs cannot use DCFC. Similarly, a high ratio of PHEVs to BEVs favors L2 EVSE, and a high ratio of BEVs to PHEVs favors DCFC. The need for both power levels rises as the range of PEVs declines, since shorter-range PEVs require more non-residential charging. The need for both types of charging infrastructure decreases as the share of PEVs in cities increases, because daily average vehicle miles traveled (VMT) is lower in denser urban areas (see Appendix B). More home charging also reduces the need for both types of charging infrastructure.

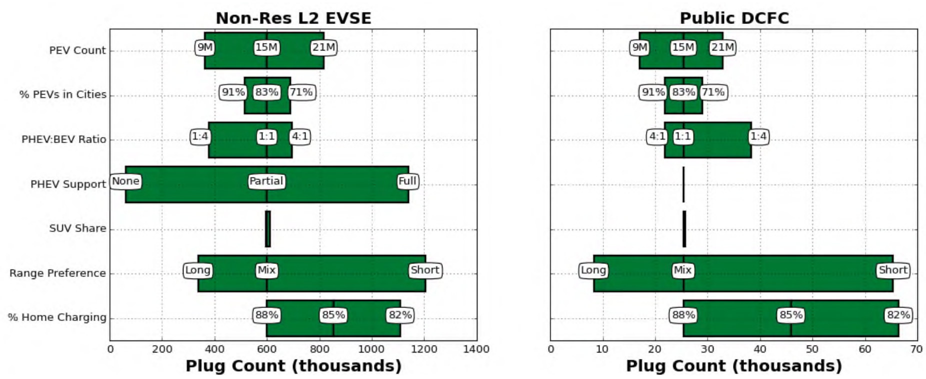

Figure 8. Effects of input variables on estimated total national plug requirements.

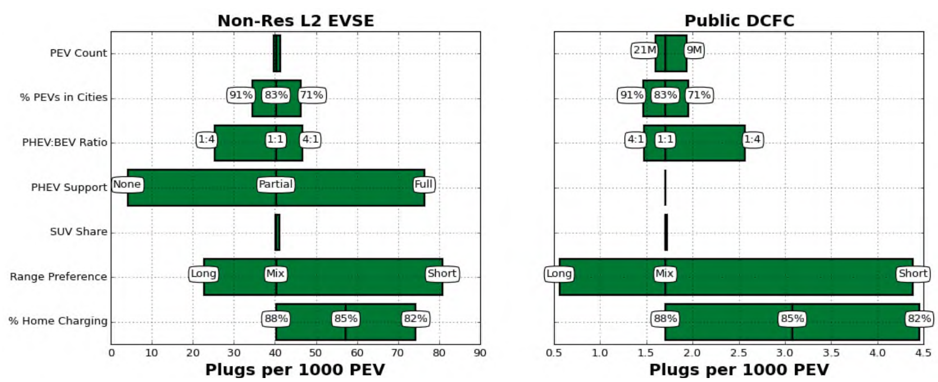

Figure 9. Effects of input variables on normalized national plug requirements (EVSE/PEV ratios).

4 DCFCs for Corridor Charging

Long-distance travel has been a critical barrier to BEV adoption, which has been exacerbated by the real and perceived range anxiety of drivers in the United States. While most single-day travel surveys suggest that a large majority of daily driving can be accommodated with a relatively short driving range (approximately 100 miles), analysis of longitudinal driving patterns reveals that a large segment of U.S. drivers routinely use personal vehicles for long-distance travel, with an average vehicle traveling 100 miles or more on 6 days per year (see Appendix). These drivers would presumably require long-distance single-charge ranges and DCFC support along travel corridors to consider adopting BEVs as fully capable replacements for their existing vehicles. Even drivers who seldom make LDTs might exhibit similar adoption requirements based on their perceived need for long-distance driving.

This issue can be alleviated by providing access to an extensive and convenient network of DCFC stations along corridors that enable reliable long-distance intercity travel. The U.S. Interstate Highway System is an ideal basis for such a long-distance DCFC network. Its extensive, high-speed, controlled-access highways connect population centers and cross the country via various routes. Yet providing comprehensive DCFC coverage for the Interstate System presents a much smaller and simpler task compared with providing comprehensive coverage based on all other U.S. highways and state routes. Interstate-based coverage that is already underway and planned could result in a robust, national network within a few years, whereas community DCFC coverage of the scope described in Section 3 will likely take longer.

This section estimates the number of DCFC stations necessary to provide charging coverage across several network designs based on the Interstate System. Next, charging demand requirements are estimated to quantify the number of plugs at interstate corridor DCFC stations needed to support long-distance travel and minimize queuing during periods of high traffic. Then, a set of challenges associated with constructing and maintaining Interstate corridor DCFC stations is discussed. The analyses in these sections (Sections 4.1 to 0) consider only highways that are part of the Interstate System. Section 0 provides a brief discussion of the corridor charging support that could be enabled by the community-based DCFC stations discussed in Section 3.

4.1 DCFC Interstate Corridor Coverage Calculations

This section first defines the full Interstate network as a basis for developing hypothetical DCFC networks (Section 4.1.1). Because the full Interstate network is large, Section 4.1.2 prioritizes corridors to develop four alternative national DCFC network scenarios, forming a total of five hypothetical DCFC corridor networks as shown in Table 8. Finally, Section 0 discusses station spacing requirements for corridors. National corridor DCFC methodology and sensitivities are summarized in Figure 10.

Table 8. National DCFC Coverage Scenarios along U.S. Interstate Corridors

DCFC Corridor Scenario	Comment
Full Interstate Network	DCFC coverage is provided across all U.S. Interstate corridors
Mega-Regions	DCFC coverage within U.S. mega-regions (per America 2050 study), but not between mega-regions
DOT Alternative Fuel Corridors	DCFC coverage provided on all corridors specified in U.S. DOT Alternative Fuel Corridors for Electric Vehicles (DOT 2017a)
HPMS-Based Coverage (80%)	DCFC coverage on corridors representing 80% of FHWA Highway Performance Monitoring System annual average daily travel for interstate corridors
TAF-Based Coverage (80%)	DCFC coverage on corridors representing 80% of FHWA Traveler Analysis Framework annualized automobile trips on interstate corridors

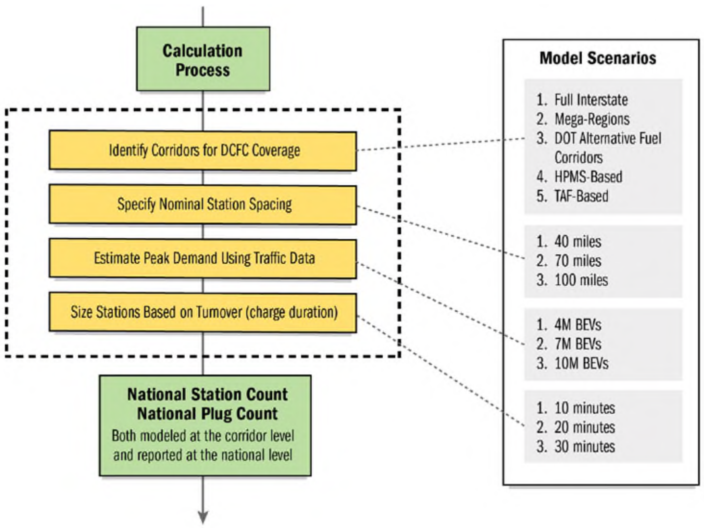

Figure 10. Methodology and sensitivity schematic for corridor DCFC analysis.

Table 9 and Figure 11 summarize the station-count results for each coverage scenario assuming three different average station-spacing values. The national station count ranges from 96 (for the mega-region network with 100-mile spacing) to 713 stations (for the full Interstate network with 40-mile spacing). Although this range is large, all scenarios are relatively modest compared with the regional DCFC investments that already have been made. As of June 2017, a total of 2,164 DCFC stations have been installed (357 by Tesla alone). However, most of these stations have been concentrated in urban areas, and the small number of corridor DCFC stations has been concentrated in areas of high PEV adoption—most notably along the West Coast, through northeast sections of the I-95 corridor, and in rural areas around Atlanta. Again, using the Tesla network as an example, as of June 2017 there were a total of 161 corridor DCFC stations in Tesla's Supercharger network, enabling long-distance travel across most of the United States.

Table 9. Estimated National DCFC Station Counts to Cover Corridors under Different Scenarios

Station Spacing	40 miles	70 miles	100 miles
Full Interstate Network	713	408	285
Mega-Regions	239	137	96
DOT Alternative Fuel Corridors	306	175	122
HPMS-Based Coverage (80%)	530	303	212
TAF-Based Coverage (80%)	436	249	174

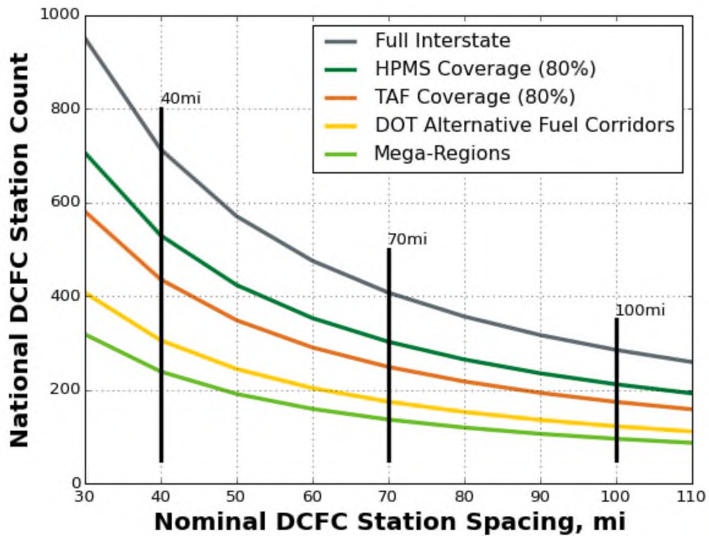

Figure 11. Nationwide DCFC station counts to cover corridors as a function of station spacing for different scenarios.

4.1.1 Full Interstate Network

This section's proposed network for hypothetical DCFC stations consists of Interstate segments connecting cities with a total length of 31,510 miles. This network excludes segments of Interstates within cities since DCFC stations within urban areas are assumed to be available; station count estimates for DCFC in cities are developed in Section 3. Excluding segments shorter than 25 miles (resulting from cities in close proximity), the relevant Interstate network is scaled down to a total length of 28,530 miles, illustrated in Figure 12, which also shows the network with 70-mile-radius buffers (approximating network coverage). This mile count does not consider double miles for both directions of travel or number of lanes on individual corridors, because a single DCFC station is assumed to serve both directions of travel and all lanes (assuming sufficient capacity, which is discussed in Section 4.2).

This road network was derived from the DOT's National Highway Planning Network (v14.05) data set available through the Federal Highway Administration (FHWA) in shapefile format (FHWA 2017c). The full source data set was initially filtered to a set of Interstate highways. Next, a spatial overlay process clipped the filtered set of lines to exclude all segments and portions of line segments overlapping urban areas. A shapefile derived from the U.S. Census Bureau's 2015 MAF/TIGER geographic database filtered to just urban areas provided the clipping bounds (U.S. Census Bureau 2015). Finally, post-processing routines assembled the many small remaining road segments into contiguous network segments. These segments were further separated at junctions where three or more original road segments converged.

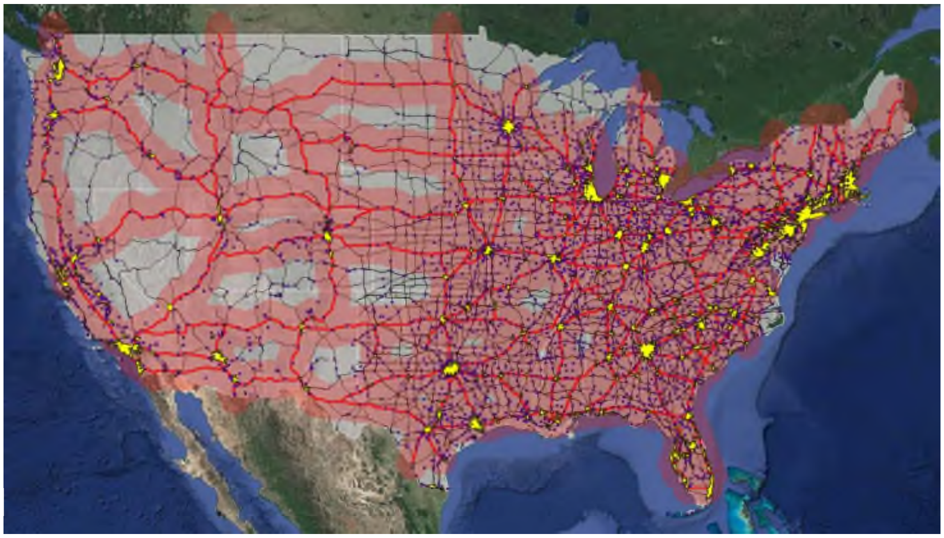

Figure 12. Interstate corridor network (thick red lines) considered in this analysis (70-mile radius red buffer approximates areas that would be served by the proposed DCFC network). Included for reference: yellow polygons represent cities, purple points represent towns, and thin black lines represent the national highway system.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

Providing full coverage to this Interstate Highway network would require many stations, some of which would be poorly utilized owing to the uneven distribution of traffic volume on the network. Hence, it is desirable to prioritize corridors that will provide the highest utility to BEV drivers traveling beyond their vehicle's range. In the next section, this prioritization is discussed for four alternative scenarios.

4.1.2 Corridor Prioritization

Here the Mega-region, DOT Alternative Fuel Corridors, Highway Performance Monitoring System (HPMS), and Traveler Analysis Framework (TAF) scenarios are described.

4.1.2.1 Mega-regions (Scenario 1)

Mega-regions are an interesting geographical trend that has emerged over the last few decades. Interlocking economic systems, shared natural resources and ecosystems, and common transportation systems link these population centers together. Most of the nation's rapid population growth, and an even larger share of its economic expansion, are expected to take place in these large networks of metropolitan areas. The America 2050 initiative defines 11 U.S. mega-regions, reported in America 2050 (2017). Providing coverage for PEV charging along Interstates within each mega-region (that is, enabling reliable PEV travel within each mega-region, but not among different mega-regions) would result in the DCFC network shown in Figure 13, encompassing 96 to 239 DCFC stations (depending on station spacing). In Figure 13 and subsequent similar figures, the yellow buffer represents areas that hypothetically would be served by the proposed DCFC network.

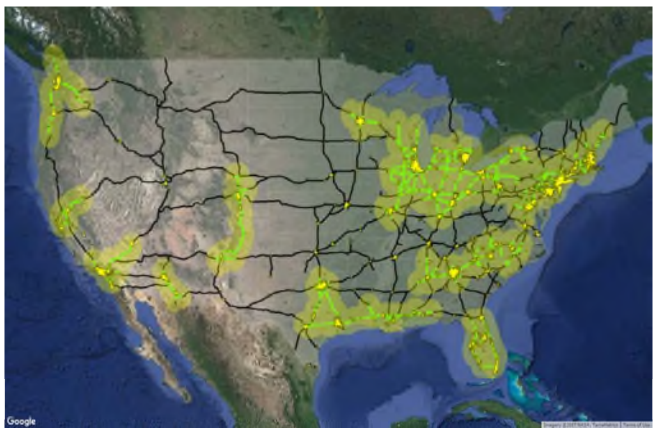

Figure 13. DCFC corridors providing coverage to intra-mega-region travel (70-mile radius yellow buffer approximates areas that would be served by the proposed DCFC network).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

4.1.2.2 DOT Alternative Fuel Corridors (Scenario 2)

The DOT Alternative Fuel Corridor Map for PEVs, shown in Figure 14, is also proposed as a scenario for a hypothetical DCFC network along U.S. highways (DOT 2017a). DOT has designated national PEV charging corridors in strategic locations along major highways to improve the mobility of electric vehicles (DOT 2017a). These corridors were nominated by state and local officials and elaborated in partnership with industry stakeholders. Every 5 years, DOT will issue a report reviewing charging and fueling infrastructure, analyzing standardization needs for fuel providers and purchasers, and reestablishing the goal of achieving strategic installation of fueling infrastructure in each corridor. Providing coverage for PEV charging along Interstates designated in the DOT Alternative Fuel Map would result in the DCFC network shown in Figure 15, encompassing 122 to 306 DCFC stations (depending on station spacing).

Figure 14. PEV Alternative Fuel Corridors as designated by DOT Alternative Fuel Corridor Map

(DOT 2017a)

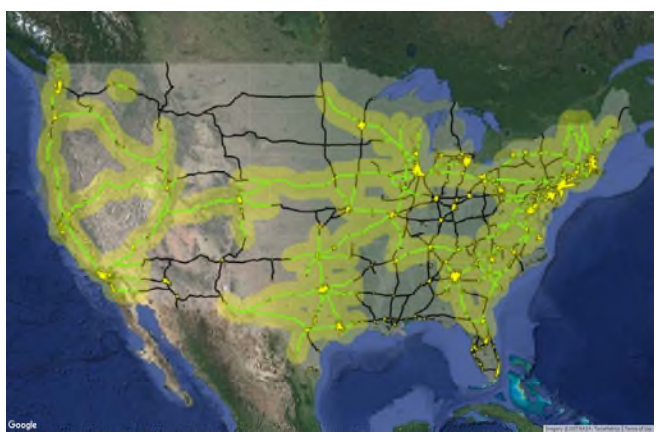

Figure 15. DCFC corridors providing coverage as designated by the DOT Alternative Fuel Corridor Map (DOT 2017a) (70-mile radius yellow buffer approximates areas that would be served by the proposed DCFC network).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

4.1.2.3 Highway Performance Monitoring System (Scenario 3)

The HPMS is a freely available national-level data set that provides a wide array of detailed information on the nation's highways (DOT 2017b). The HPMS contains information on most public roads as well as a combination of measured and estimated annual averaged daily traffic volumes. The latter is highly valuable for infrastructure planning purposes, because it enables traffic-based prioritization. Figure 16, in which line thickness is proportional to average traffic volume, shows that most road traffic is concentrated around major urban areas near the coasts and in the Midwest and South Central regions.

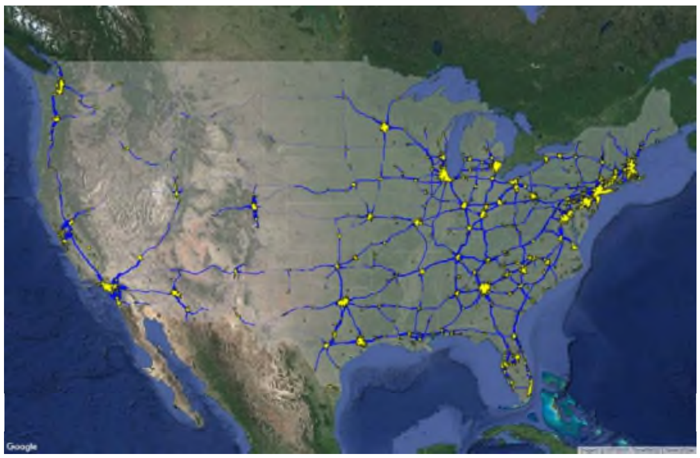

Figure 16. U.S. Interstate Highway corridors. Line thickness is proportional to HPMS average daily traffic.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

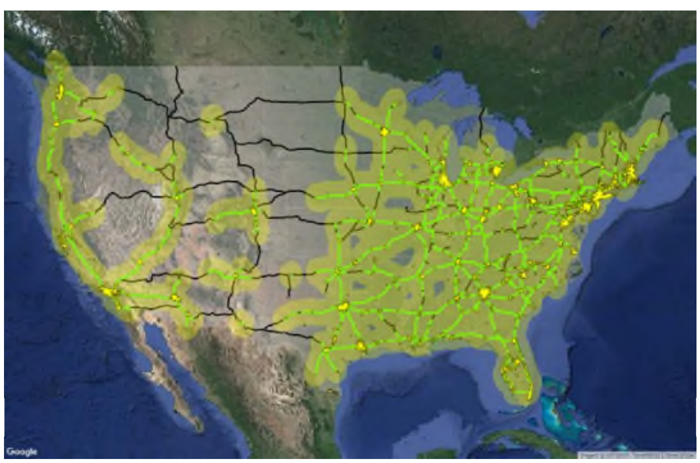

Figure 17. DCFC corridors providing coverage to the top 80% of HPMS annual average daily traffic (70-mile radius yellow buffer approximates areas that would be served by the proposed DCFC network).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

Providing coverage to the corridors capturing 80% of the traffic volume of the HPMS corridors would result in the DCFC network shown in Figure 17, encompassing 212 to 530 DCFC stations (depending on station spacing). Although it provides excellent coverage in the eastern half of the country and on the west coast, it does not enable cross-country travel. Another shortcoming of this network is that the total traffic volumes reported by HPMS are dominated by short-distance, routine commuting trips, which are unlikely to require DCFC. To address this shortcoming, another travel data set is investigated, as described in the following section.

4.1.2.4 Traveler Analysis Framework (Scenario 4)

Because it is impossible to single out LDTs from overall traffic volume, the FHWA created a synthetic data set to estimate long-distance passenger travel. FHWA's TAF was modeled using a variety of predictors, such as population and economic activity, and calibrated to a large travel survey (FHWA 2013). TAF consists of a set of county-to-county trip tables for long-distance passenger trips (defined as trips longer than 100 miles) by automobile, bus, air, and rail. The TAF projects person-trip flows for the base year (2008) and for 2040, shown in Figure 18. This data set is valuable because it enables isolation of LDTs, which are typically difficult to isolate from standard single-day travel surveys owing to the relatively low frequency of such travel events. Isolating long-distance travel is of particular importance in the analysis of charging stations along intercity corridors.

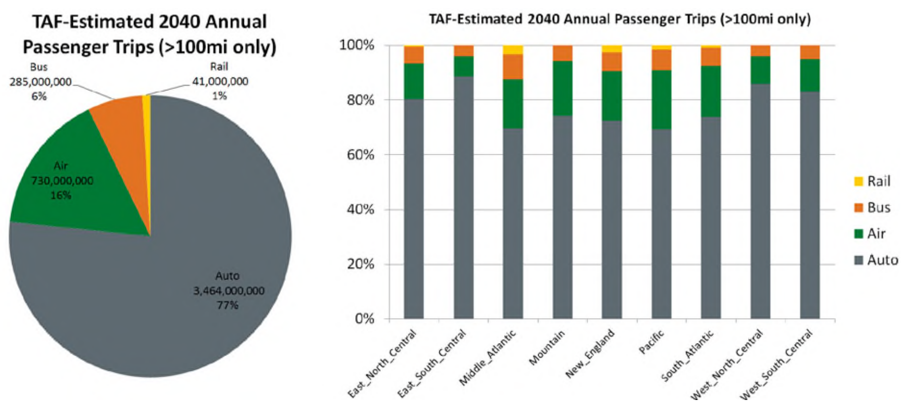

Figure 18. TAF summary statistics

Data from (FHWA 2013)

Figure 19 provides a visualization of the qualitative trip differences between travel modes. Air travel is the dominant mode for very long, cross-country trips. Bus and auto trips are mainly intra-regional, whereas passenger rail travel is restricted to a few routes where railways are available.

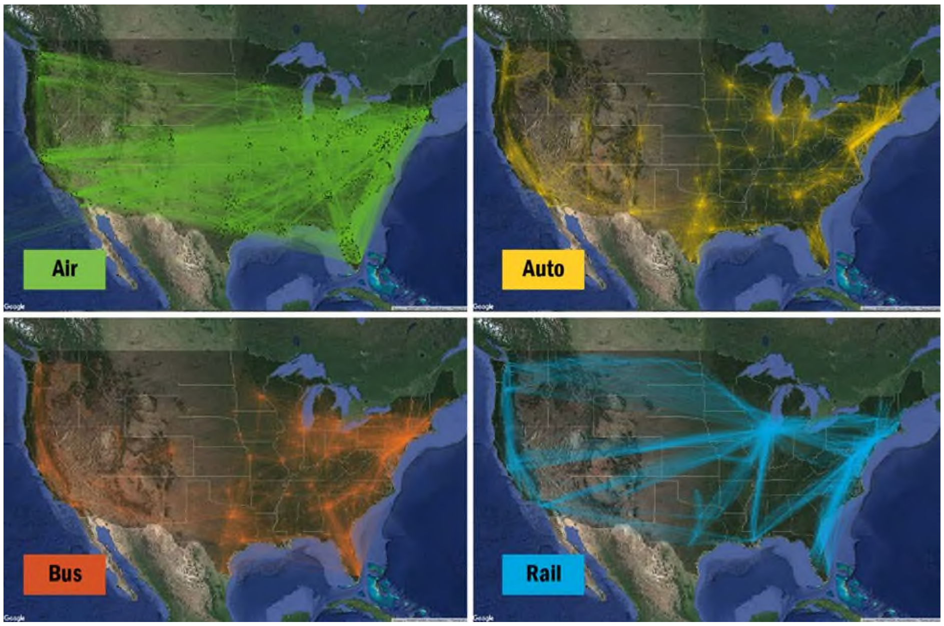

Figure 19. TAF long-distance travel origin–destination pairs by mode; only top 10% visualized here for clarity.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas) Data from FHWA (2013)

The county-level resolution of TAF is highly valuable for long-distance traffic volume estimation, but it is too granular for meaningful visualization. Aggregating TAF data at the census division level, shown in Figure 20, reveals deep insights into intra- and inter-regional travel for different modes. A chord diagram (Krzywinski et al. 2009) provides a visually compelling way to visualize the travel volumes within and between regions. In such a diagram, the outermost band displays the relative share of trips originating from or ending in a given region. The innermost band shows the absolute volume in million passenger-trips per year. Finally, the chords connecting two regions are sized according to the volume of travel between them. Figure 21 shows an enlarged image of the TAF auto routes (top 10% of origin-destination pairs), and Figure 22 shows a chord diagram for the automobile TAF data set (top 10% of origin-destination pairs) by Census Division. Results in Figure 22 show that the South Atlantic, West South Central, and Pacific regions together account for nearly half the nation's annual long-distance auto passenger trips. In addition, more than 80% of trips taking place in the Pacific division are within that division, whereas most LDTs in the East South Central division connect it with neighboring divisions.

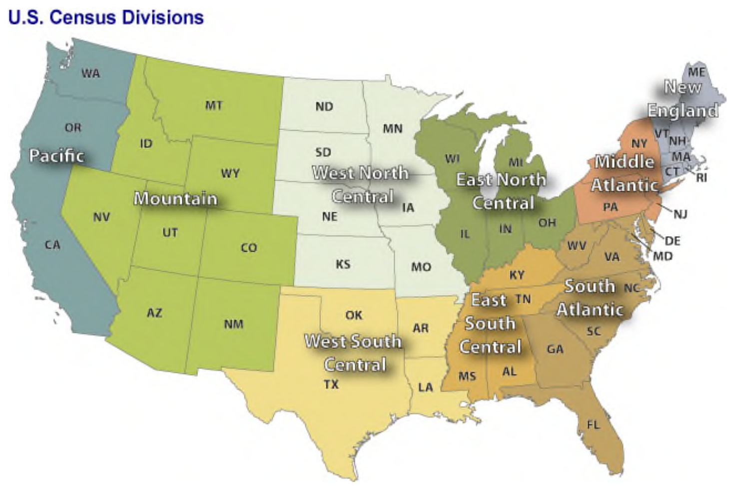

Figure 20. Map of U.S. Census divisions

(National Oceanic and Atmospheric Administration 2017)

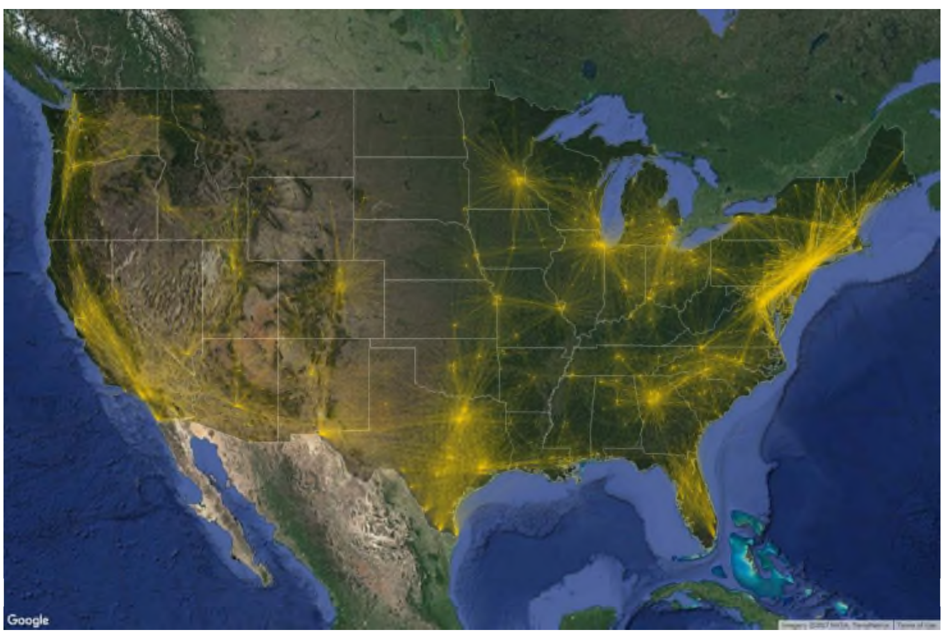

Figure 21. TAF long-distance auto passenger trip origin-destination pairs; only top 10% visualized here for clarity.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas) Data from FHWA (2013)

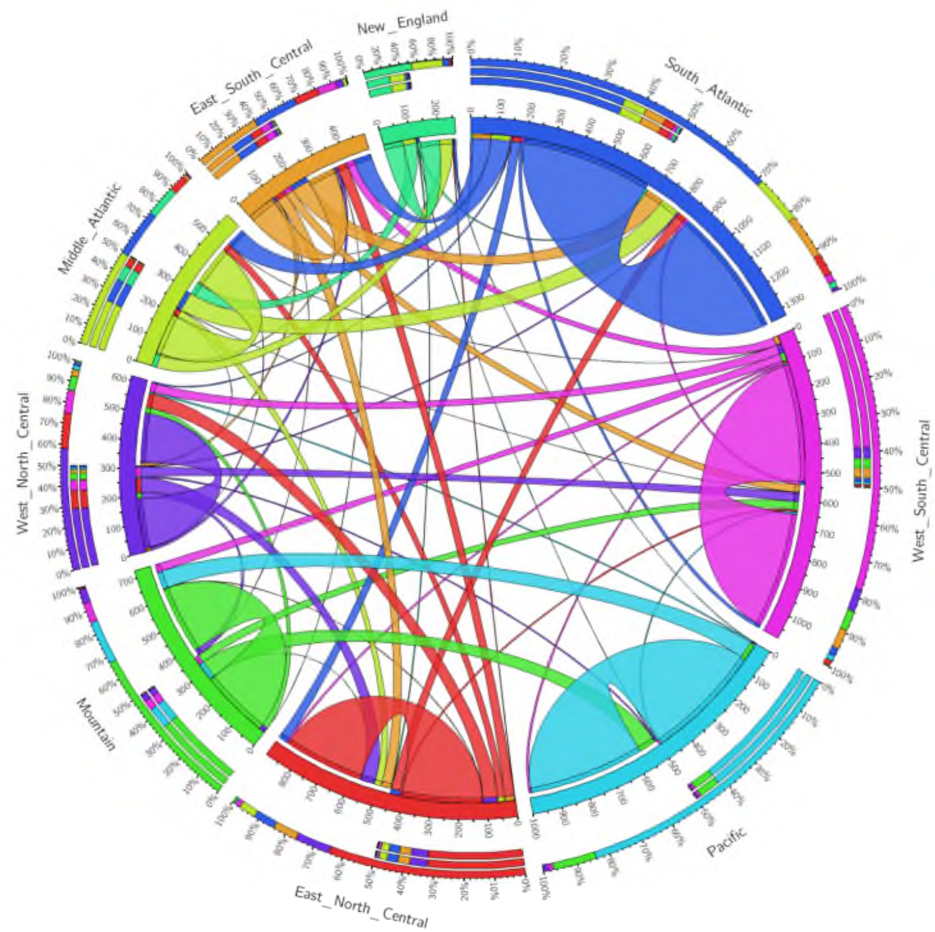

Figure 22. Chord diagram generated using TAF long-distance auto passenger travel volume

(FHWA 2013)

To estimate long-distance travel volumes by highway corridor, the county-level origin-destination pairs in the TAF data set were routed onto the interstate network using a web-based mapping service that seeks to minimize travel time, the MapQuest Directions API (MapQuest 2017). Use of the MapQuest API is intended to approximate routes consumers actually take when completing LDTs. Figure 23 shows the results of this routing process where the thickness of each corridor corresponds to the total number of estimated annual LDTs on that corridor. Providing coverage to the corridors capturing 80% of the traffic volume of the TAF corridors would result in the DCFC network shown in Figure 24, encompassing 174 to 436 DCFC stations (depending on station spacing).

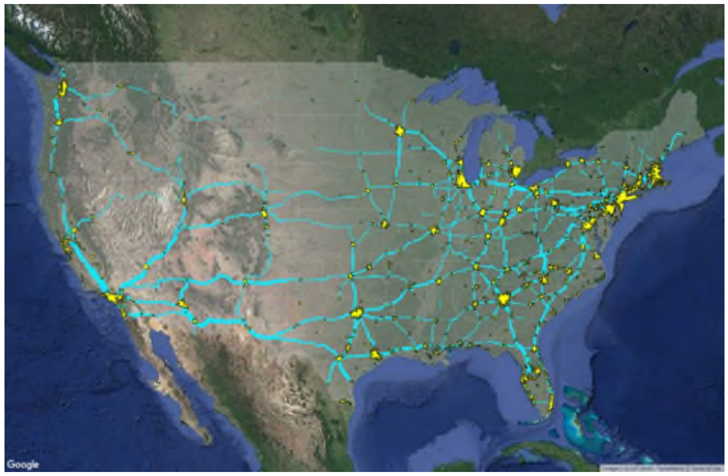

Figure 23. U.S. Interstate Highway corridors. Line thickness proportional to TAF long-distance auto traffic.

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

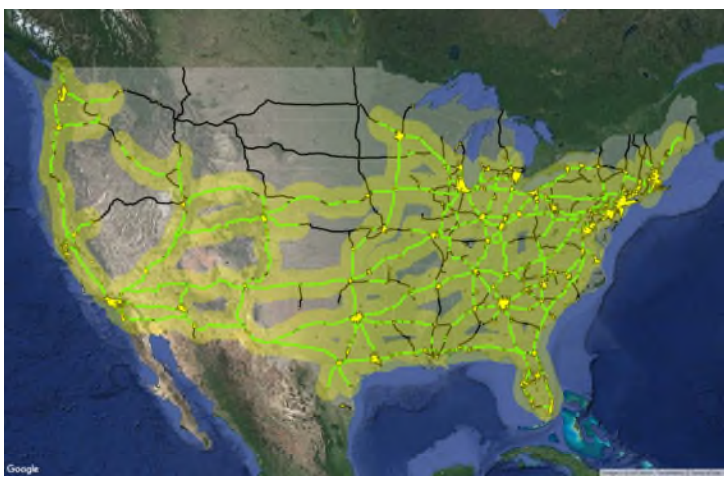

Figure 24. DCFC corridors providing coverage to the top 80% of the TAF long-distance auto traffic (FHWA 2013) (70-mile radius yellow buffer approximates areas that would be served by the proposed DCFC network).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

NREL's processing of TAF data onto the interstate network was compared against the HPMS data. Figure 25 shows NREL-derived TAF auto volume as a percentage of HPMS volume; green corridors have low TAF percentages and are primarily composed of short-distance trips, and magenta corridors have high TAF percentages and are primarily composed of LDTs. This map suggests that the majority of Interstate traffic in the Southwest consists of long distance (i.e., >100 miles) driving trips, whereas LDTs represent less than 20% of total traffic volume in most of the eastern half of the country. The fact that TAF-derived Interstate volumes are a fraction of HPMS-estimated volumes helps to establish confidence that the corridor volumes derived from TAF are within a reasonable range.

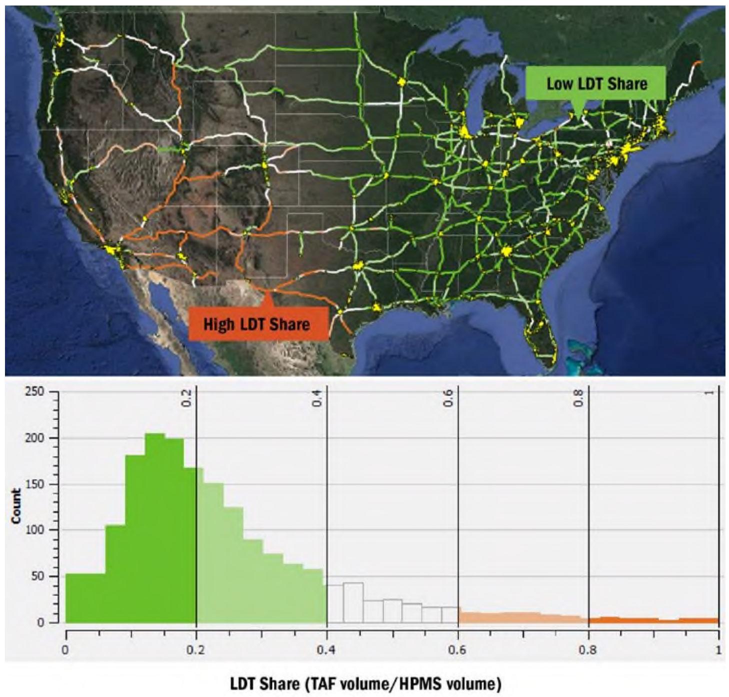

Figure 25. Comparison of TAF and HPMS volumes (color scale proportional to TAF:HPMS ratio).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

4.1.3 Station Spacing

Another important consideration for planning effective DCFC networks is the spacing between two consecutive DCFC stations, here estimated based on the effective BEV range. Although the U.S. Environmental Protection Agency-rated range (Fueleconomy.gov 2017) provides a good estimate of vehicle ranges under typical driving conditions, the effective range often varies based on ambient and road conditions as well as driving style (Lohse-Busch et al. 2013, Neubauer and Wood, 2013). Moreover, battery capacity tends to slowly degrade over time, negatively affecting the real driving range of BEVs (Shirk and Wishart 2015, Neubauer and Wood 2015). In addition to technical considerations limiting the effective range of BEVs, consumer travel logistics and convenience play a significant role in how far a BEV driver is willing to drive on a single charge. Drivers are typically reluctant to wait until their battery is completely drained before recharging, resulting in an "arrival allowance." Moreover, the rate of charge at DCFC stations tends to decrease toward high battery state-of-charge levels owing to battery safety considerations, and consumers are likely to depart a DCFC station before a BEV battery is fully charged to reduce their time spent charging, resulting in an "early departure penalty." To capture these behavioral effects, it is assumed that under realistic conditions a BEV will be recharged with an arrival allowance of 30 miles of remaining range, and it will depart the DCFC station early with only 80% of charge. Figure 26 summarizes the factors determining the effective BEV range considered in this study.

Three scenarios are proposed for nominal station spacing (100, 70, and 40 miles), providing various levels of support for longer- and shorter-range BEVs. These station spacing scenarios are believed to cover the range of nominal station spacing ranges being pursued by industry. Electrify America has announced an average station spacing of 70 miles for its DCFC corridor network (Electrify America 2017). This spacing is almost identical to the Tesla supercharger network; nearest-neighbor analysis was performed on the Tesla Supercharger station locations publically available in the Alternative Fuels Data Center data set (DOE 2017b), revealing an average Tesla station spacing of 67 miles. Additionally, Navigant Research proposes two station spacing scenarios in its *DC Charging Map for the United States*: 130 miles for long-range BEVs, and 75 miles to also support short-range BEVs (Navigant Research 2016).

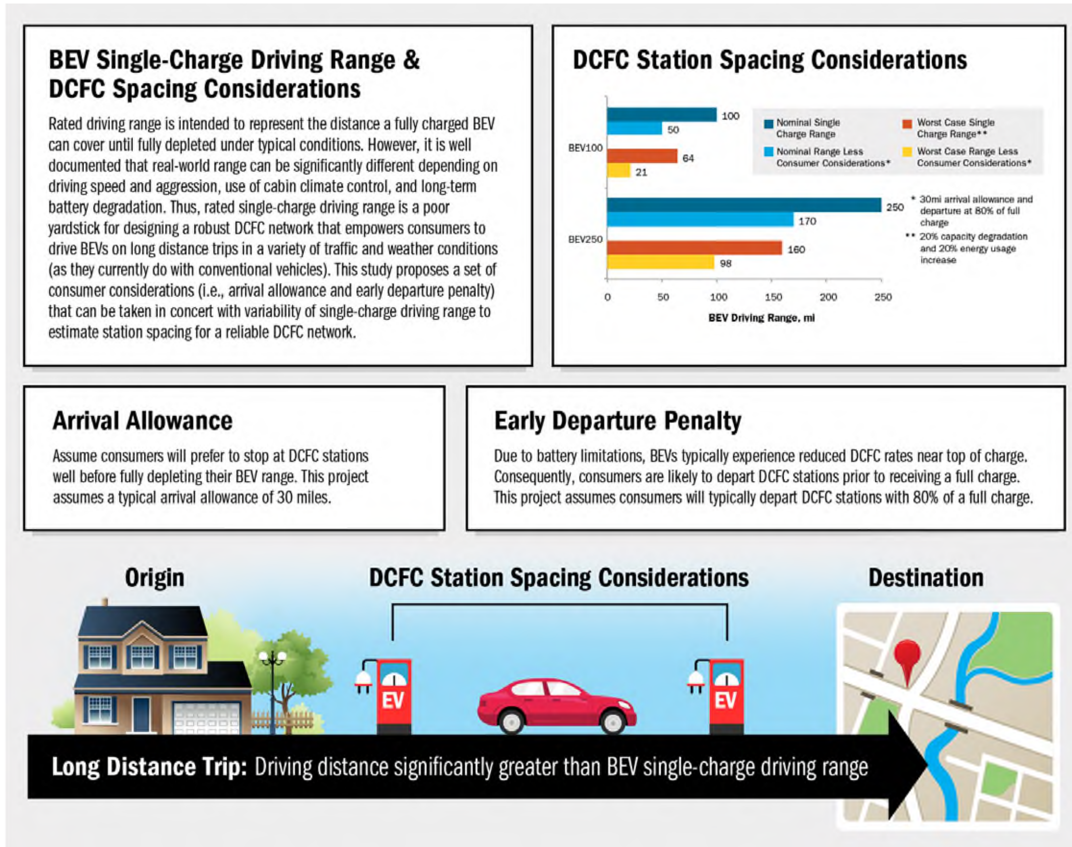

Figure 26. Station spacing methodology proposed in this study.

4.2 DCFC Interstate Corridor Demand Calculations

The number of stations required to cover the proposed U.S. corridor network has been determined for a variety of coverage and station spacing scenarios. The utilization of these stations, however, will vary significantly depending on their location and on the size of the regional and national PEV markets. This section estimates the number of plugs required at each station to adequately respond to corridor charging demand as the PEV market evolves over time.

Plug count per station estimates are calculated for each corridor station as a function of DCFC charging time, BEV adoption level, peak traffic volume, and station spacing. This model assumes that faster DCFC charging times will decrease plug count requirements (faster vehicle turnover), that high peak traffic volumes from BEVs on long distance trips will increase plug count requirements (more vehicles to serve at individual stations), and that decreasing station spacing will decrease plug count requirements per station (allowing consumers to occasionally skip stations while on long distance trips).

4.2.1 DCFC Power Level

Extreme fast charging, with power levels from 120 kW up to 400 kW, has gained significant interest in recent years. These very high charge rates could provide 200 miles of range in 20 minutes for a 150-kW charger and under 10 minutes for a 400-kW charger, making BEVs more attractive to customers. The Tesla supercharger network currently provides up to 120 kW of power, while most other installed DCFC stations are currently rated at 50 kW.

Higher DCFC power levels are modeled as lowering the number of plugs per station required to support long-distance travel in BEVs: faster turnover of vehicles warrants less redundancy in terms of plugs per station. This report considers 150 kW per plug DCFC power levels providing a 20-minute charge to a BEV250 in the central scenario, with sensitivities explored between 10 and 30 minutes per fast charge event. Additionally, assumptions from Section 0 are carried over, namely that BEVs would on average arrive with 30 miles of range remaining and depart with 80% of a full charge.

4.2.2 TAF Volumes

Annualized estimates of LDT volume were developed for each segment of the corridor network using TAF projections (interpolated between 2008 and 2040 to represent 2030 long distance traffic volumes). Person-trips were converted to vehicle-trips using an average occupancy factor of 3.0, in accordance with the TAF documentation (FHWA 2013); note that the estimated occupancy factor on long-distance auto trips is significantly higher than urban occupancy factors, which include large shares of single-occupancy vehicles.

FHWA's Traffic Monitoring Analysis System was used to estimate peak traffic ratios along Interstate corridors (FHWA 2017b). To estimate charging requirements for DCFC stations along corridors, the ratio between peak and average traffic volume was calculated for interstate corridor traffic count stations in California; California represents the largest PEV market, and results have been spot checked against other states for representativeness.

The peak hourly volume at the average Interstate corridor traffic count station in California was found to be 4.5 times greater than the annual average volume. Sizing for peak traffic using this factor would imply near elimination of queueing and potentially oversize the system. As such, a 90^{th} percentile value traffic volume was found to be 2.3 times greater than the annual average volume. The peak factor of 2.3 is used in this work.

4.2.3 Results and Discussion

Plug requirements from individual corridors are aggregated to obtain an average number of plugs per DCFC station as a function of station spacing and projected BEV adoption. Figure 27 presents these aggregate results for three market adoption scenarios. They range from two plugs per station at a station spacing of 40 miles and a BEV adoption of 4 million to 12 plugs per station at a station spacing of 100 miles and a BEV adoption of 10 million. Six plugs per station are required for the central values of 70-mile spacing and 7 million BEVs. For comparison, Electrify America's plans include five plugs per station with an average station spacing of 70 miles to support a BEV market of up to 10 million vehicles in 2030. Tesla's existing proprietary network features an average of seven plugs per station and a spacing of 67 miles on average.

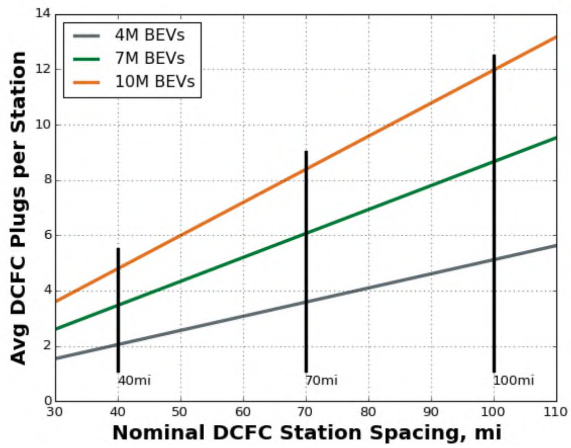

Figure 27. Nationwide corridor DCFC station count versus station spacing, annual average volume.

Plug requirements at individual stations vary based on the long-distance travel associated with a given corridor. Figure 28 illustrates this variance using the central scenario as an illustrative example (full interstate coverage, 7 million BEVs, and 70 mile average station spacing). The majority of hypothetical DCFC stations are located on lower-traffic corridors for coverage purposes, some featuring plug requirements that are only 10% of the average station's requirements (average station requiring 6 plugs to meet peak demand). Conversely, a minority of stations on very high traffic corridors are expected to require up to 450% as many plugs as the average station to adequately serve charging demand.

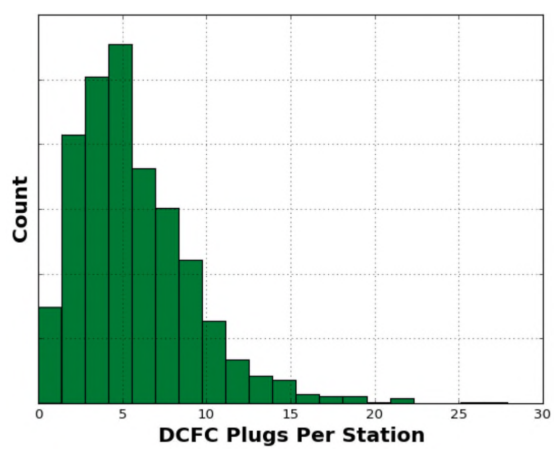

Figure 28. Plug requirement variance between stations.

Figure 29 puts the results in terms of total station counts and plug counts, and it shows the sensitivity of these counts to the corridor network selected, station spacing, BEV count, and charge time. The station counts chart (at left) illustrates the corridor coverage results from Table 9; because coverage requirements are independent of vehicle penetration, BEV count and charge time have no effect on them. In the plug counts chart (at right), the "network" bar multiplies the plugs per station results from Figure 27 by the mega-region, TAF, and full Interstate scenarios' coverage requirements from Table 9. Assuming an average station spacing of 70 miles and 7 million BEVs, 822 plugs are required in the mega-region scenario, 1,494 in the TAF scenario, and 2,448 in the full Interstate scenario. The full Interstate network is used to explore the remaining sensitivities. National corridor DCFC station estimates range from 285 to 713 for average spacing values from 100 to 40 miles. Notably, national corridor DCFC plug count estimates show no sensitivity to average station spacing between 40 and 100 miles. While both station counts and plugs per station are sensitive to station spacing, they are inversely related (implying conservation of aggregate national demand) and result in no sensitivity between average station spacing and national corridor DCFC plug count estimates. The effect of the number of BEVs results in plug counts ranging from about 1,461 at 4 million BEVs to 3,419 at 10 million BEVs, under the central network scenario (full Interstate). Finally, charge time sensitivity was explored from 10 to 30 minutes, resulting in national plug counts from 1,236 to 3,709.

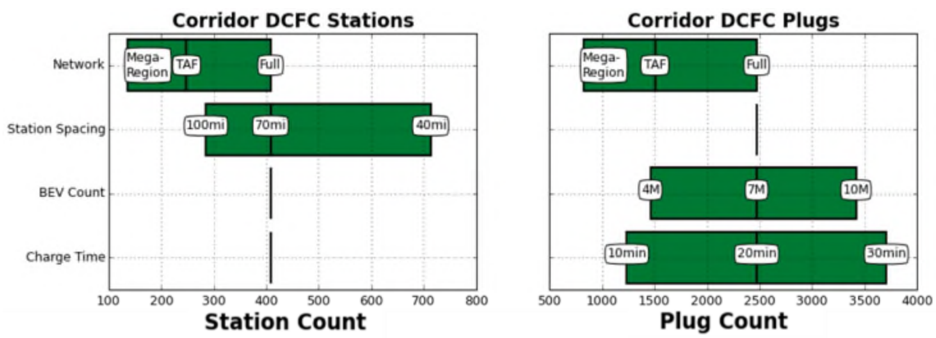

Figure 29. Sensitivity of corridor DCFC station and plug counts to network, station spacing, BEV count, and charge time.

4.3 Challenges to Interstate Corridor Charging Infrastructure

The development of a comprehensive network of corridor DCFC stations presents several challenges, primarily related to sustainable business models, to address the substantial costs associated with deploying and operating a network of DCFC stations (Francfort et al. 2017, Svitak et al. 2017, Melaina et al. 2016, Alternative Energy Systems Consulting 2015) as well as minimizing the impact on the electric grid. Although there appears to be sufficient generation capacity to electrify the U.S. LDV fleet (Denholm and Short 2006, Duvall et al. 2007), large-scale PEV adoption and charging station installations might affect the electric infrastructure in several ways. Some of the long-term impacts are reduction in transformer life expectancy, accelerated wear and tear of feeder networks, power quality considerations, and capacity upgrades at the substation level to handle the incremental charging demand (Green et al. 2011). At the same time, the network of stations could represent a business opportunity for the electric industry, and smart charging could be used to optimize power demand in demand response programs where the DCFC stations vary the timing of their demand to reduce requirements on the electric power generation infrastructure (Muratori and Rizzoni 2016).

Moreover, two geographic challenges are associated with the development of a national network of DCFC stations: 1) availability of commercial land for siting DCFC stations, and 2) proximity of electric substations to the interstate corridor network. These are explored below in a limited geographic information system analysis.

4.3.1 Retail Land Use Availability

A publically available land use data set (Conservation Science Partners 2017) with a spatial resolution of 30 meters was used to identify all retail and commercial land parcels in the United States (Theobald 2014). A 1 km buffer on either side of the interstate corridor network served as a mask to clip the nationwide data set to the immediate vicinity of the highway network. The remaining adjacent retail land use polygons were then consolidated to generate potential candidate sites. The network distance between two potential consecutive sites was calculated by cutting the highway network into smaller segments linking candidate sites to each other, and measuring the length of resulting sub-segments.

Figure 30 shows the resulting national map with the Interstate network colored by the maximum spacing interval between consecutive parcels of commercial land use. Overall, it appears that the frequency of retail sites along the Interstate highway network would not be a significant obstacle to the installation of a national DCFC network along Interstate corridors. The average distance between consecutive parcels of commercial land use was 5.4 miles, and across the entire network of Interstate corridors only 0.8% features intervals between consecutive commercial land use types of over 50 miles.

Figure 30. Distance between consecutive candidate retail sites.
(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

4.3.2 Existing Electrical Infrastructure: Proximity between Interstate Exits and Electrical Substations

In order to minimize the capital cost associated with corridor DCFC station installations, it is desirable to locate DCFC stations close to existing electrical substations. A spatial analysis was performed to combine an electrical substation data set to Interstate exits to measure relative proximity between the two. The substation data were extracted from ABB Energy Velocity Suite, ©2017. Results indicate the median distance between a highway exit and the closest electrical substation is 2.2 miles, while the average distance is 2.9 miles. Out of the 11,710 Interstate exits along the entire corridor highway network, only 3% are farther than 10 miles from the nearest electrical substation, 16% farther than 5 miles, and 35% farther than 3 miles. The map in Figure 31 shows that the majority of exits with poor proximity to electrical substations are located in the western part of the United States. Overall, it appears that the frequency of retail sites along the interstate highway network would not be a significant obstacle to the installation of a national DCFC network along interstate corridors.

Figure 31. Highway exits color-coded by distance to the nearest electrical substation.
(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

4.4 Corridor Charging Support from Community-Based DCFC

As described above, the U.S. Interstate System provides a basis for DCFC infrastructure that can efficiently satisfy long-distance driving demands in the near term. The Interstate System is not, however, entirely isolated from community-based DCFC infrastructure. Although full community-based infrastructure may take longer to establish, it could provide travel corridors with charging backup options, route flexibility, and additional coverage along U.S. highways and state routes. Figure 34 shows the national DCFC station coverage enabled by providing the level of community-based charging station coverage quantified in Section 3. Each covered city and town has a 70-mile radius buffer around it, approximating station coverage.

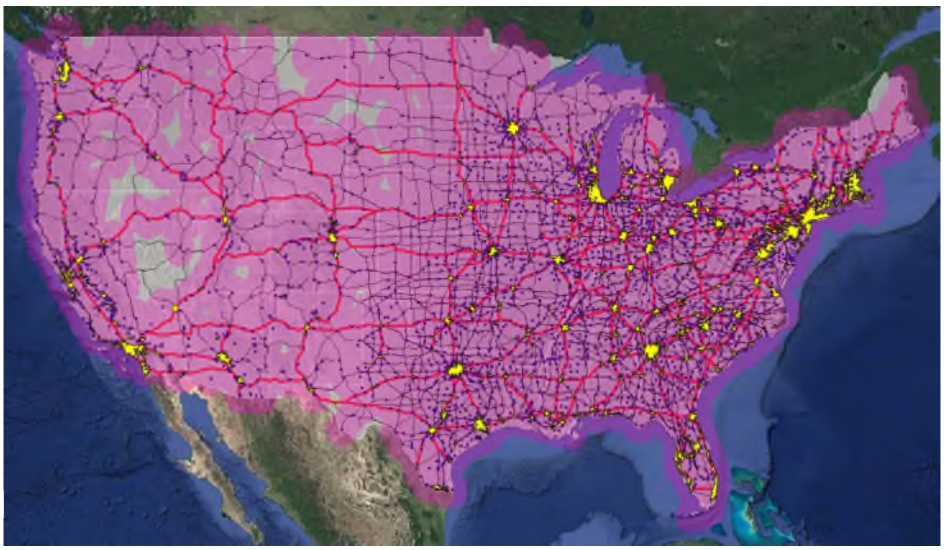

Figure 32. National charging station coverage enabled by providing minimum DCFC station coverage (70-mile buffers placed around all cities and towns).

(Satellite imagery credit: © 2017 Google, Map Data © 2017 Tele Atlas)

5 Conclusions

An analytic process for estimating national PEV non-residential charging requirements within communities and along Interstate corridors has been presented. Scenario analysis was conducted to illustrate EVSE requirements for a range of potential PEV markets. The analysis makes no assumptions regarding which PEV market scenarios are more or less likely. Rather, a range of plausible PEV markets with unique features is developed to explore the relationship between the evolution of the PEV fleet and charging infrastructure requirements.

5.1 Major Conclusions

To facilitate understanding, this report separates PEV charging infrastructure requirements by area served (cities, towns, rural areas, and Interstate corridors) and role during the PEV market growth trajectory (providing coverage to early PEVs versus satisfying demand due to high PEV penetration).

Cities are expected to have the greatest charging infrastructure requirements under both the coverage and demand assessments. About 8,000 DCFC stations would be required to provide a minimum level of coverage nationwide in cities and towns (based on uniform station spacing assuming BEVs are never more than 3 miles from a charging station). Such a network would provide consumer support for long-distance intra-city travel, serve as a safety net for emergency charging situations, and dampen range anxiety concerns.

Demand analysis of community charging demonstrates how utilization of the DCFC coverage network would be expected to grow in a high PEV penetration market. Modeled results for a 15-million PEV market estimate a DCFC plug requirement of 25,000 in U.S. communities (approximately 3.1 plugs per average DCFC station and 3.4 plugs required to support 1,000 BEVs under a home-dominant charging assumption). Demand for non-residential L2 EVSE (including work and public charging) is estimated at 600,000 plugs necessary to support 15 million PEVs (approximately 40 plugs per 1,000 PEVs).

Sensitivity analysis of the community results for consumer charging demand indicates a strong relationship between the evolution of the PEV and EVSE markets. As this analysis attempts to arrive at charging infrastructure solutions that fill the eVMT gaps between consumer travel patterns and PEV electric ranges, infrastructure requirements are not only proportional to the total number of PEVs in the system, but also inversely proportional to the electric range characteristics of these PEVs. Manufacturer and consumer preferences with respect to electric range, charging power, and utilization of residential EVSE have direct and dramatic consequences on the level of charging demand calculated in this study.

Results suggest that relatively few corridor DCFC stations could enable long-distance BEV travel between U.S. cities, where vehicles are concentrated. Under most scenarios, the number of required stations is similar to the number of corridor DCFC stations already established by Tesla or the number planned by Electrify America within the next two years.

Understanding driving patterns and vehicle characteristics and then prioritizing corridors and setting station spacing accordingly—as illustrated in the network scenarios—could help optimize the utility and economics of early-market corridor-coverage stations. The analysis identifies the majority of consumer long-distance automobile travel as being regional rather than truly cross-country, which emphasizes the importance of multi-state DCFC corridor planning (such as the West Coast Electric Highway, corridor planning across Colorado/Utah/Nevada, and the I-95 Fast-Charge ARC led by Nissan and EVgo).

Despite the relatively low number of corridor DCFC stations estimated by this analysis, establishing the financial viability of these stations will be difficult, particularly in the face of low initial utilization and high capital/operating costs. Requirements for the average DCFC complex necessary to support peak traffic volume for 7 million BEVs is estimated at six plugs per station (assuming 70-mile station spacing). Given a national BEV stock of approximately 250,000 through the end of 2016, this implies that the average corridor DCFC station should expect relatively low levels of utilization as the PEV market continues to mature. Utilization expectations for corridor DCFC stations are further tempered when considering the current segmentation of DCFC protocols (Tesla, CHAdeMO, and SAE CCS).

Regardless of geographic scope, organizations planning for charging infrastructure to support consumer adoption of PEVs should be aware of the importance of consumer preferences with respect to electric range and charging behavior. Furthermore, planners are encouraged to focus efforts on providing consumers with adequate charging coverage (particularly DCFC supporting adoption of BEVs) with the expectation to monitor station utilization and grow charging capacity (both in terms of rated power and number of plugs) as the PEV market continues to grow over time.

5.2 Summary of Modeling Limitations

One of the fundamental assumptions of this study is that consumers will attempt to operate their PEVs in the future as they have operated their conventional gasoline vehicles in the past. This assumption places the burden on PEVs that they are able to serve as 1-to-1 replacements for gasoline vehicles in a given consumer's household fleet of vehicles. In the real world, it is uncertain if consumers will hold PEVs up to this requirement. For instance, National Household Travel Survey (NHTS) data suggest that over 80% of consumer vehicles are owned by multi-vehicle households. Such ownership circumstances may result in corridor charging demand below what is estimated in this analysis as the household gasoline vehicle could be perceived as the more convenient option for long distance travel (based on refueling time, infrastructure availability, or attributes unrelated to driving range).

Similarly, the baseline travel data used to calibrate EVSE estimates in this analysis assume consistent personal mobility patterns out to 2030. In reality, the world of personal mobility is poised to undergo a paradigm shift as the sophistication and adoption of automated driving technology continues to grow. Interactions between evolving mobility patterns and refueling infrastructure supporting advanced technology vehicles are currently being investigated by the consortium of national laboratories participating in the DOE's SMART Mobility Initiative (DOE 2017c).

The EVI-Pro model used in this analysis assumes charging infrastructure must be sufficient to enable any consumer to maximize eVMT in any PEV. In reality, some degree of consumer self-selection in the new and used PEV markets is likely to reduce the need for non-residential charging as households right-size PEV purchases to meet the daily driving needs of their individual household. While the extent to which consumers are able to successfully right-size PEV purchases is largely unknown, its effect would reduce infrastructure requirements relative to estimates made in this analysis.

EVI-Pro's fundamental objective of maximizing consumer eVMT enforces no minimum utilization criteria on individual charging stations, likely resulting in a percentage of stations with insufficient revenue potential. Incremental eVMT benefits and utilization of individual stations have been explored in regional simulation studies (Wood et al. 2015a, 2015b, 2017). Detailed financial analysis of the national EVSE networks explored in this study remains an ongoing area of research.

This study is intentionally vague with respect to the percentage of PEVs adopted by residents of MUDs. Inconsistent access to home charging for residents of MUDs is often cited as an infrastructure barrier to increased PEV adoption. Yet even at 15 million PEVs nationally (5% of LDV stock), this analysis is well below the threshold where MUD residents would be required to participate in the PEV market. As such, no distinction is made for MUD residents in this analysis, but sensitivities are explored for portions of PEV owners who adopt non-home-dominant charging behaviors.

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Appendix A: Supplementary Statistics on Existing EVSE

Table A-1 summarizes the number of public EVSE by network, in terms of plugs. Table A-2 summarizes the number of public DCFC plugs and stations by network.

Table A-1. Public Charging Plugs by Network (DOE 2017b)

Network	L1	L2	DCFC	Totals
ChargePoint Network	1,659	17,345	511	19,515
Not Identified	1,772	11,023	542	13,337
Tesla	14	3,935	2,478	6,427
Blink Network	0	3,997	209	4,206
EVgo Network	0	423	1,629	2,052
SemaCharge Network	0	2001	0	2,001
Greenlots	106	394	402	902
GE WattStation	0	640	0	640
OpConnect	104	384	32	520
AeroVironment Network	0	60	56	116
EV Connect	0	72	2	74

Table A-2. Public DCFC Plugs and Stations by Network (DOE 2017b)

Network	DCFC Plugs	DCFC Stations
Tesla	2,478	357
EVgo Network	1,629	701
Not Identified	542	418
ChargePoint Network	511	295
Greenlots	402	209
Blink Network	209	111
AeroVironment Network	56	56
OpConnect	32	16
EV Connect	2	1

Appendix B: EVSE/PEV Adjustment Factors to Account for Local Conditions

The nominal set of EVSE/PEV ratios is adjusted to account for the unique characteristics of all geographies based on population density, PEV concentration, and ambient temperature.

As population density increases in a region, the average VMT per vehicle decreases, and thus less EVSE capacity is required. Daily VMT data from the 2009 NHTS are used to quantify this relationship and develop a population density adjustment factor. Figure B-1 shows the daily VMT cumulative distribution functions by population density. Median VMT ranges from 14 miles per day in the most densely populated areas to 31 miles per day in the most sparsely populated areas. The INRIX travel data are resampled to mimic the NHTS daily VMT distributions (Figure B-2). For example, for each U.S. urban area with 2,000–3,999 people per square mile, the INRIX data are sampled so that vehicles modeled have the same VMT distribution as NHTS vehicles from the 2,000–3,999 density bin (see Figure B-1), and so forth. EVI-Pro computed the EVSE/PEV ratio for each population density distribution from the resampled INRIX data to generate the adjustment factor shown in Figure B-3.

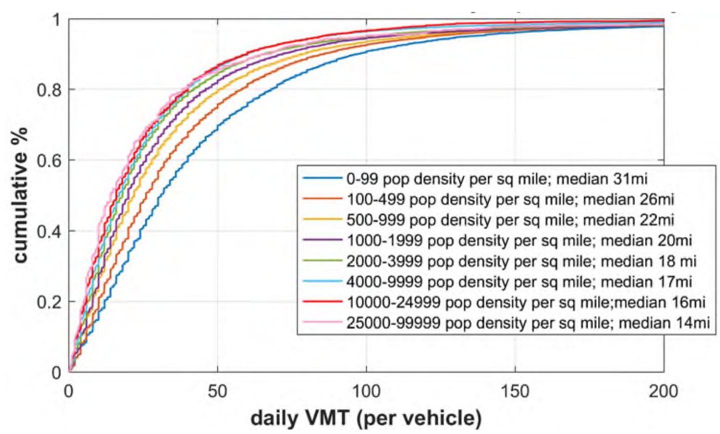

Figure B-1. Daily VMT cumulative distribution functions by population density, from the 2009 NHTS.

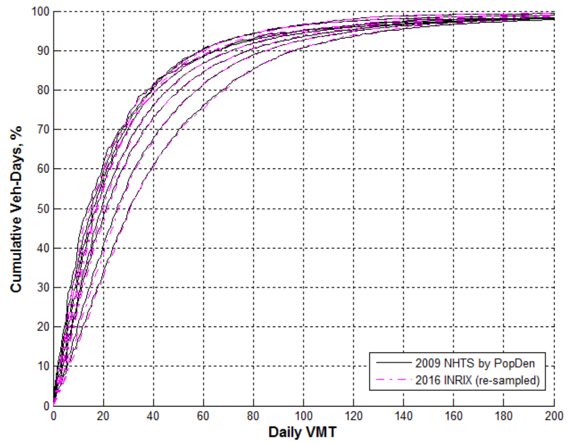

Figure B-2. Mimicking NHTS daily VMT cumulative distribution functions by population density by resampling INRIX travel data.

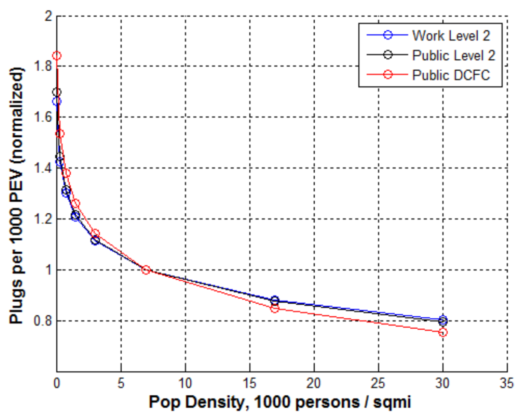

Figure B-3. Adjustment factor: non-residential EVSE/PEV ratio as a function of population density.

Similarly, an adjustment factor based on PEV concentration is generated by running EVI-Pro simulations at various PEV concentrations. Plug requirements are lower at higher PEV concentrations (Figure B-4) due to the greater opportunity for efficient infrastructure sharing.

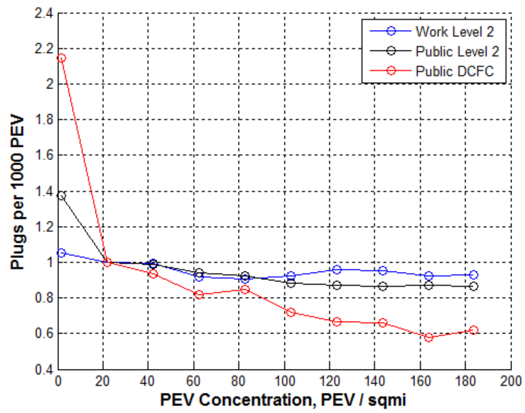

Figure B-4. Adjustment factor: non-residential EVSE/PEV ratio as a function of PEV concentration.

Ambient temperature affects battery charge and discharge rates, and the temperature adjustments applied account for both impacts. Using EVI-Pro, non-uniform discharge rates are applied to driving events depending on trip average speed and ambient temperature, based on the measured effects of temperature on Nissan Leafs (Yuksel and Michalek 2014) over simulated drive cycles (Neubauer and Wood 2013). Table B-1 shows the modeled relative battery discharge rates as a function of ambient temperature and trip average speed: very hot and very cold temperatures drain the battery more quickly at any speed. EVI-Pro also adjusts DCFC charge rates for battery temperature and charge duration, based on INL's testing of a Nissan Leaf (Figure B-5) (INL 2016). Again, temperature has a major impact, for example, reducing the 20-minute effective DCFC charge rate from over 80% of rated power at a battery temperature of 25°C to 50% of rated power at 0°C. These temperature relationships are applied across EVI-Pro simulations at multiple ambient temperatures to derive the temperature adjustment factor shown in Figure B-6.

Table B-1. EVI-Pro Driving Discharge Model: Relative Battery Discharge Rates as a Function of Ambient Temperature and Average Trip Speed

Trip Avg Speed, mph	Ambient Temperature, °C												
	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
2.5	203%	193%	186%	178%	167%	154%	141%	132%	129%	136%	153%	180%	213%
7.5	177%	168%	162%	155%	146%	135%	123%	115%	113%	119%	134%	157%	186%
12.5	163%	155%	149%	143%	134%	124%	114%	106%	104%	109%	123%	145%	171%
17.5	146%	139%	134%	128%	121%	111%	102%	95%	93%	98%	110%	130%	153%
22.5	135%	128%	123%	118%	111%	102%	94%	88%	86%	90%	102%	120%	141%
27.5	132%	125%	120%	115%	108%	100%	92%	85%	84%	88%	99%	117%	138%
32.5	135%	128%	123%	118%	111%	102%	94%	88%	86%	90%	102%	120%	141%
37.5	141%	134%	129%	124%	116%	107%	98%	92%	90%	94%	106%	125%	147%
42.5	147%	139%	134%	129%	121%	111%	102%	95%	93%	98%	111%	130%	154%
47.5	155%	147%	142%	136%	128%	118%	108%	101%	99%	104%	117%	138%	163%
52.5	164%	156%	150%	144%	135%	125%	114%	107%	104%	110%	124%	146%	172%
57.5	168%	159%	154%	147%	139%	128%	117%	109%	107%	113%	127%	149%	176%
62.5	182%	172%	166%	159%	150%	138%	126%	118%	115%	121%	137%	161%	190%

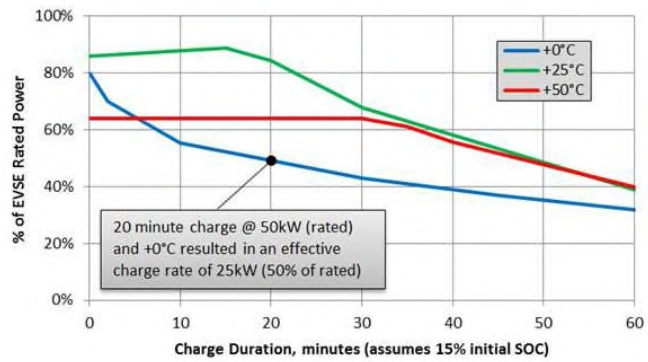

Figure B-5. EVI-Pro DCFC effective charge rate model: percentage of EVSE rated power delivered as a function of charge duration and battery temperature.

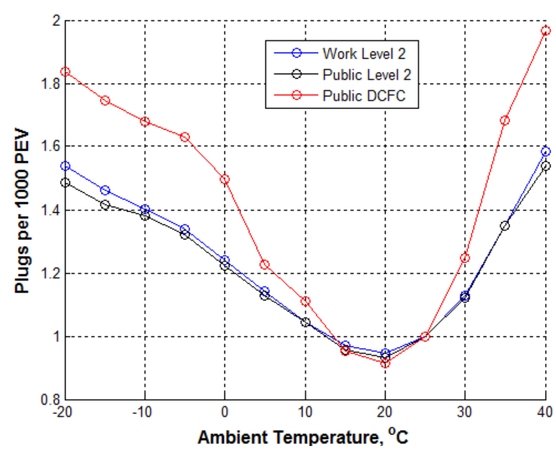

Figure B-6. Adjustment factor: non-residential EVSE/PEV ratio as a function of ambient temperature.

Appendix C: Central Scenario PEV/EVSE Estimates by State

State	Total PEVs	% BEV	Work L2 Plugs	Public L2 Plugs	Public DCFC Plugs
AK	18,000	35%	700	500	40
AL	111,000	41%	3,400	2,600	270
AR	68,000	33%	2,300	1,800	140
AZ	345,000	54%	8,200	5,500	720
CA	3,864,000	54%	73,800	44,600	4,380
CO	316,000	60%	6,700	4,500	670
CT	197,000	40%	5,700	3,600	330
DC	40,000	55%	800	500	40
DE	50,000	31%	1,500	1,100	60
FL	837,000	51%	19,800	12,900	1,550
GA	336,000	77%	5,800	4,000	1,020
HI	102,000	78%	1,400	800	240
IA	99,000	30%	3,500	2,500	170
ID	71,000	43%	2,100	1,600	170
IL	555,000	51%	13,600	8,700	880
IN	210,000	37%	6,700	4,700	410
KS	98,000	39%	2,900	2,000	160
KY	122,000	36%	3,900	2,800	230
LA	70,000	44%	2,000	1,600	170
MA	388,000	44%	10,200	6,400	610
MD	337,000	42%	8,700	5,400	430
ME	65,000	26%	2,700	2,000	110
MI	258,000	20%	9,700	6,700	290
MN	228,000	43%	6,600	4,500	370
MO	201,000	43%	5,900	4,100	370
MS	46,000	44%	1,400	1,100	130
MT	39,000	47%	1,200	1,000	130
NC	475,000	47%	12,900	8,900	1,020
ND	13,000	26%	500	400	20
NE	53,000	37%	1,700	1,100	100
NH	92,000	34%	3,200	2,200	170
NJ	335,000	48%	7,700	5,000	480
NM	89,000	42%	2,600	1,900	200
NV	114,000	60%	2,500	1,700	330
NY	607,000	35%	17,800	11,300	740
OH	393,000	38%	11,900	8,000	690
OK	97,000	45%	2,800	2,000	230
OR	305,000	65%	5,800	3,900	710
PA	470,000	39%	13,600	9,200	810

State	Total PEVs	% BEV	Work L2 Plugs	Public L2 Plugs	Public DCFC Plugs
RI	43,000	33%	1,300	800	70
SC	174,000	43%	5,000	3,500	400
SD	21,000	28%	800	600	40
TN	202,000	58%	5,000	3,600	590
TX	835,000	57%	18,300	12,400	1,720
UT	130,000	61%	2,800	1,900	340
VA	475,000	43%	12,700	8,100	690
VT	42,000	28%	1,700	1,300	70
WA	571,000	70%	10,200	6,600	1,370
WI	243,000	36%	7,800	5,500	450
WV	35,000	28%	1,300	1,000	60
WY	13,000	45%	400	300	40

Appendix D: Long-Distance Travel Frequency from the SHRP2 NDS

FHWA's second Strategic Highway Research Program's Naturalistic Driving Study (SHRP2 NDS) data set is used to evaluate LDT frequency. As a longitudinal safety study, SHRP2 NDS tracked 3,710 vehicles (exclusively non-PEVs, consisting mostly of conventional gasoline vehicles and a small number of HEVs) across six cities for up to 3 years to record crash, near-crash, and baseline driving events, resulting in data on approximately 5.4 million driving trips (Campbell 2012, Hallmark et al. 2013, Dingus et al. 2015). To estimate LDT frequency, the 3,352 vehicles that were tracked for at least one year or more were considered. Trip distances were aggregated on a daily basis using the unique vehicle ID provided in the data set. The resulting SHRP2 NDS sample was compared to the 2009 NHTS (FHWA 2017a) to assess its overall representativeness of driving in the United States. SHRP2 NDS shows a higher share of vehicles classified as "car" compared to the 2009 NHTS (71% in SHRP2 NDS versus 49% in the 2009 NHTS), and the average vehicle age across all classifications in the SHRP2 NDS data set is 10.84 years, whereas an average age of 9.33 years is reported in the 2009 NHTS. Figure D-1 and Figure D-2 compare daily and annual VMT distributions between the 2009 NHTS and the SHRP2 NDS. Daily VMT and long-distance driving patterns are mostly consistent between the two data sets; nearly 96% of SHRP2 NDS vehicle-days have VMT less than 100 miles, compared with 94% for the 2009 NHTS. However, a higher share of SHRP2 NDS vehicles had annualized VMT of 4,000 to 10,000 miles compared with vehicles from the 2009 NHTS.

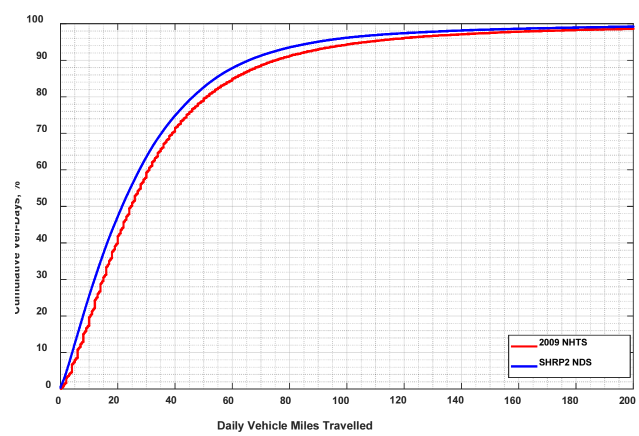

Figure D-1. Cumulative distribution of daily VMT in 2009 NHTS and SHRP2 NDS.

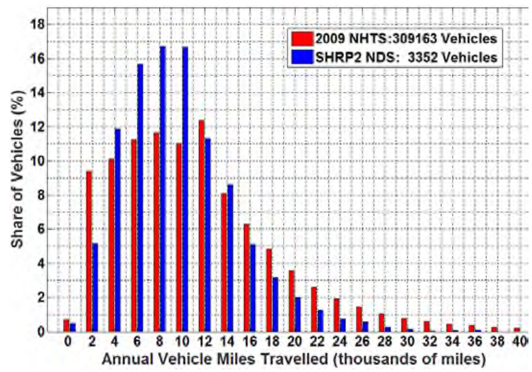

Figure D-2. Annual VMT distribution in 2009 NHTS and SHRP2 NDS.

Of the 3,352 vehicles in the SHRP2 NDS, 1,669 show a daily VMT of above 100 miles for at least 1 day during the tracked period. The average SHRP2 NDS vehicle traveled 100 miles or more 6 days/year (2 days/year for daily VMT greater than 200 miles and 1 day/year with daily VMT greater than 300 miles). These results imply that a large degree of heterogeneity exists between LDT frequencies in the SHRP2 NDS data set. On the one hand, 50% of the sample never drove more than 100 miles on any travel day, implying a potentially good match with short-range BEVs with approximately 100 miles of single-charge driving range. On the other hand, a large segment of the SHRP2 NDS vehicles exhibits long-distance travel days multiple times per month: travels that could only be accomplished in a BEV with a large single-charge driving range and DCFC support on corridors.

Longitudinal surveys, such as the SHRP2 NDS, are time consuming and expensive to administer. Instead, annual VMT is much easier to estimate using odometer readings from traditional single-day travel surveys (such as the 2009 NHTS), and can serve as a reasonable proxy for LDT frequency. Figure D-3 shows the correlation between annual VMT and LDT frequency. Vehicles with higher annual VMT have generally higher LDT frequency (days/year) for all daily distance thresholds selected (100, 200, and 300 miles).

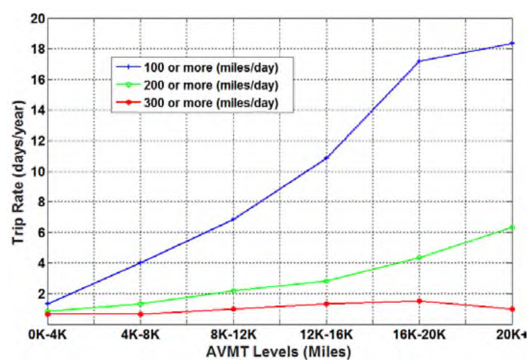

Figure D-3. Impact of annualized VMT (AVMT) on average long-distance travel frequency from SHRP2 NDS.

As mentioned previously, a significant degree of heterogeneity exists in driving data sets such as SHRP2 NDS. Figure D-4 reflects this fact by displaying percentile curves for frequency of LDT days with at least 200 miles of driving versus annual VMT (note that percentile curves below 60 are not shown as 50% of the sample exhibited no LDT). Taking the 70th percentile curve as an example, the data show that 70% of the SHRP2 NDS vehicles drove more than 200 miles on 3 or fewer days per year.

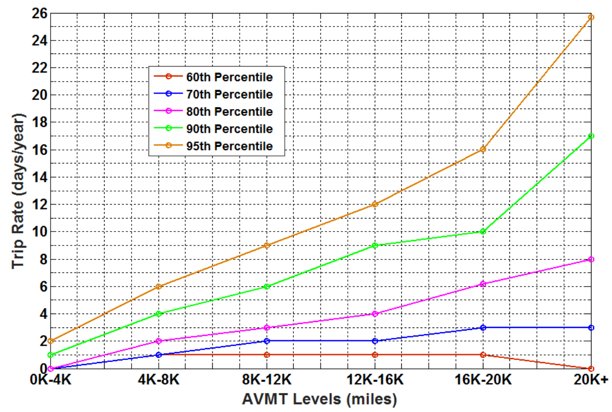

Figure D-4. Impact of annualized VMT (AVMT) on long-distance travel frequency from SHRP2 NDS (percentile bins, frequency of 200+ mile days).

Evidence from the SHRP2 NDS data set suggests that a large segment of drivers routinely use their existing conventional vehicles for long-distance travel (e.g., 50% of SHRP2 NDS vehicles drove more than 100 miles one day per month on average) and would presumably require long-distance single-charge ranges and DCFC support along corridors to consider adopting a BEV as a fully capable replacement for their existing vehicle. And even the remaining class of drivers that never makes a LDT over the course of a year might exhibit similar adoption requirements based on their perceived need for long-distance driving.

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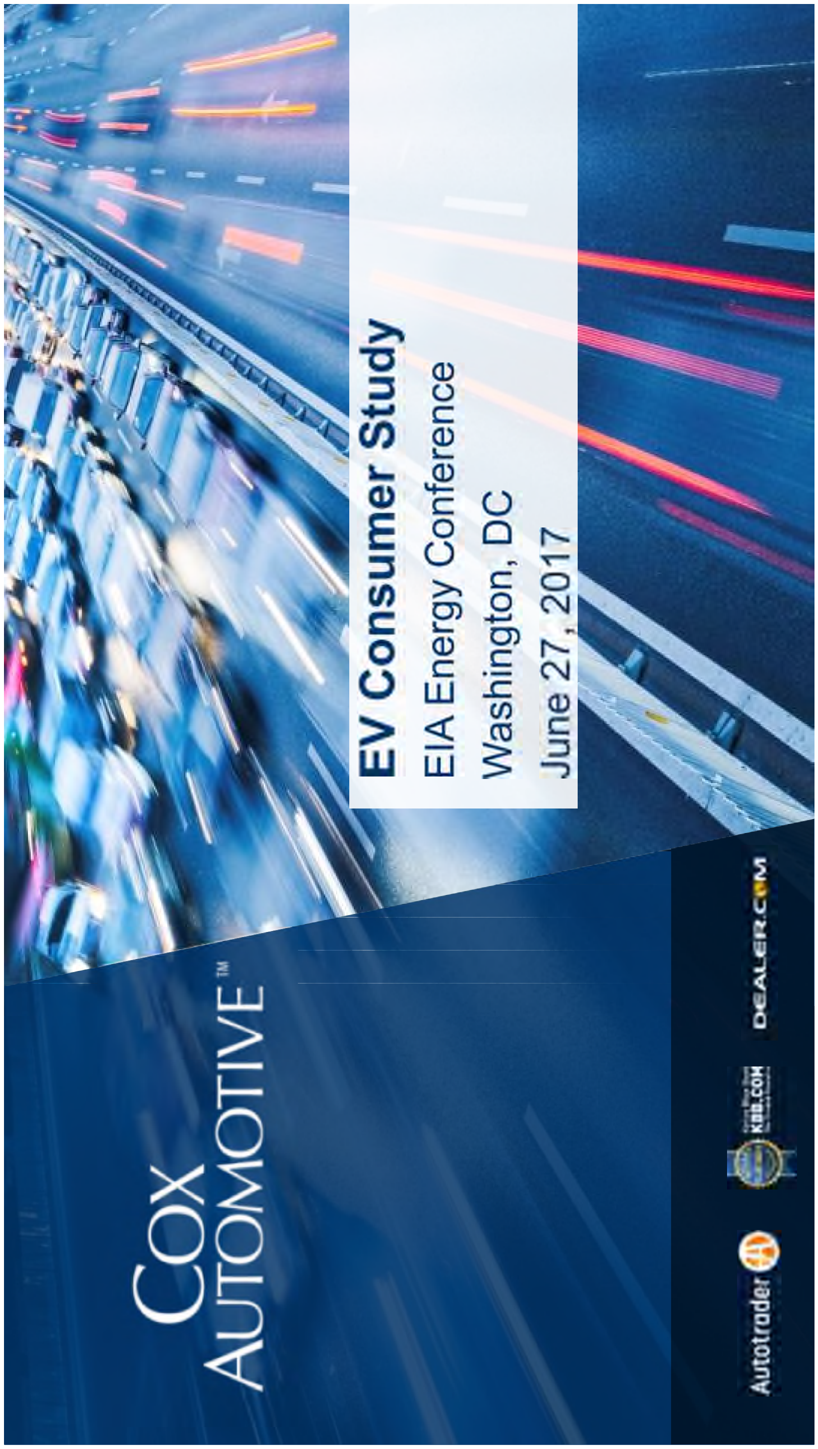
EV Consumer Study
EIA Energy Conference
Washington, DC
June 27, 2017
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WHO WE ARE
About Cox Automotive
Cox Automotive is a leading pr[redacted]r of products and services that span the automotive ecosystem worldwide.
Our goal is to simplify the trusted exchange of [redacted]s and maximize value for dealers, manufacturers and car shoppers.
We've built the industry's strongest family of more than 25 brands to provide industry-leading digital marketing, [redacted]re, financial, wholesale and e-commerce solutions to help our clients thrive in a rapidly changing automotive marketplace.
O[redacted]r Vision
Transform the way the [redacted]d buys, sells and owns [redacted]
33,000+ team members
40,000+ clients
MOST RECOGNIZED BRANDS
Autotrader & Kelley Blue Book
73% OF ALL CAR BUYERS
use Autotrader or KBB.com
2

WHO WE ARE

About Cox Automotive

Our client-obsessed culture breeds passionate, proactive people who ensure each client gets the right solution.

As a subsidiary of 116-year-old Cox Enterprises Inc., one of the world's largest privately owned communications, media and automotive services companies, innovation and leadership is in our DNA.

Our focus on building a better future for our clients, consumers and the industry is ingrained in everything we do, from responsible services and solutions development, to team member care and giving back to the communities where we live, work and play.

$50B+
vehicle values sold annually through Manheim

45M+
financed titles managed by Dealertrack

$4.2B+ IN LOANS TO 23,000+ DEALERS
NextGear Capital

3


OUR BRANDS
4
INVENTORY SOLUTIONS
Manheim
DEAL SHIELD Be Assured.
Ready Logistics
AiM
RMS AUTOMOTIVE
CentralDispatch
RETAIL SOLUTIONS
Dealertrack
vAuto LIVE MARKET VIEW
VinSolutions
xtime
HomeNet AUTOMOTIVE
MEDIA SOLUTIONS
Autotrader
Kelley Blue Book KBB.COM The Trusted Resource
DEALER.COM
FINANCIAL SOLUTIONS
NEXTGEAR CAPITAL
INTERNATIONAL
Manheim
MOTORS
NEXTGEAR CAPITAL
xtime
First Choice
incadea
Dealer Solutions
Modix
AUTOST
RMS
BitAuto 易车
精真估 JINGZHENGU
Dealer-Auction.com
MOLICAR

Survey Methodology

Survey Field Dates: 9/16/2016 – 9/30/2016

Goals:

- Understand the current value proposition of EVs
- Learn how to market EVs to multiple consumers: EV owners, EV considerers, and non-EV considerers
- Recognize the gap from consumers' expectations and current EV realities
- Learn what brands and models are successful in marketing EVs

Sampling Information:

- Mobile Survey: fielded to individuals visiting the KBB.com mobile websites
- Total of **6499** Respondents
- Sample representative of a geographically spread of the U.S.

- Other sources of information: U.S. Department of Energy, Vehicle Technology Office.

- Sources are listed in the slide footers


COX AUTOMOTIVE™
EV continues as a niche market
Autotrader
KBB.COM
DEALER.COM
6

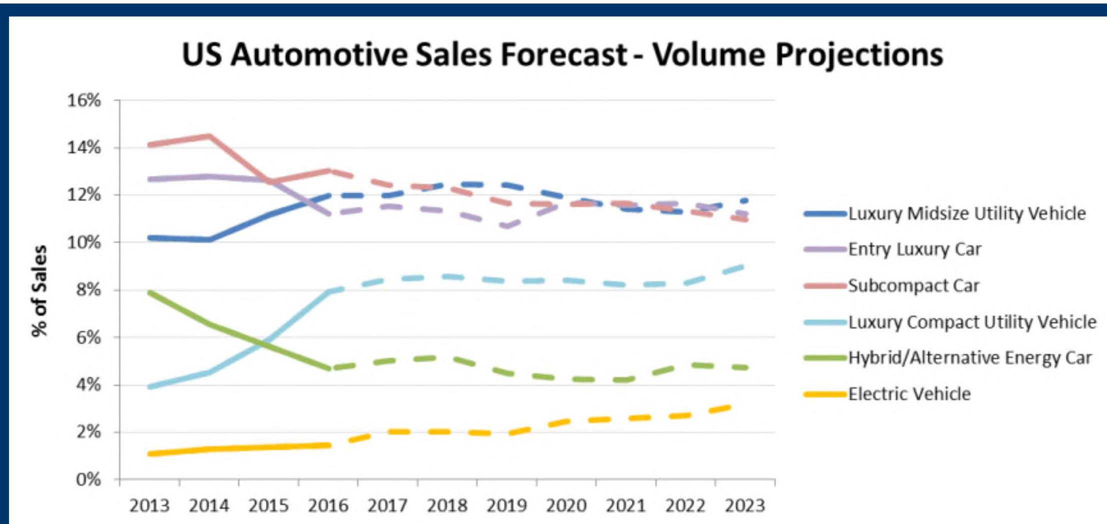
Consumers feel the road to mass EV ownership is long

7

COX AUTOMOTIVE

Kelley Blue Book EV Strategic Study, Sept. 2016
Q: In how many years would you expect Electric Vehicles to be as common on the road as non-electric vehicles? N = 2165

There's little indication consumer demand will increase even as new products emerge



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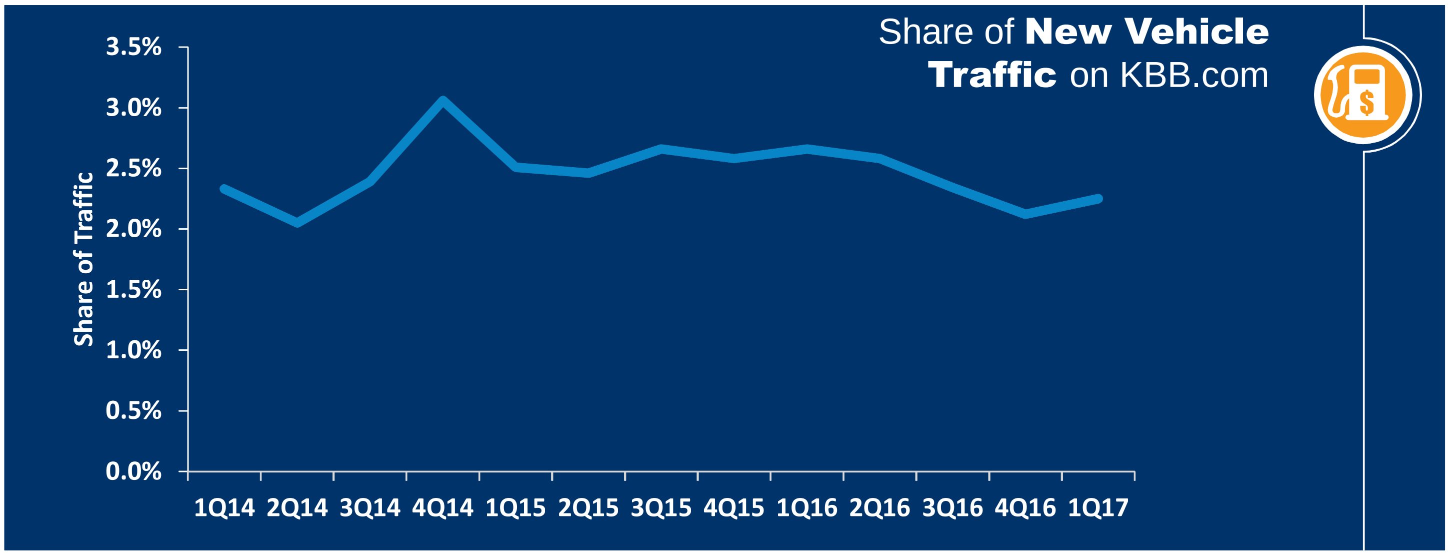
LMC Automotive US Automotive Sales Forecast, 2013Q1 – 2016Q4

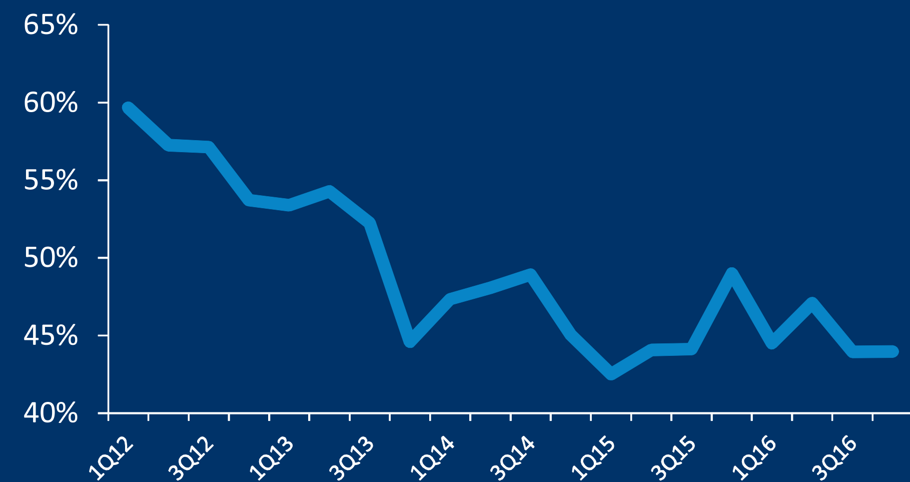
After declining through 2016, EV traffic increased slightly due to interest in Chevrolet Bolt



KBB.com Site Traffic

Fuel efficiency has declined in importance to consumers

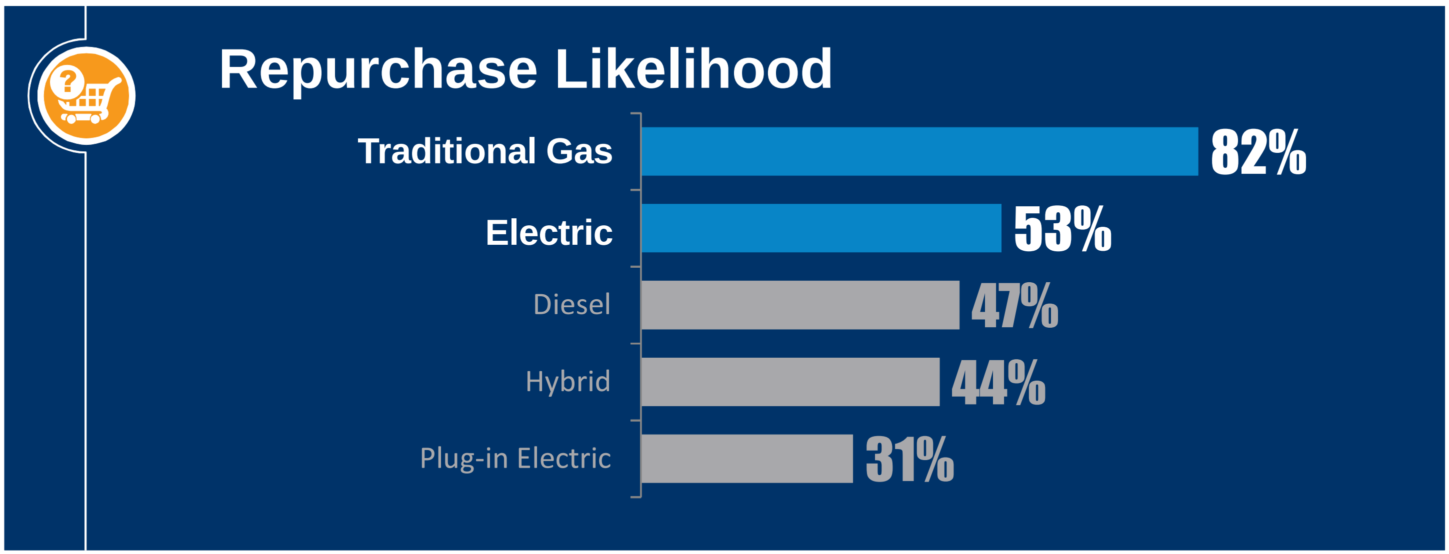
BrandWatch
Factor Importance
- Fuel Efficiency



COX AUTOMOTIVE

Kelley Blue Book BrandWatch, 2012Q1 – 2016Q3

More than half of current EV owners would buy again, but is that enough?



Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Do you currently own any of the following types of vehicles? (Please select all that apply) N = 6499
Q: Which of the following are you most likely to purchase/lease for your next vehicle? (Please select one response only) N = 5402

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How do consumers think about EVs?
Autotrader
KBB.COM
DEALER.COM
12

It's less about the environment and more about the economics

Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Which of these is the primary reason you feel people purchase electric vehicles? N = 2165
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165
Q: Do you currently own any of the following types of vehicles? (Select all that apply) N = 2165

Cox Automotive

After that, owners are driven by practical factors

PRACTICAL

- Lower maintenance
- Cheaper monthly payment/lease
- Receiving an HOV sticker

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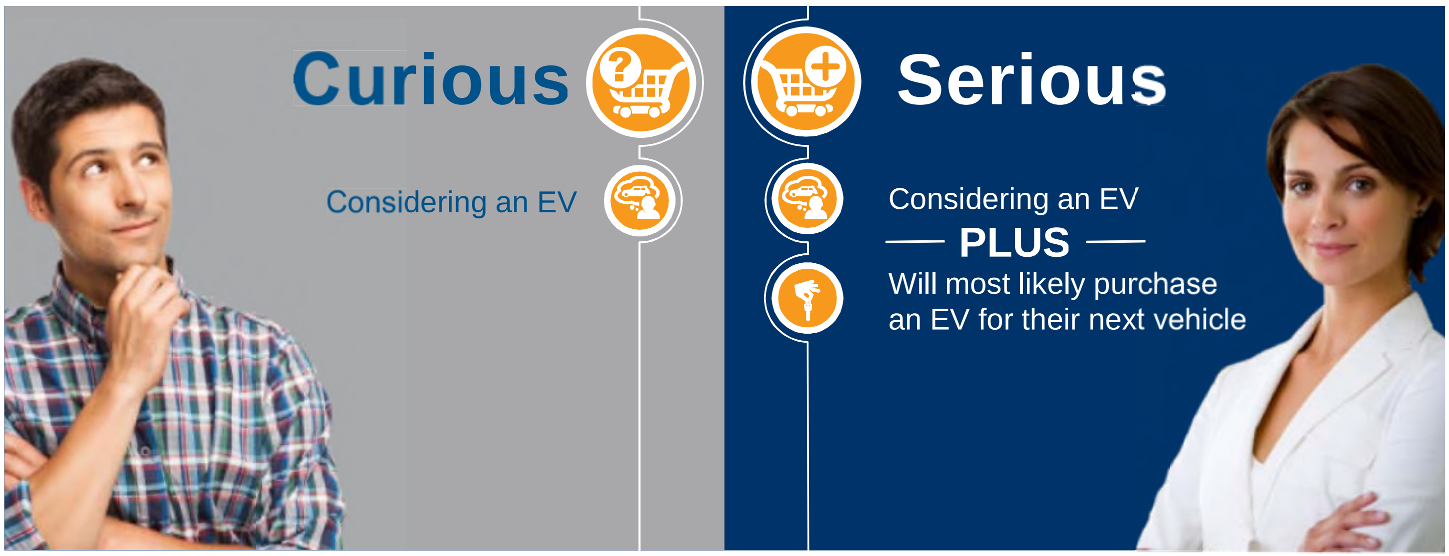
Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Which of these is the primary reason you feel people purchase electric vehicles? N = 2165
Q: Do you currently own any of the following types of vehicles? (Select all that apply) N = 2165

Consideration split into Curious vs. Serious



Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Which of these is the primary reason you feel people purchase electric vehicles? N = 2165
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165
Q: Which of the following are you most likely to purchase/lease for your next vehicle? N = 1713

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Serious considerers think more practically, like an owner

Kelley Blue Book EV Strategic Study, Sept. 2016

Q: Which of these is the primary reason you feel people purchase electric vehicles? N = 2165
Q: Which of these questions do you think would be top of mind for someone shopping for an electric vehicle? (Select 2) N = 2165
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165
Q: Which of the following are you most likely to purchase/lease for your next vehicle? N = 1713

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Mass market pricing could put EVs on more shoppers' radars

What it would take for non-EV considerers to think about purchasing EVs?

Affordable Pricing
52%

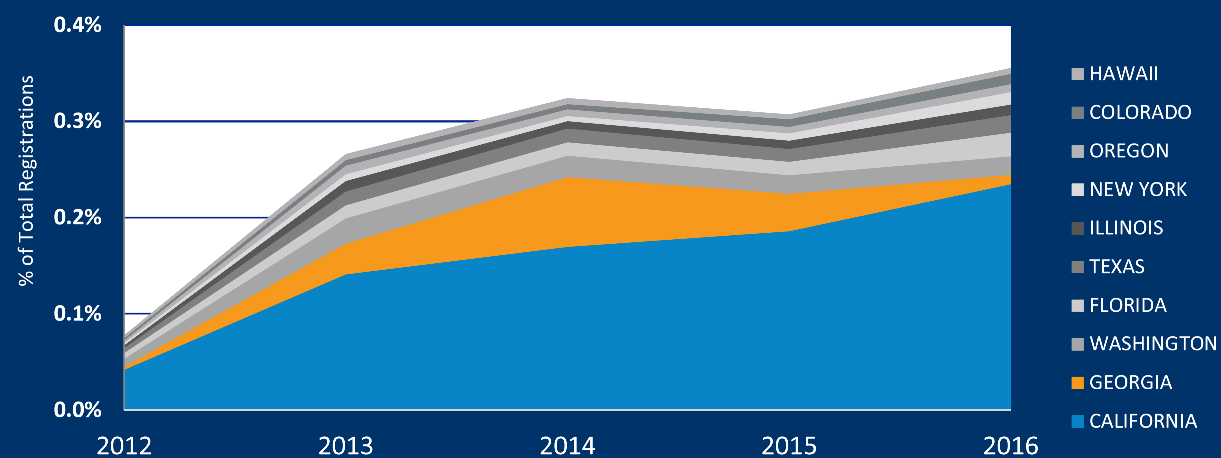
Longer Driving Range
37%

Improved Infrastructure
19%

COX AUTOMOTIVE

Kelley Blue Book EV Strategic Study, Sept. 2016
Q: What would it take for you to consider an Electric Vehicle? N = 1872, "Nothing would make me consider an electric vehicle" option removed

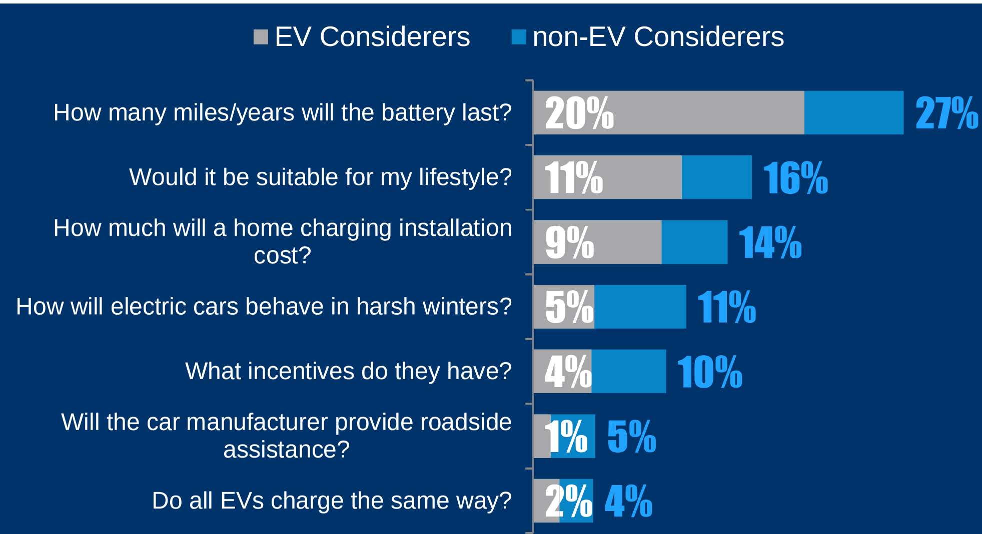
EV purchases dropped after Georgia's $5K Zero Emission Vehicle Tax Credit ended in 2015



Experian Automotive 2012 – 2016, New Vehicle Registration (Retail only) (chart)
Georgia Environmental Protection Division, https://epd.georgia.gov/air/alternative-fuels-and-tax-credits (Georgia Alternative Fuel Tax Credit)

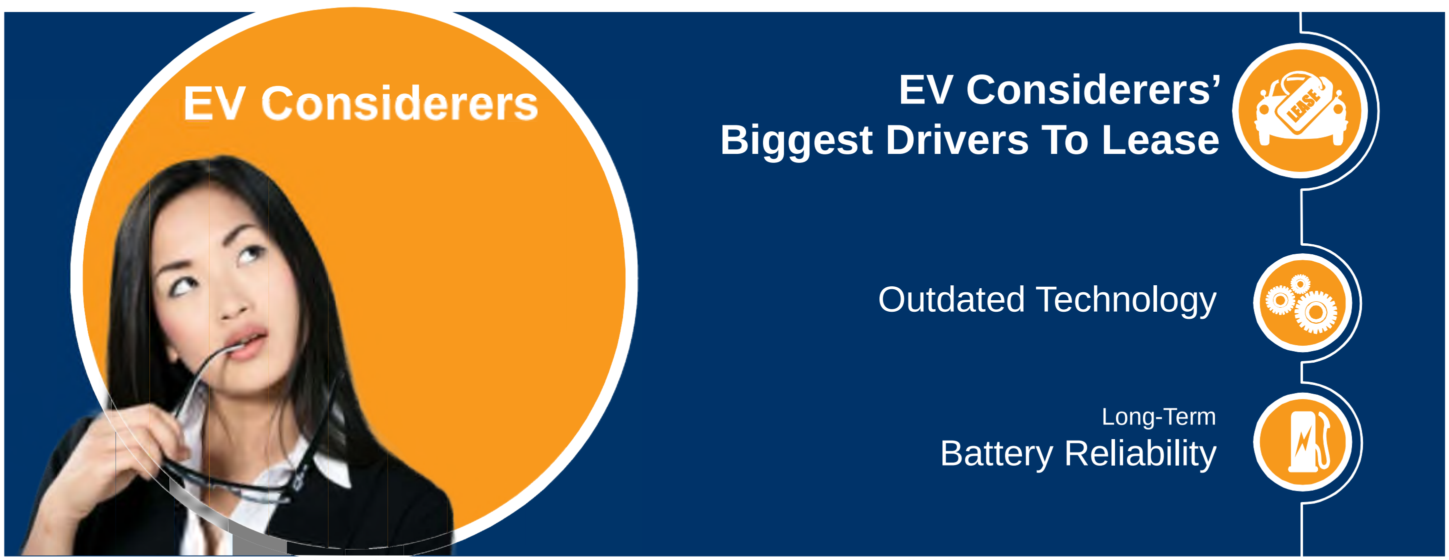
There are many concerns that keep people from considering EVs

Non-Considerers care more about these issues than Considerers



Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Which of these questions do you think would be top of mind for someone shopping for an electric vehicle? (Select 2) N = 2165
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165

EV considerers are concerned about obsolescence, so are more likely to lease



Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Are you more likely to buy or lease an Electric Vehicle? N = 293
Q: Why are you more likely to lease (vs buy)? N = 53
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165

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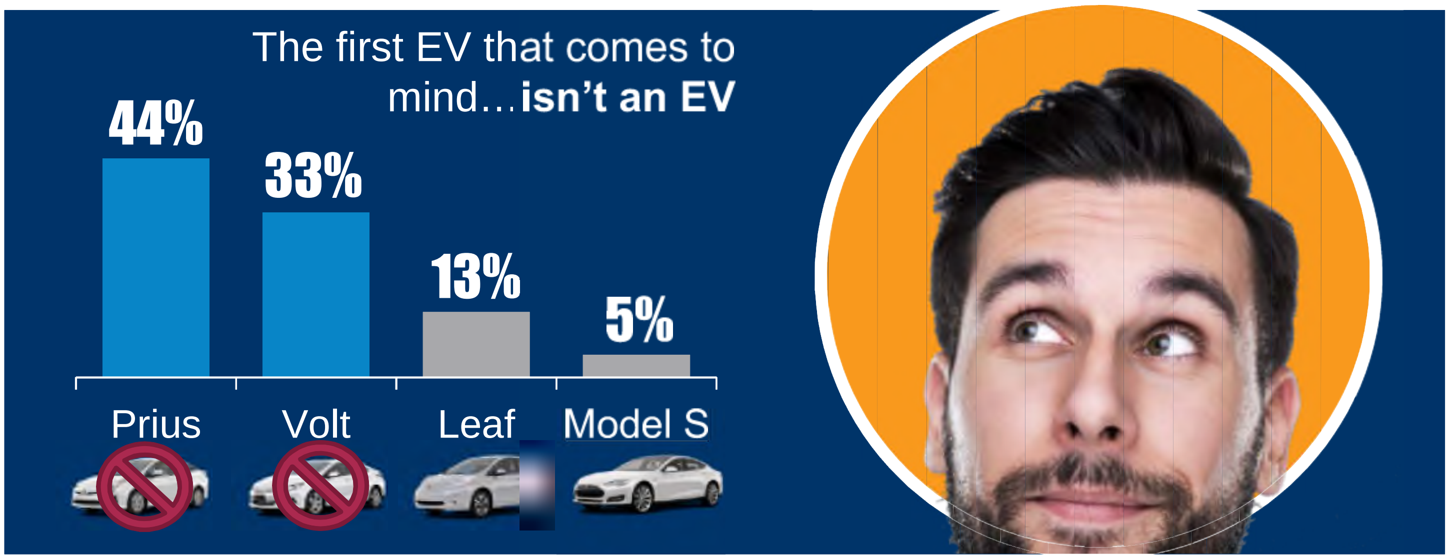
Autotrader KBB.COM DEALER.COM

21

Consumers have trouble distinguishing hybrids from EVs



Kelley Blue Book EV Strategic Study, Sept. 2016

Q: Name the first electric vehicle that comes to mind. (Free response) N = 2169

So it comes to no surprise that they aren't familiar with which brands have EVs in their product line-up

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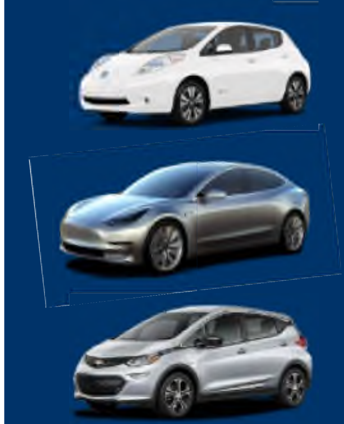
Kelley Blue Book EV Strategic Study, Sept. 2016
Q: Name the first electric vehicle that comes to mind. (Free response) N = 2169

Current range doesn't meet the average consumer's expectations, even for EV shoppers

Consumers are willing to spend an additional $5K for an increased range from 150 to 200 miles



107 mi

215 mi

238 mi

ACCEPTABLE

minimum driving range

EV Shoppers — **245-250 mi**

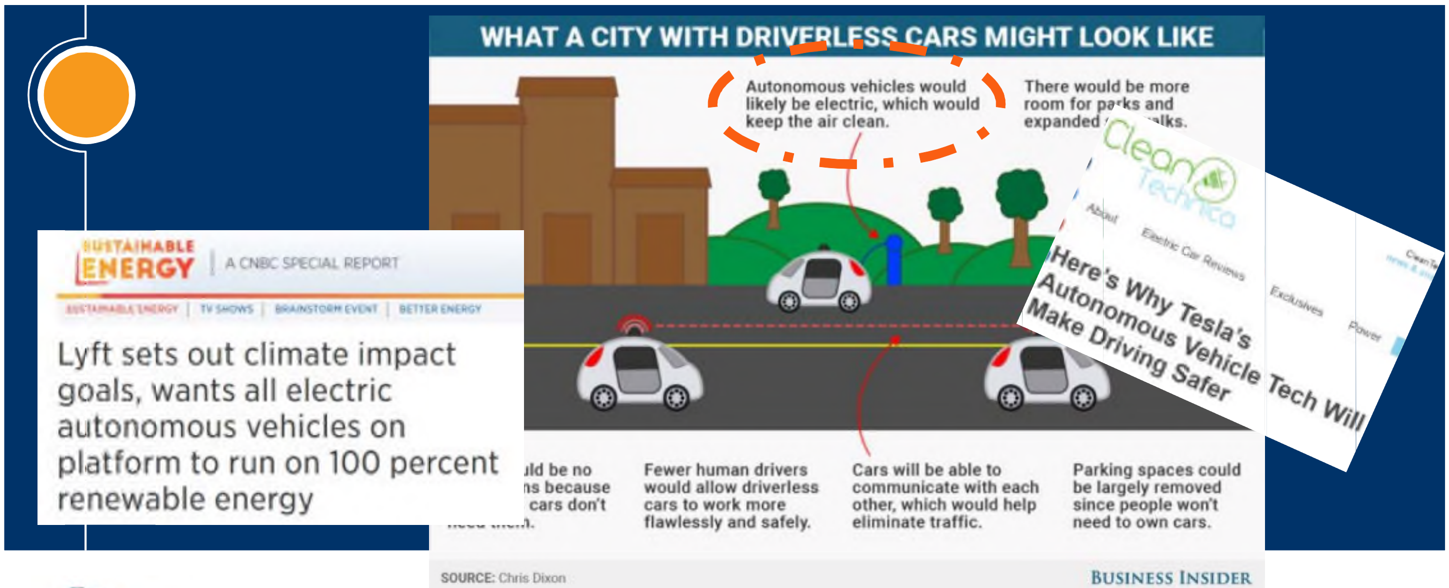
Other Shoppers — **300 mi**

Q: For an EV, what is the minimum driving range that is acceptable between battery charges? (Please indicate the number of miles per full charge) (Free response) N = 2165 (Median reported)
Q: Which of the following types of vehicles would you consider? (Select all that apply) N = 2165, Q: Do you currently own any of the following types of vehicles? (Select all) N = 2165
Q: Imagine a $30,000 electric vehicle that has a range of 150 miles when fully charged. What would you expect the price to be for a version of the same vehicle that had a 200 mile range? 150 mile range = $30,000, 200 mile range = (enter price) N = 2165 (Median reported)

Cox Automotive

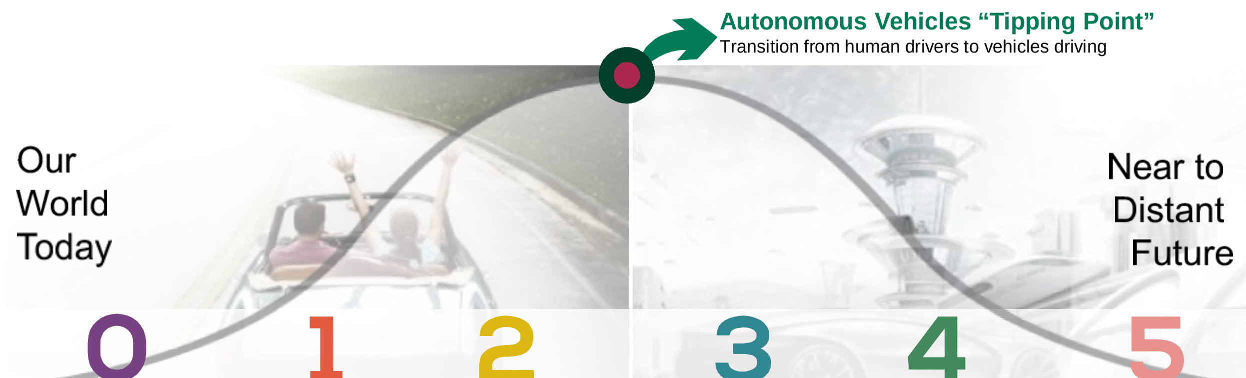

COX AUTOMOTIVE™
And Then There's This…
Autotrader
KBB.COM
DEALER.COM
25

Changing trends in mobility may change consumer perceptions of EVs



Cox Automotive

Levels of Autonomy



0	1	2	3	4	5
HUMAN ONLY	MODERN VEHICLE	MODERN PLUS	PARTIAL AUTONOMY	FULL AUTONOMY (+ HUMAN)	FULL AUTONOMY (NO HUMAN)
The driver (human) controls everything: steering, brakes, throttle, power	*Most functions are still controlled by a driver, but some (like braking) can be done automatically by the car*	*At least 2 functions are automated (like cruise control & lane-centering), but the driver must be ready to take control of the vehicle*	*Drivers are still necessary, but are not required to monitor the situation as with previous levels*	*Vehicles perform all safety-critical driving functions and monitor roadway conditions for an entire trip, with option for human driving*	*No option for human driving - no steering wheel or controls*

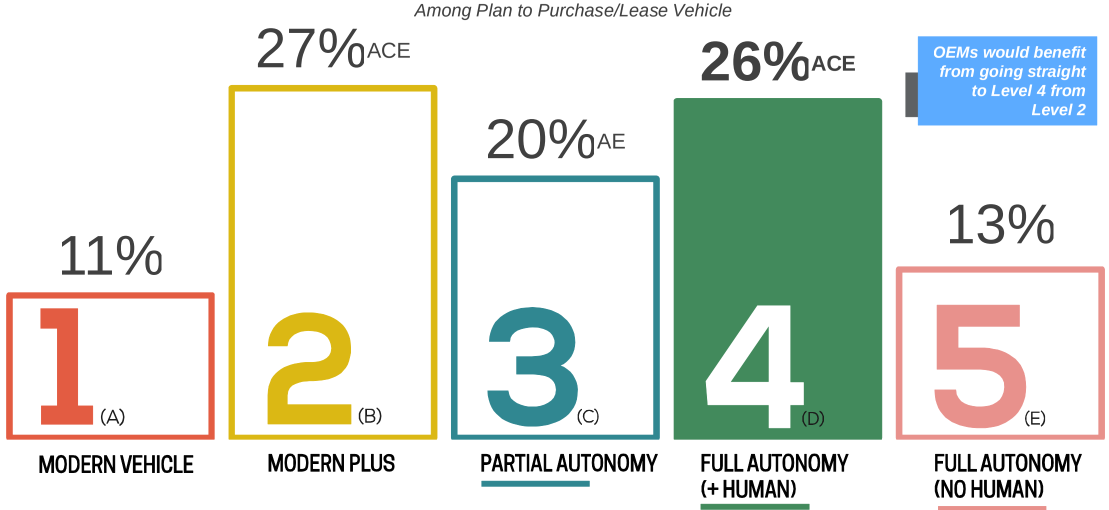
http://www.techrepublic.com/article/autonomous-driving-levels-0-to-5-understanding-the-differences/

A COX AUTOMOTIVE BRAND

Americans want to buy Level 4 Full Autonomy (+ Human) as much as vehicles available today

Purchase Consideration (Forced Choice)

Among Plan to Purchase/Lease Vehicle

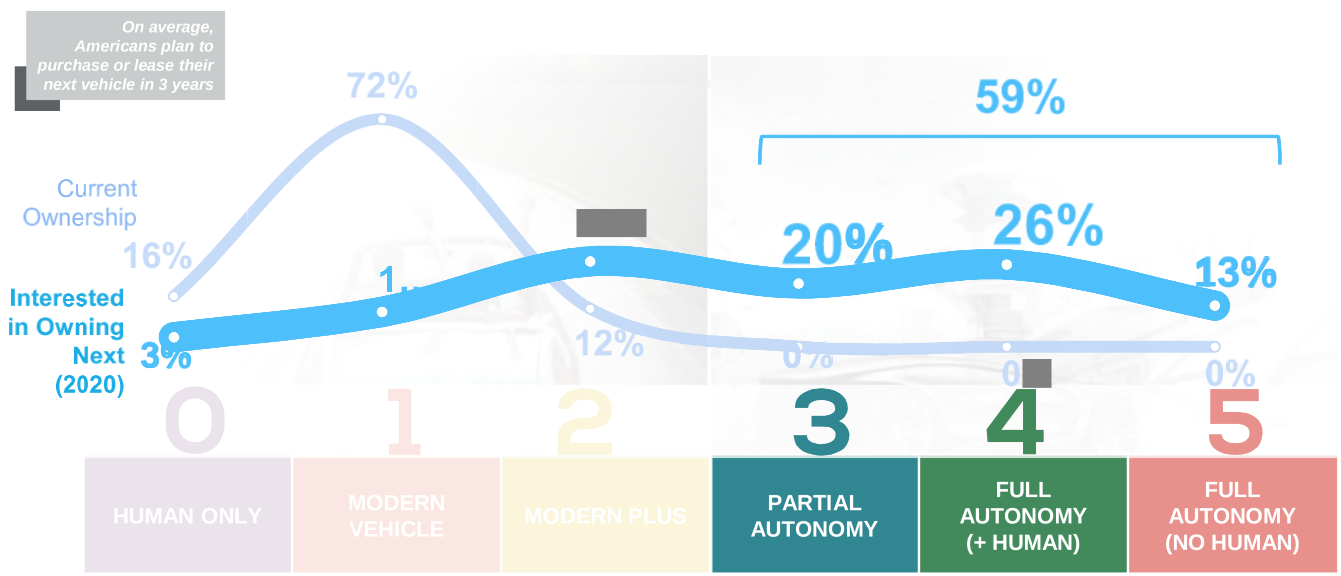


> **LEVEL 4** is the most appealing to me because it allows the vehicle to take over all driving tasks for the human, **while still allowing the human to have 'executive control'** in case of emergencies, system errors, or other unforeseen circumstances.

Please Note: Capital letters indicate statistical differences at the 95% confidence level: A-E
Base: Plan to Purchase/Lease Vehicle at Some Point (n=1695)
AV11. Assuming each level of autonomy was available on the market today, what level of autonomy would you be most likely to purchase/lease?

A COX AUTOMOTIVE BRAND

By 2020, assuming all levels of autonomy are available, 59% of consumers would be interested in purchasing/leasing higher levels of autonomy



Base: Currently Own/Lease (n=1550); Planning to Purchase in the Future (n=1234)
S16. When are you planning to purchase or lease your next vehicle? (n=1770)
AV4. Please select what level of vehicle autonomy applies to a car you currently own or lease, or have owned or leased in the past.
AV11. Assuming each level of autonomy was available on the market today, what level of autonomy would you be most likely to purchase/lease?

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Key Takeaways

Disconnect between regulator/government pressure to advance EVs and consumer demand will continue

- Slow change in perceptions and low fuel prices remain the challenge

More concerted education effort is needed

- Consumers are hoping for better pricing, but missing many advantages of EVs

Autonomous/self-driving vehicles could change all this

- If most AVs are EVs, consumers could become amenable to EVs

Thank you!

Rebecca Lindland
Executive Analyst, Kelley Blue Book
Rebecca.lindland@kbb.com
+1-203-984-1664

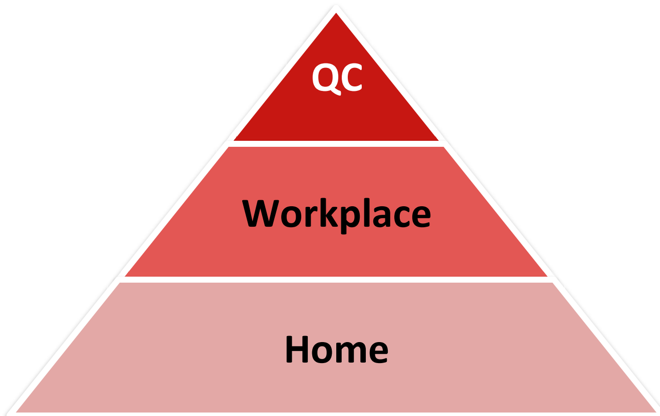
1700 Fast Chargers by 2016

David Peterson
Nissan North America
3-10-2015 | California PEV Collaborative

Nissan Public Charging Approach

Range Confidence' by ensuring drivers have access to at least 2 of 3 charging options

Home 3.6kW	Workplace	Public

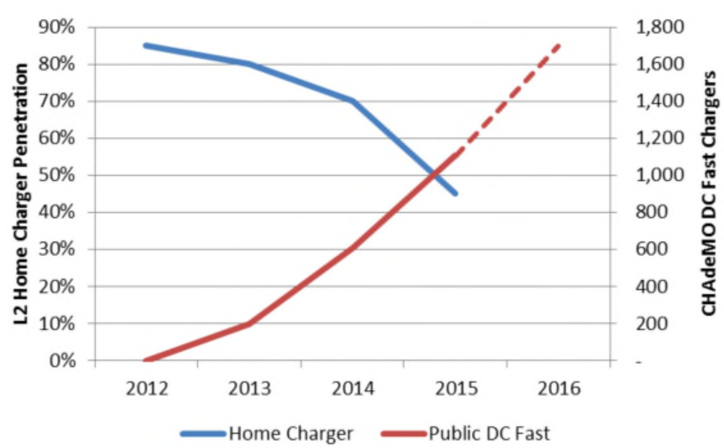


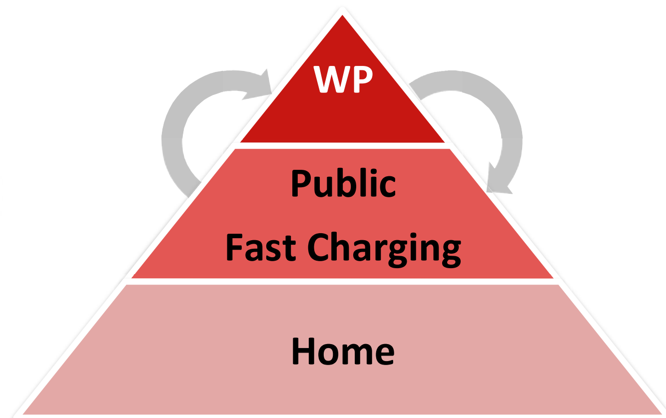
ZERO Emission

Increasing Reliance on Public Charging

- Decreasing Home L2 penetration since 2011
- Inversely correlated with Public QC growth (market-by-market analysis)
- Increased importance of Public Fast Charging
- Workplace charging will keep pace wherever possible

Home Charger vs. Public Fast Charger





Zero Emission

Drivers Prefer DC Fast Charging

Drivers who charge regularly at home (L2 & L1)
*also **Fast Charge** whenever possible*

ZeroEmission

-2/3 of LEAF drivers use public infrastructure, 1/4 at least 1x per week

-Fast Charging always preferred **6:1** vs. L2 (excluding workplace)

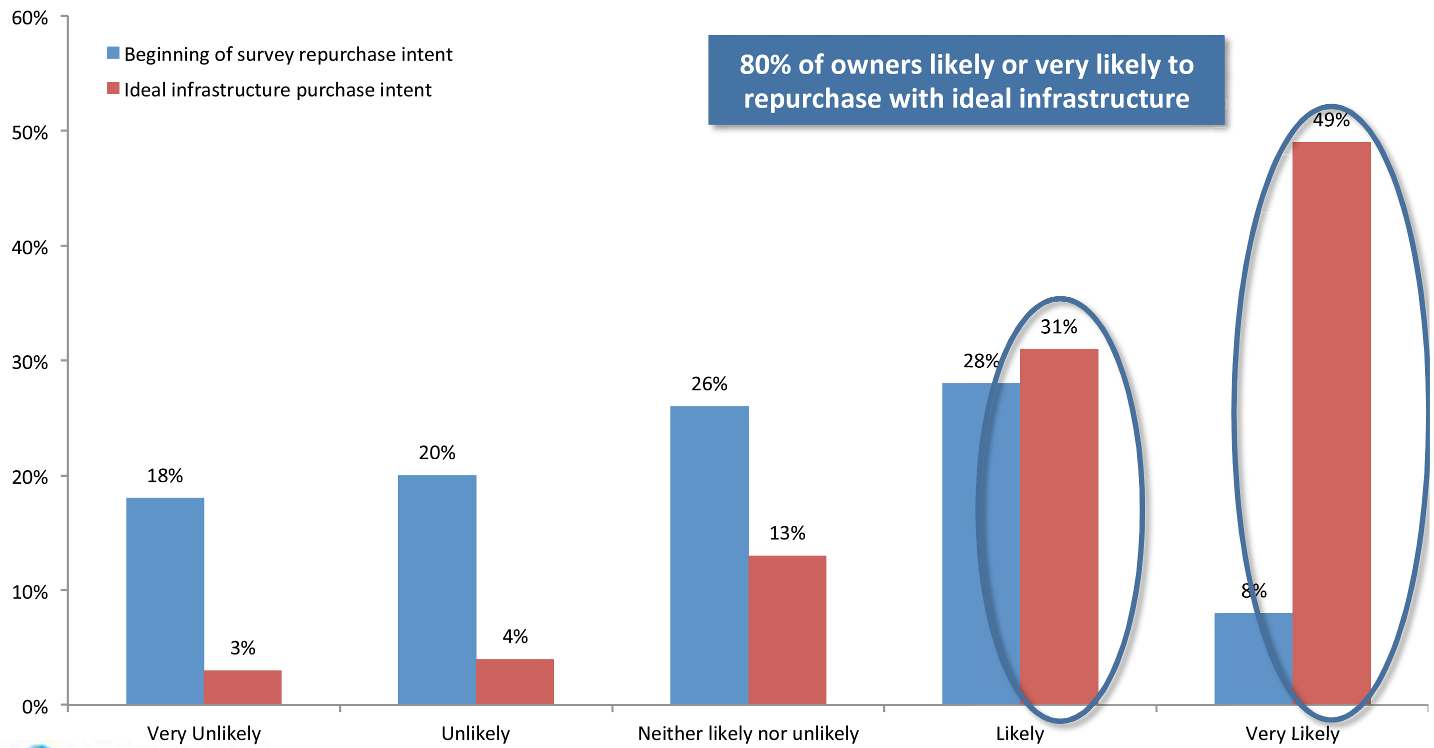
-Time to charge is #1 consideration

-Must be affordable and cost-effective

Source: Nissan, 2014

Infrastructure Key to Repurchase

- 2014 Nissan Market Intelligence LEAF survey (n=2600)
- **Owners** are much more likely to repurchase LEAF in infrastructure expectations are met



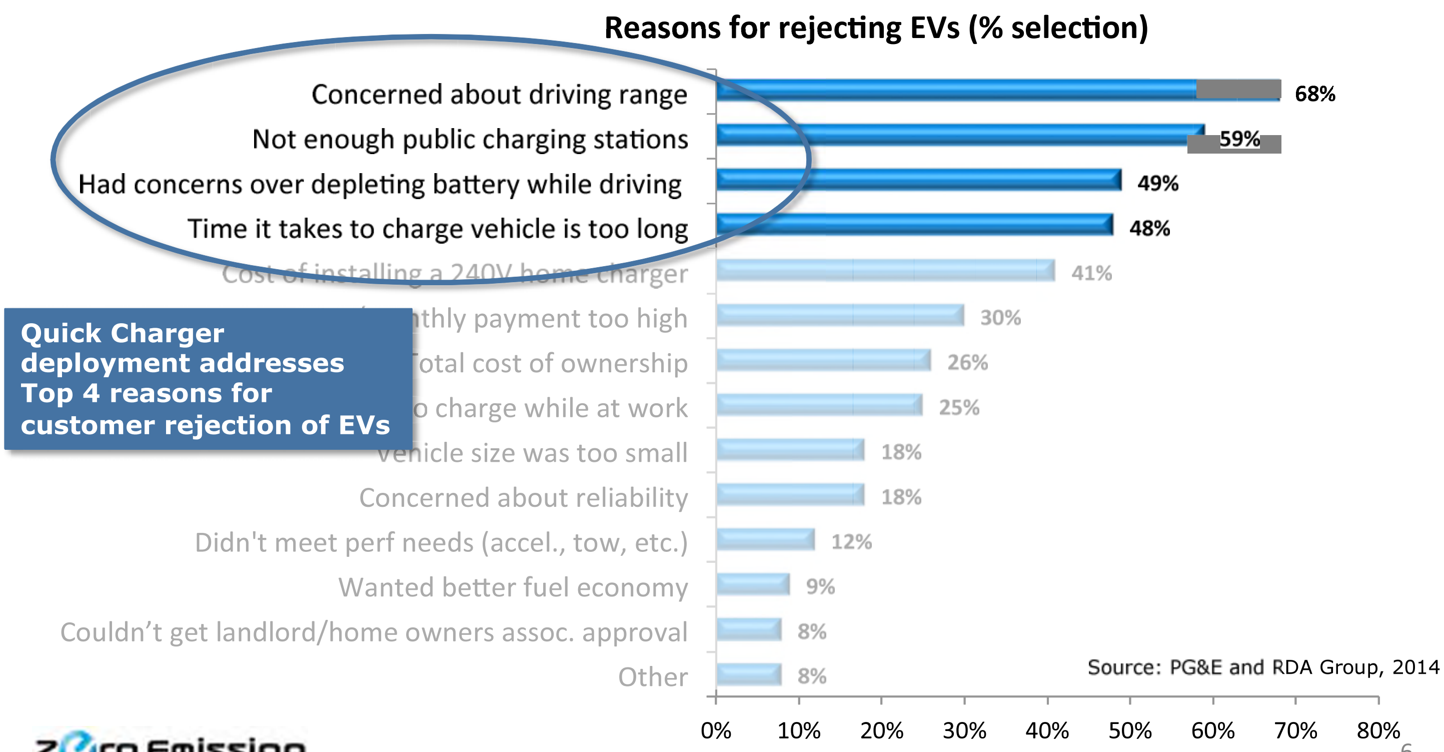
Zero Emission

Source: Nissan, 2014

5

QC Addresses Rejecter Reasons

- PG&E and RDA Group study of CA EV owners, intenders and rejecters (n=808)
- Survey question assessed reasons for rejecting EV purchase
- **Top 4 reasons respondents rejected an EV were related to infrastructure**



Source: PG&E and RDA Group, 2014

Zero Emission

6

Pathway to the Future

- QC charge time expectations DO NOT CHANGE with longer range vehicle
- High penetration + concentrations of QCs necessary to meet future needs
- EXAMPLE: LR vehicle charges 30 minutes 2-3x per week – satisfies 100% of daily travel

Vehicle Dwell Time	Today	Future
Short (<30 minutes)	50 kW DC	High Penetration of 50 kW
Medium/Long (>1 hour)	L2 (3-6kW AC)	Ubiquitous L2 20-30kW DC
	LEAF	Longer Range EV

EV Driving Range (miles) & Battery Energy Density (kWh)

ZERO Emission

No Charge to Charge

no charge to charge

- 2 years of Complimentary Public Charging (excluding workplace)
- Launched 4 markets in CA in 2014
- More CA markets planned in 2015
- **Fast, Abundant, Affordable** -- addresses all consumer feedback

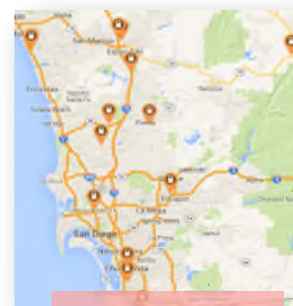
MPG 20	MPG 25	MPG 30	MPG 35	No Charge to Charge
$13.44	$10.75	$8.96	$7.68	$0

Assumes 80% charge from zero and $4 per gallon gasoline

Sacramento
17

SF Bay Area
122

Los Angeles
137



San Diego
32

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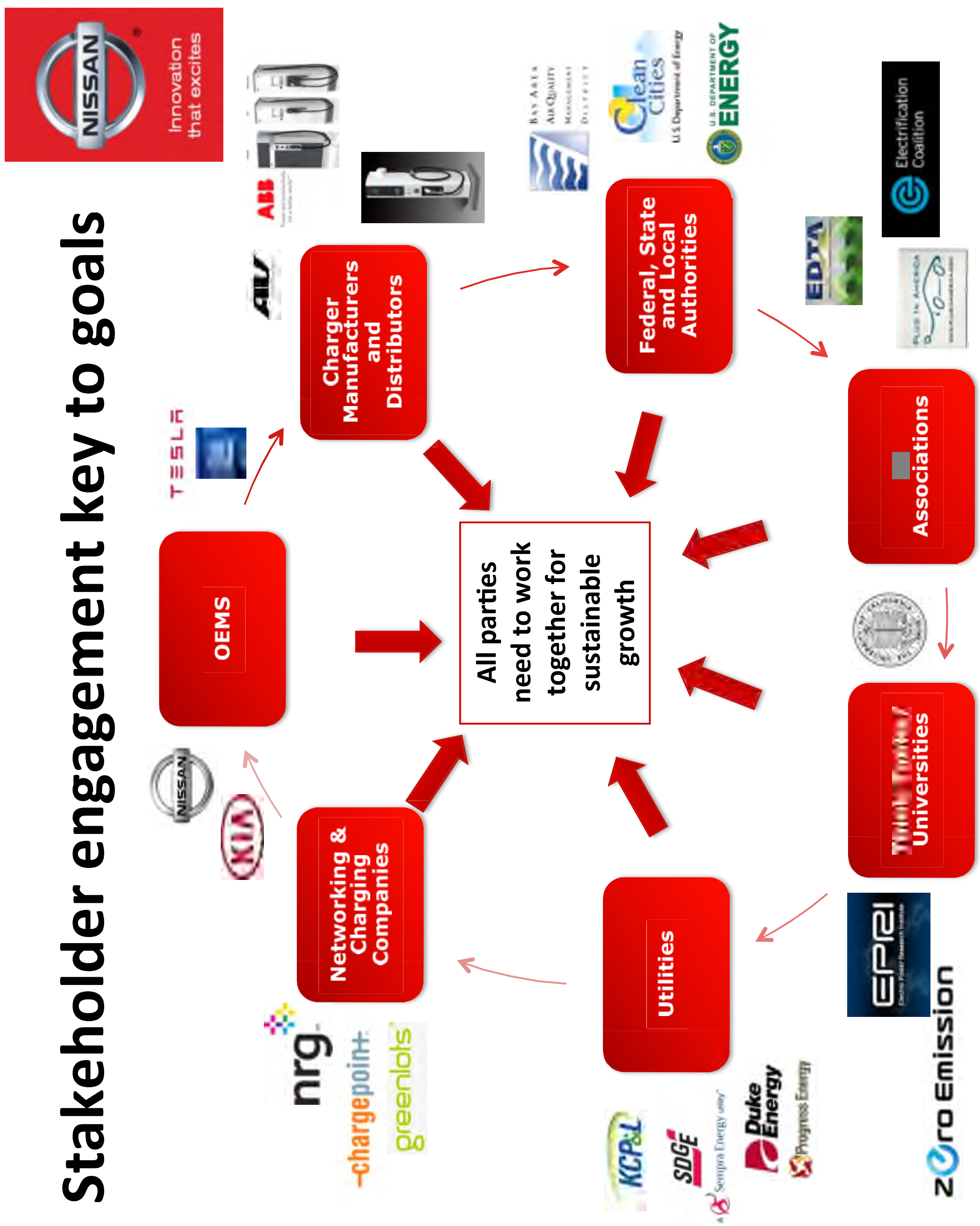

Stakeholder engagement key to goals
NISSAN
Innovation that excites
OEMS
TESLA
Charger Manufacturers and Distributors
ABB
Federal, State and Local Authorities
Clean Cities
U.S. Department of Energy
ENERGY
EDTA
Electrification Coalition
Plug In America
Associations
All parties need to work together for sustainable growth
Universities
EPRI
Electric Power Research Institute
Zero Emission
Utilities
KCP&L
SDG&E
Sempra Energy utility
Duke Energy
Progress Energy
Networking & Charging Companies
nrg
chargepoint+
greenlots
KIA
NISSAN

10

NISSAN
Innovation that excites

Thank You

ZeroEmission

Appendix: No Charge to Charge Savings

Assumptions

- Gas: $4.00/gallon
- Starting State of Charge (SOC) = 0
- Ending State of Charge (SOC) = 80%
- LEAF Efficiency = 3.5 miles/kWh

Zero Emission

DOCKETED

Docket Number:	15-IEPR-10
Project Title:	Transportation
TN #:	203909
Document Title:	Vehicle Attributes and Alternative Fuel Station Availability Metrics for Consumer Preference Modeling
Description:	Energy Commission Workshop - March 19, 2015
Filer:	Raquel Kravitz
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	3/17/2015 1:11:35 PM
Docketed Date:	3/17/2015

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

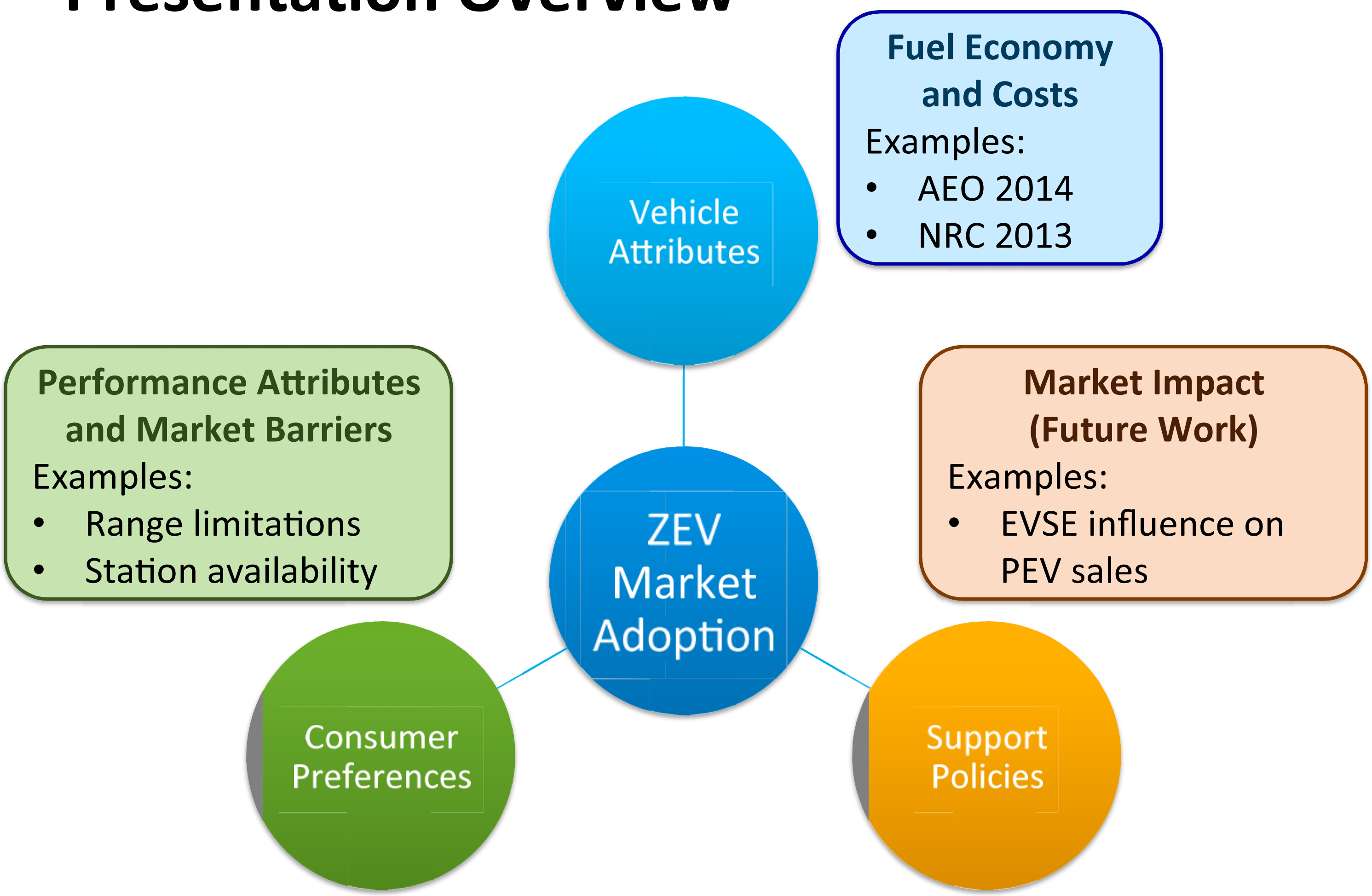
Vehicle Attributes and Alternative Fuel Station Availability Metrics for Consumer Preference Modeling

Energy Commission Workshop
Sacramento, California
March 19, 2015

M. Melaina, Y. Sun and A. Brooker
Systems Analysis and Integration
NREL Transportation Center

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Presentation Overview



Background: Key Points

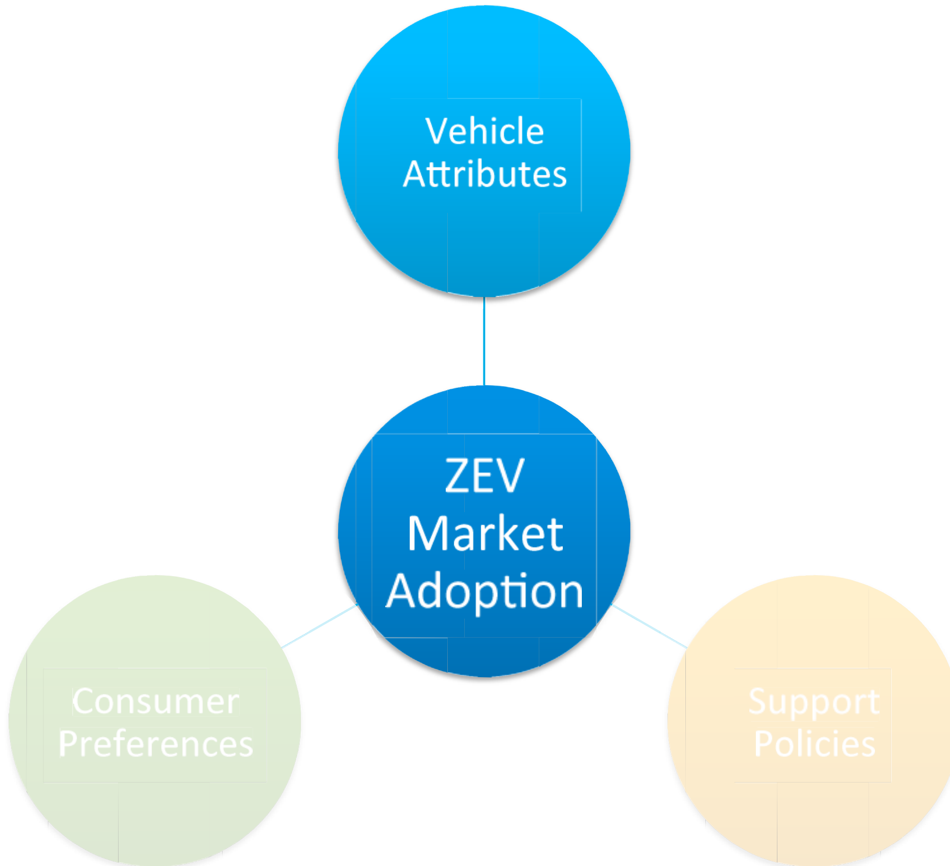
Vehicle Attributes

- Incumbent vehicles will continue to be competitive
- Alternative fuels and ZEVs (BEVs, PHEVs, FCEVs) have the potential to provide deep carbon reductions over the long term
- Technology innovation trends cannot be considered separately from market transformation policy drivers

Consumer Preferences

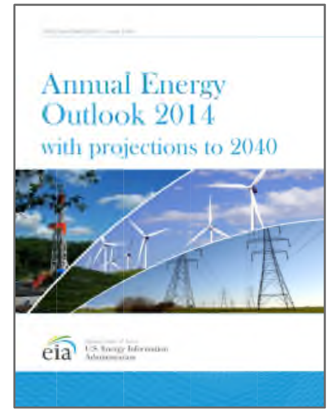
- Range penalties may be significant
- Station availability (EVSE & hydrogen stations)
  - May be an important barrier for BEV adoption, as well as a limiting factor for achieving e-miles in BEVs and PHEVs
  - Critical market barrier for FCEV adoption
  - Major uncertainties around consumer responsiveness

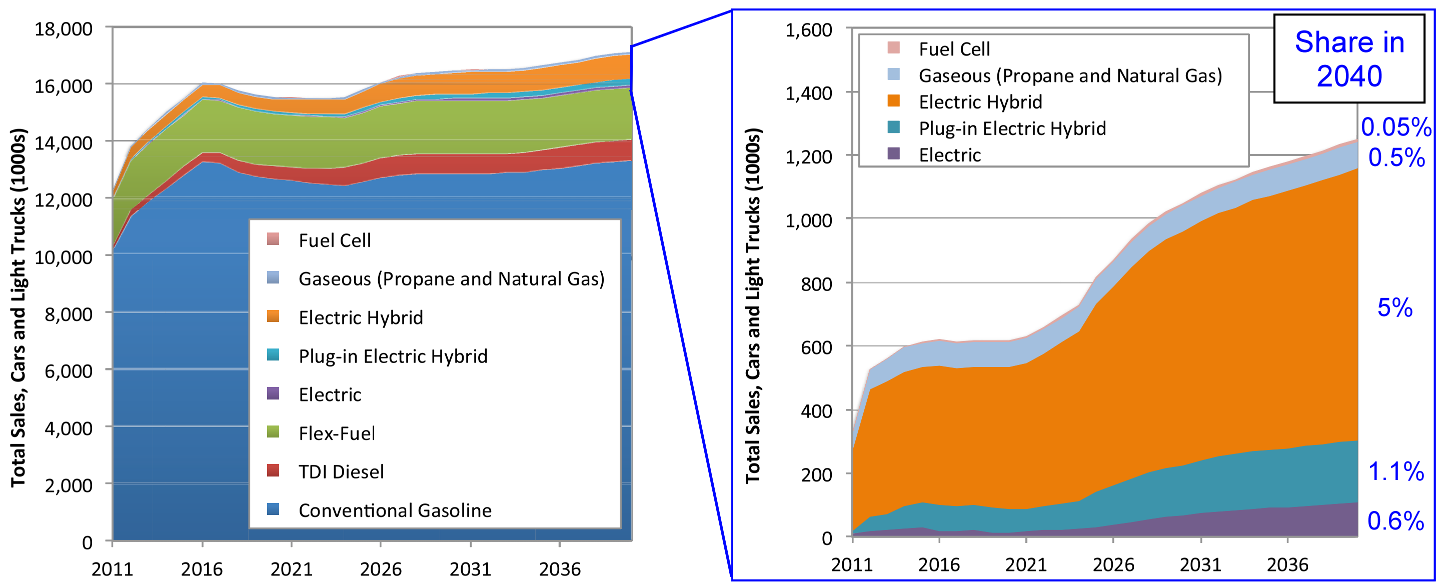
Vehicle Attributes



Energy Information Administration's Annual Energy Outlook (AEO 2014)

- Independent analysis of energy markets, data, and technology trends
- AEO 2014 suggests very modest market growth for alternative light duty vehicles (LDVs, Cars & L. Trucks)





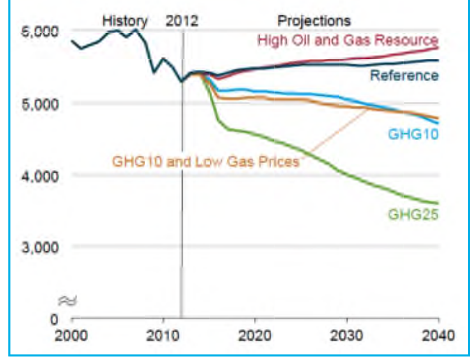
Source: AEO's Interactive Table Viewer: http://www.eia.gov/oiaf/aeo/tablebrowser/

LDV Shares for Alternate AEO 2014 Cases: *High Oil Price* and *GHG25*

Very minor differences in Market Share by 2040

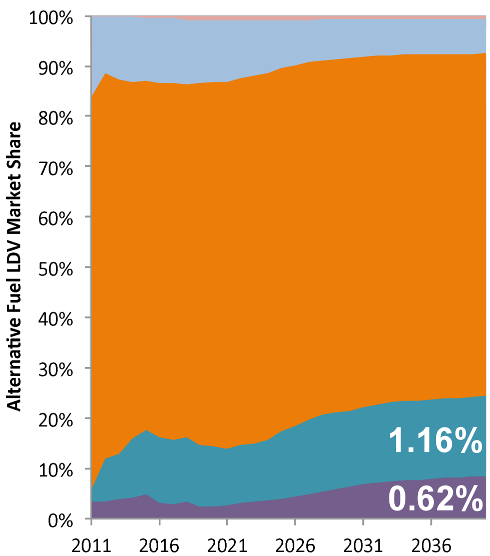
Figure MT-4. North Sea Brent crude oil spot prices in three cases, 1990-2040 (2012 dollars per barrel)

Figure ES-7. Energy-related carbon dioxide emissions in five cases, 2000-40 (million metric tons)

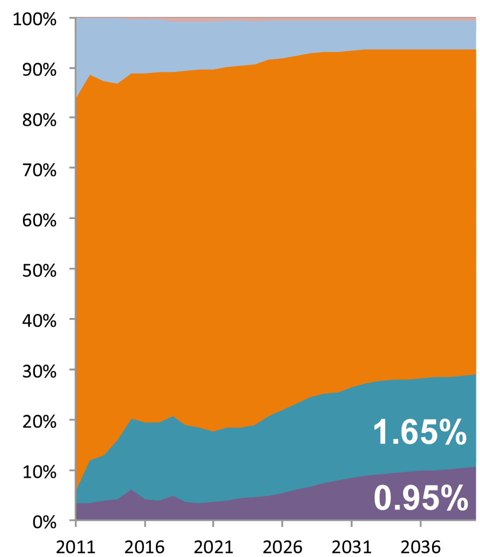


Source: AEO 2014

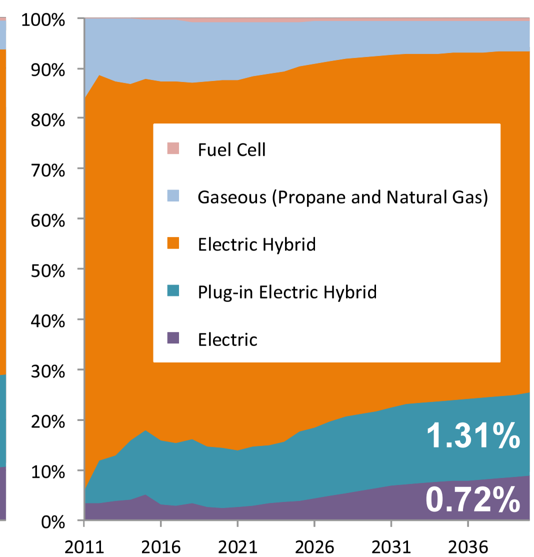
Reference Case



High Oil Price Case

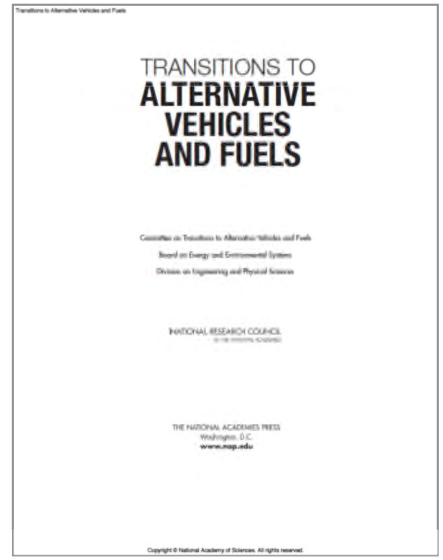


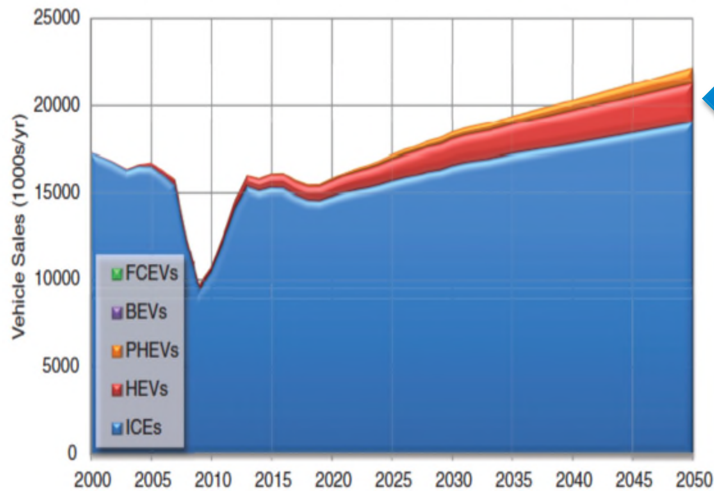
GHG25 Case



National Academy of Sciences 2013 report on reducing LDV GHG emissions 80% by 2050 (NRC 2013)

Report explores multiple options for deep GHG reductions in LDV fleet





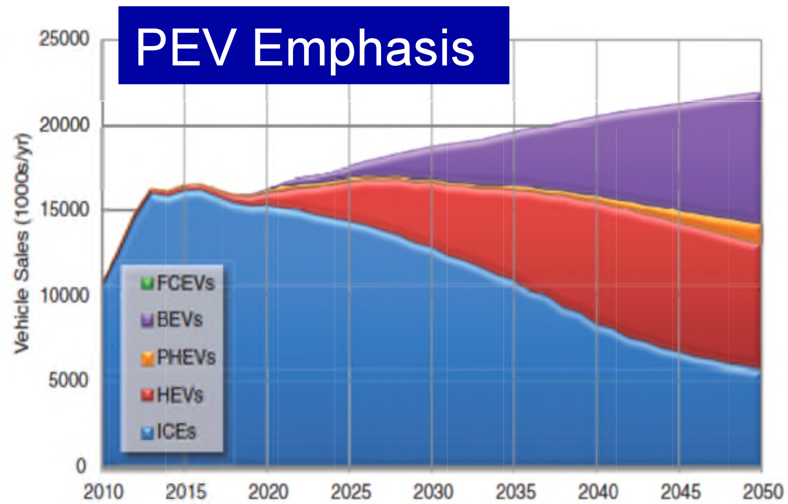
Source: NRC 2014

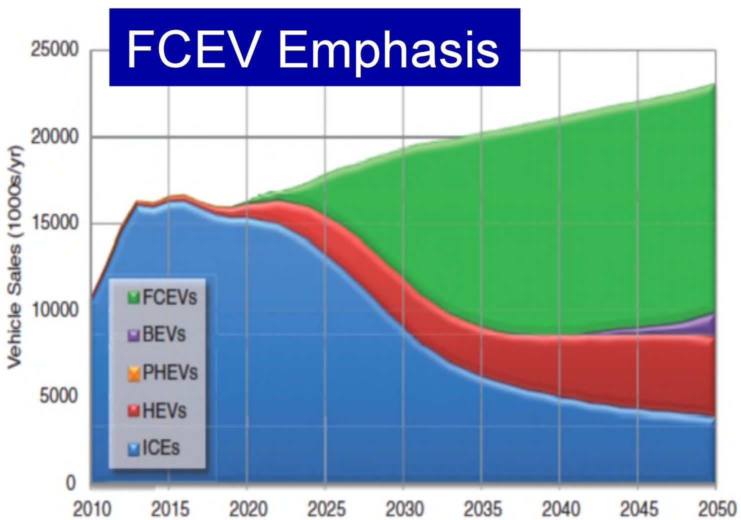
Business as Usual Scenario

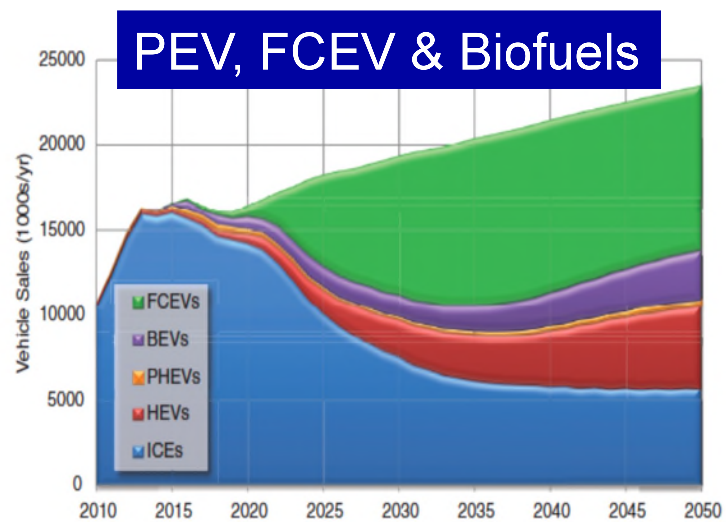
- BAU scenario is similar to the AEO Reference Case
- Other scenarios include emphasis on: biofuels, PEVs, FCEVs, and CNGVs

Three Scenarios examine success with electric-drive vehicles

All three require significant vehicle subsidies to achieve market success

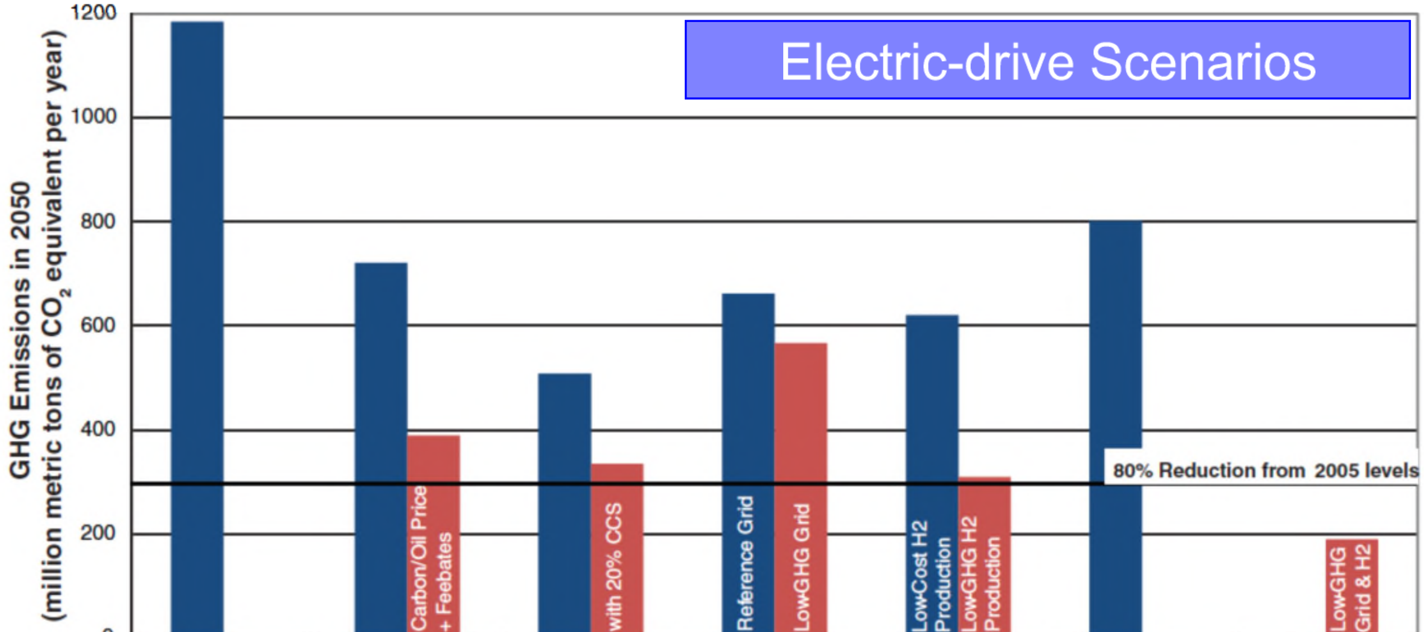






Source: NRC 2014

Only some NRC Scenarios meet 2050 80% Goal



	Committee Reference (Current Policies)	Efficiency	Efficiency + Biofuels	Plug-In Electric Vehicles (PEVs)	Fuel Cell Electric Vehicles (FCEVs)	Natural Gas Vehicles	PEVs + FCEVs + Biofuels
Reference Production	1184	721	508	662	621	801	
Low-GHG Production		389	335	567	310		190

FIGURE S.2 Estimated U.S. LDV GHG emissions in 2050 under policies emphasizing specific technologies. All scenarios except the Committee Reference Case (current policies, including the fuel economy standards for 2025) include midrange efficiency improvements. Fuel production for these scenarios is assumed to be constrained by policies controlling GHG emissions (low GHG production).

Source: NRC 2014

Major Differences between AEO & NRC Scenarios

Scenario Goals

- AEO goal is objective projections
- NRC goal is to examine 2050 GHG 80% goal

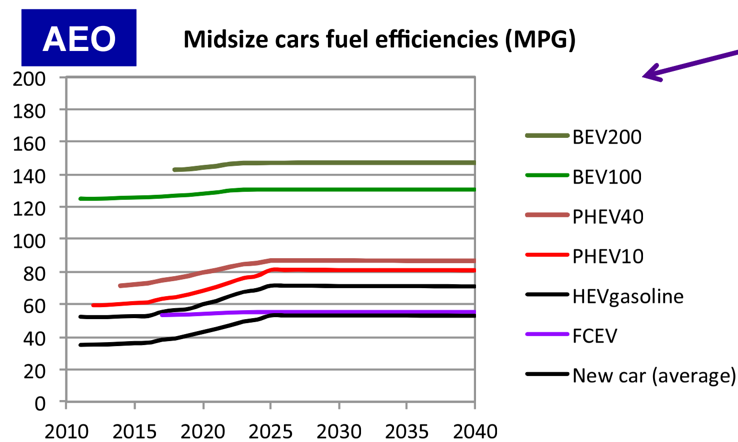
Policy Context

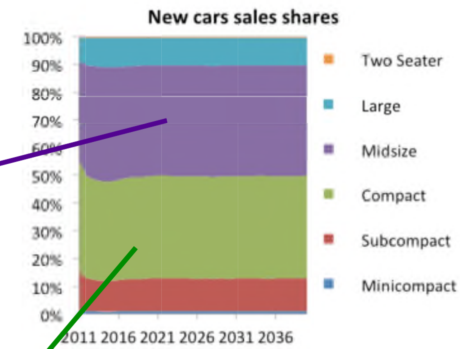
- AEO: primarily existing policies
- NRC articulated and estimated the magnitude of the (very aggressive) policies required to meet the GHG 2050 goal

Technology Trends

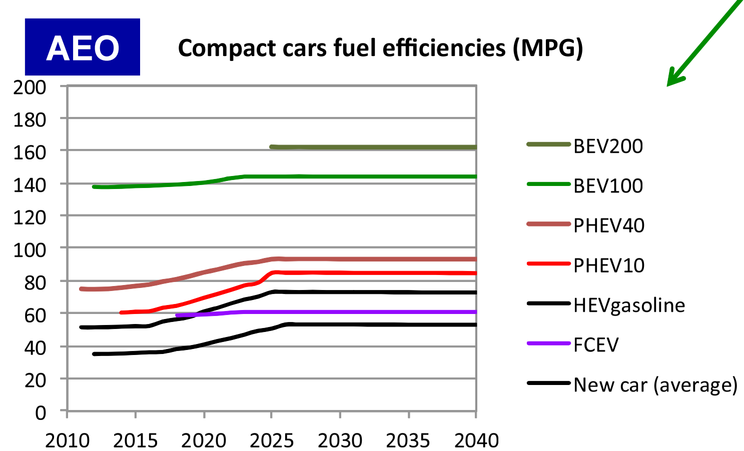
- AEO: Market viability without major transportation policy drivers or major innovation improvements
- NRC: Very aggressive performance and cost improvements for LDVs (midrange and optimistic)

Comparing Fuel Economy Reference Cases (cars)

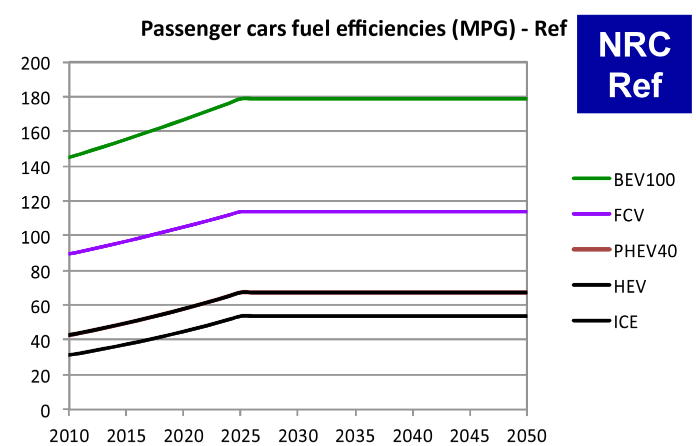




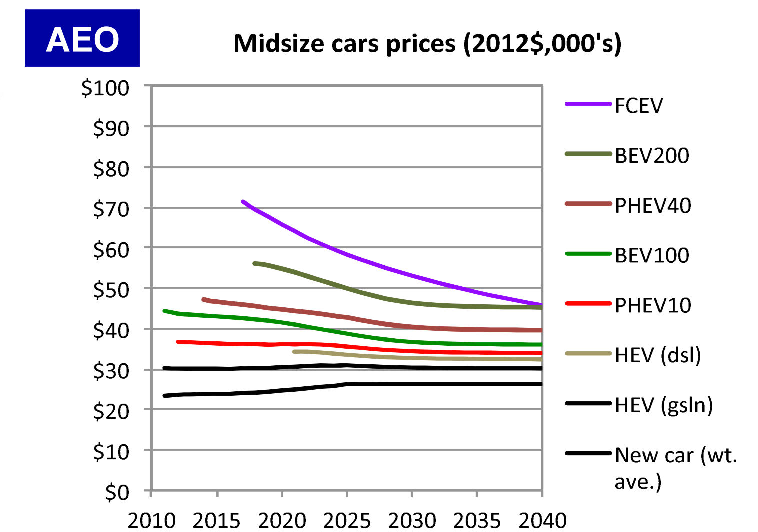
BEVs are significantly higher in NRC Ref Case. FCEVs do not improve in AEO due to lack of growth.

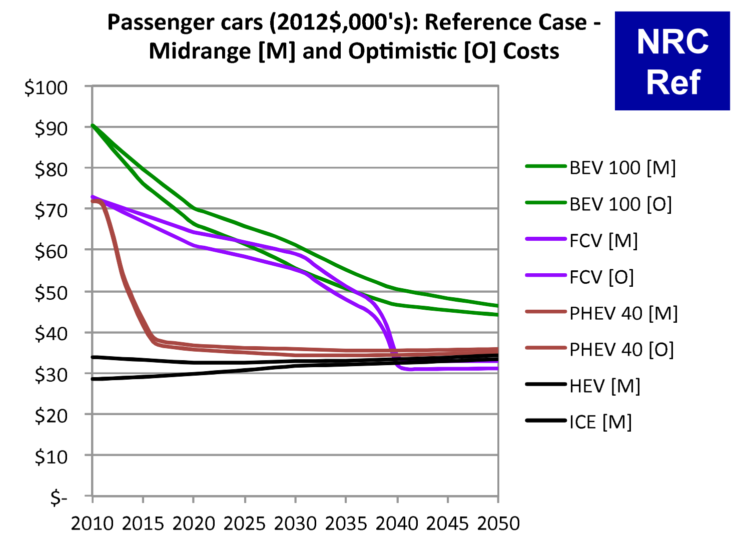


New Car = average across all car sizes



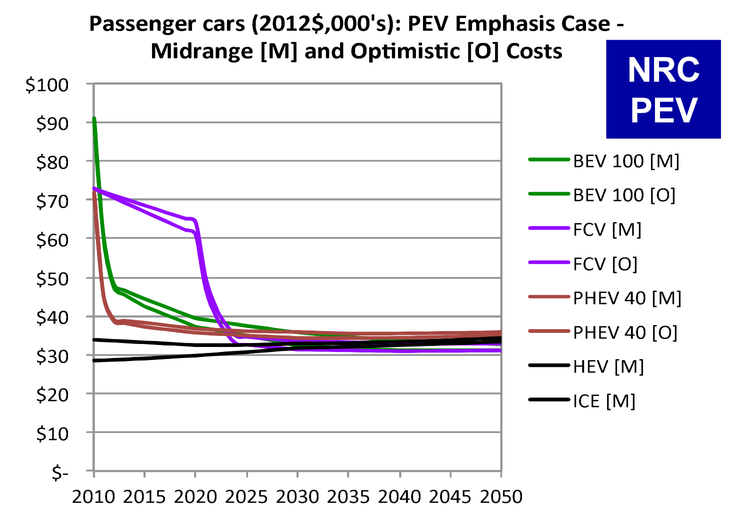
Passenger Car = all cars





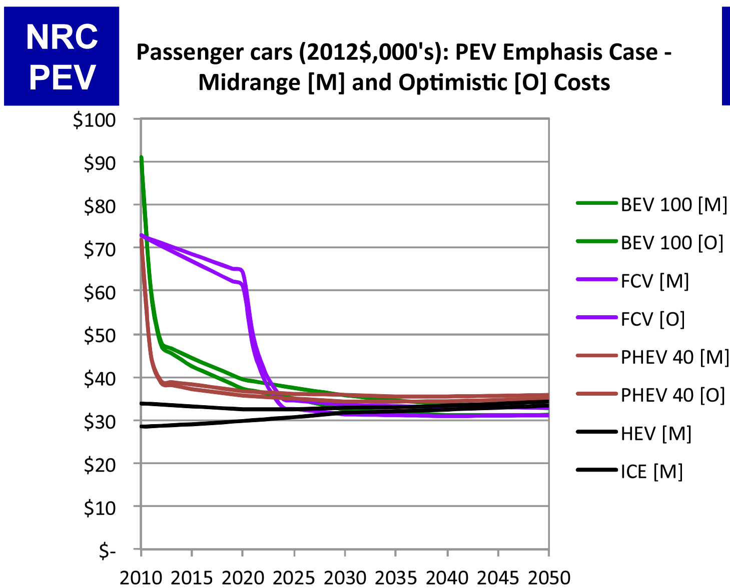
Car Prices

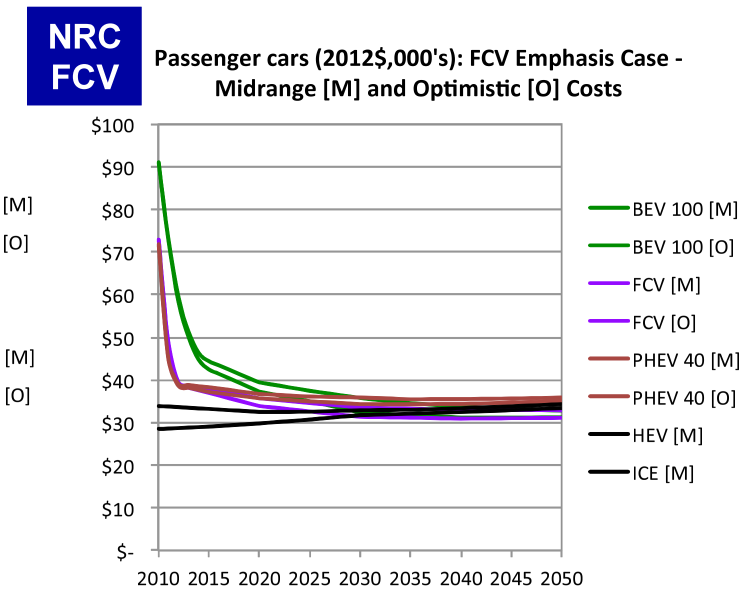
- Reference cases above have limited market growth in BEVs, FCEVs, PHEVs
- NRC **<u>PEV Emphasis</u>** case at right achieves rapid market growth and correspondingly rapid cost reductions
- Even FCEV costs decline due to some market growth



Vehicle prices vary between scenarios

- Variations are based upon cost multiplier penalties that decline with increasing economies of scale and learning
- Scenarios includes subsidies to accelerate market growth, resulting in movement down cost curves at different rates
- The volume of subsidies required to achieve market success is very sensitive to these multiplier penalties





"Fully Learned" and "At Scale" costs are achieved only with significant subsidies and policies

- These cost differentials from the baseline ICE vehicle cost occur after all learning and scale reductions have been achieved
- Volume of subsidies depends upon area under **learning curves**, the **effectiveness of market support policies**, and **consumers preferences**

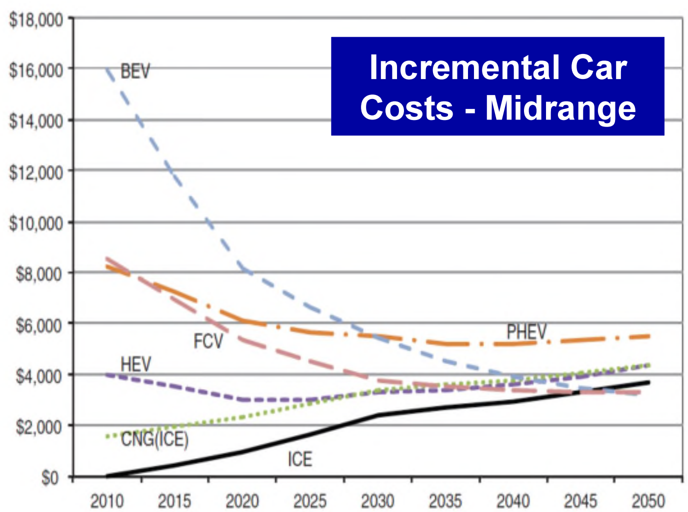


FIGURE 2.8 Car incremental cost versus 2010 baseline ($26,341 retail price)—Midrange case.

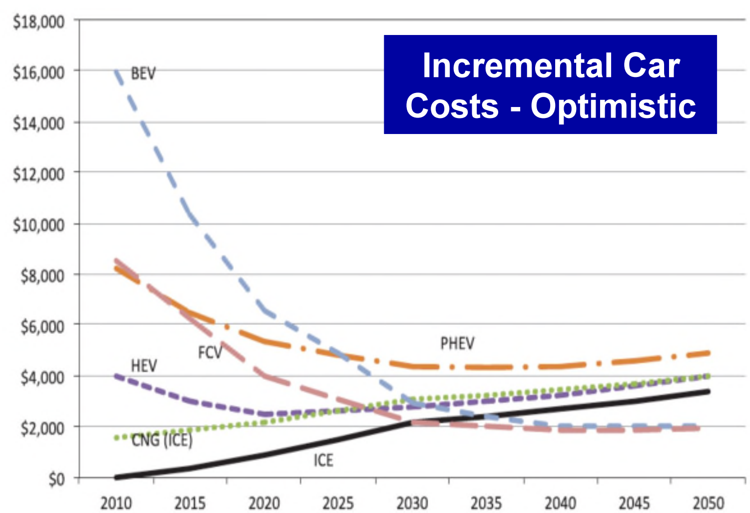
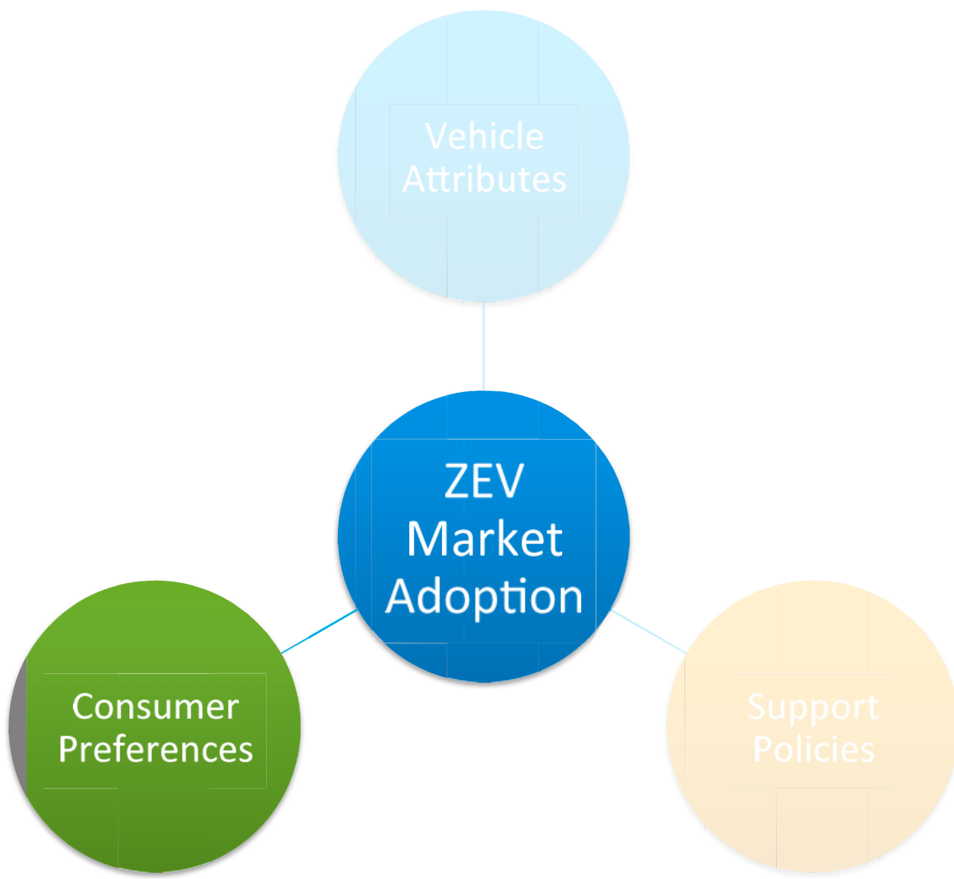


FIGURE 2.10 Car Incremental cost versus 2010 baseline ($26,341 retail price)—Optimistic case.

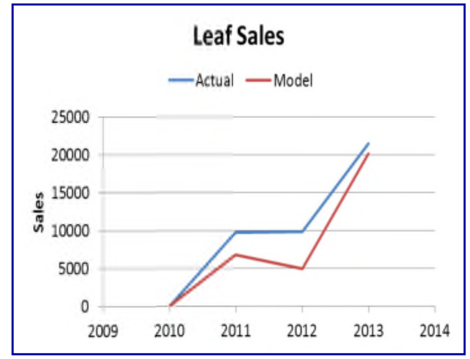
Source: NRC 2014

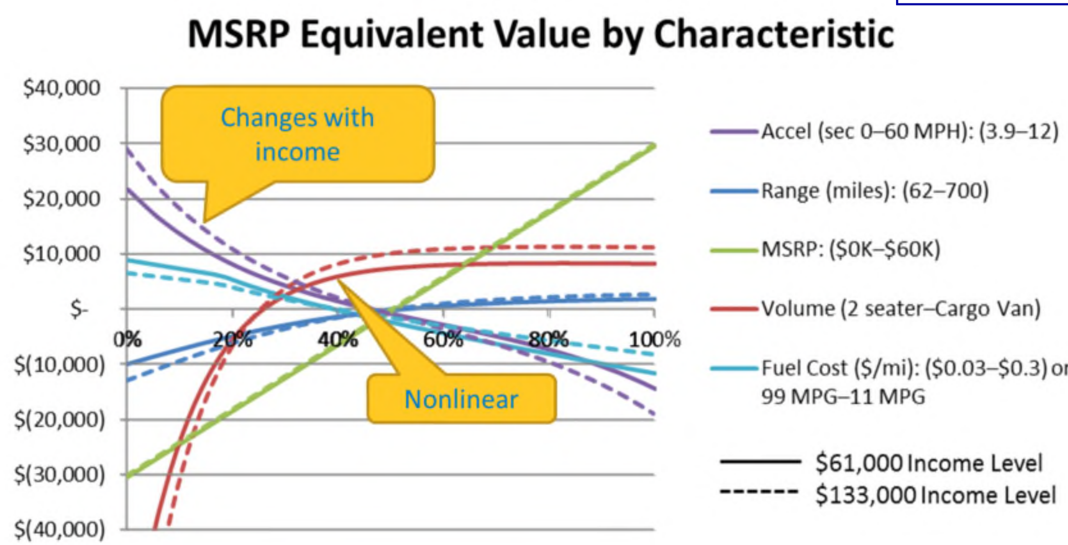
Consumer Preferences



Example: What is the penalty for limited range from a consumer perspective?

- NREL's ADOPT consumer preference model estimates market share using coefficients derived from empirical sales data
- Range penalty is based upon limited data, but aligns well with Leaf sales





Source: Brooker, A. (2015) *ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model*, SAE World Congress, 2015 (forthcoming)

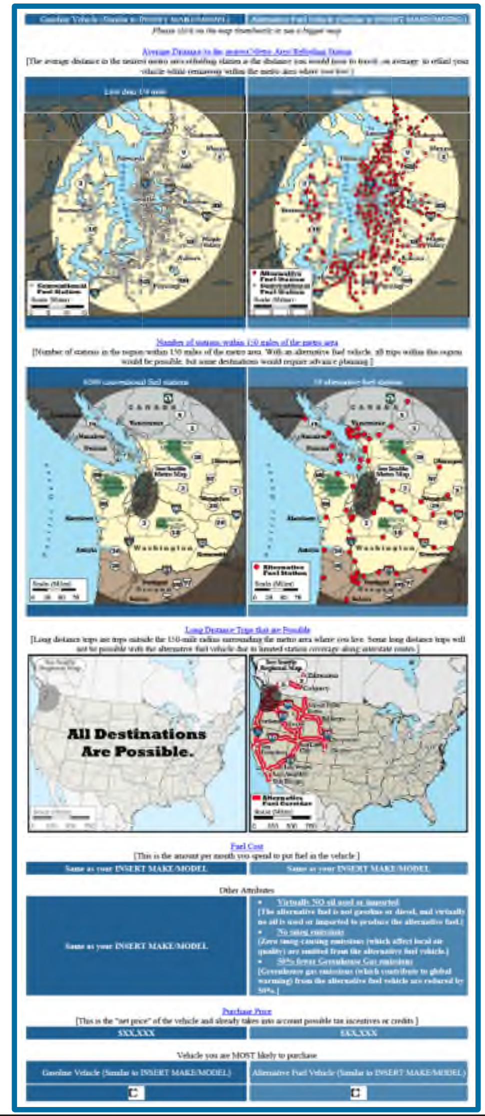
Stated Preference Survey

NREL and *PA Consulting* study

- Developed and fielded 3 discrete choice surveys, each improving on the previous design
- Final survey gave best results
- Relied upon in-house computer survey panels

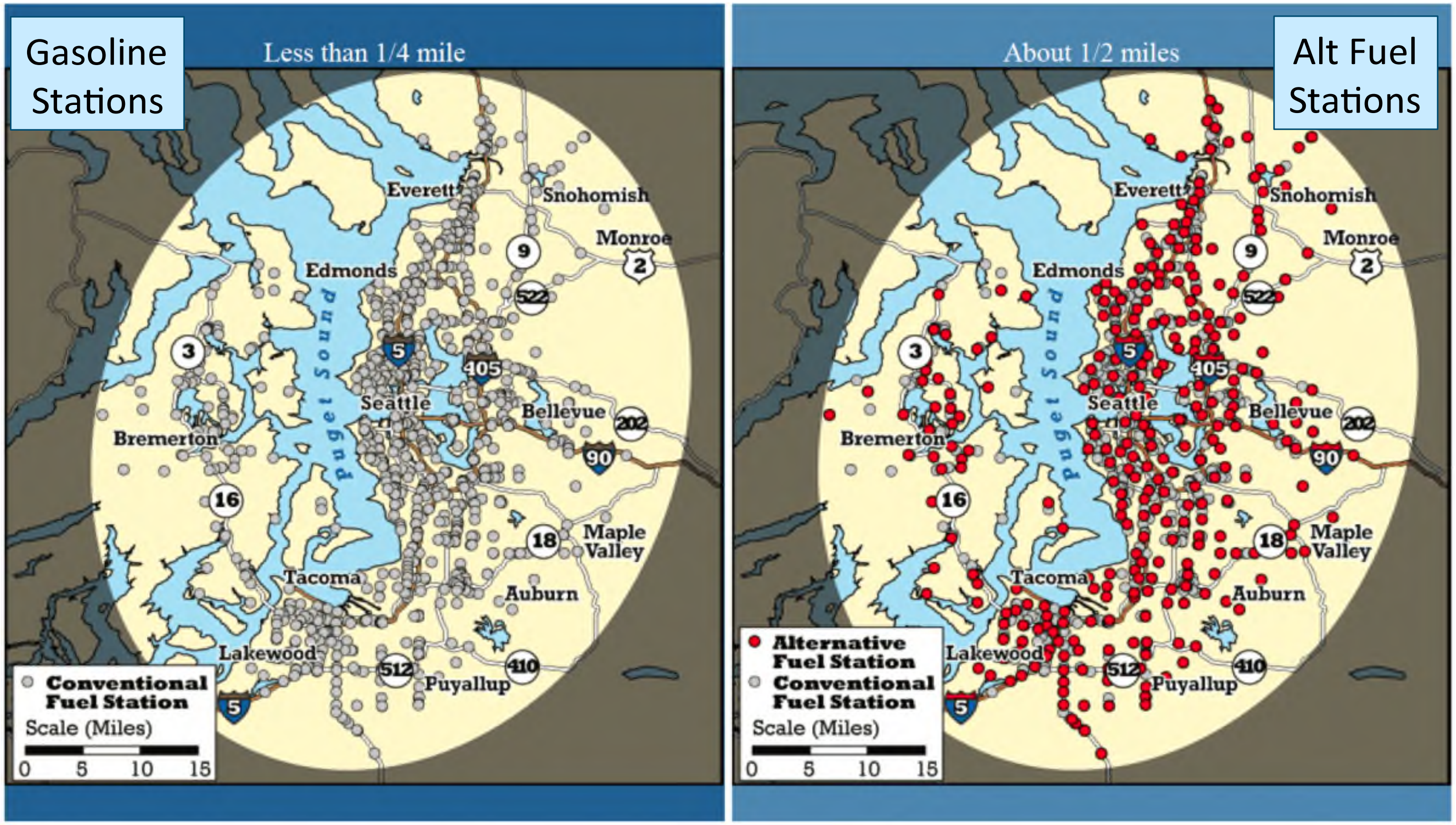
Survey Design

- Sequence of 10 vehicle purchase decisions, with attributes shown side-by-side: Vehicle purchase price, fuel cost, and *station coverage at three geographic scales: local, regional, national*
- Algorithm varies attribute levels based upon previous responses
- Dedicated vehicle for generic alternative fuel
- ~500 surveys completed in each major city: Los Angeles, Atlanta, Minneapolis and Seattle



Source: Melaina, M., J. Bremson, K. Solo (2012). Consumer Convenience and the Availability of Retail Stations as a Market Barrier for Alternative Fuel Vehicles, Presented at the 31st USAEE/IAEE North American Conference, Austin, Texas, November 4-7, 2012.
Available online: http://www.nrel.gov/publications/

Example of Local Coverage Maps: Los Angeles



Four Levels: (1) No Alt Fuel Stations, (2) sparse, (3) many, (4) same as gasoline

Source: Melaina, Bremson and Solo (2012).

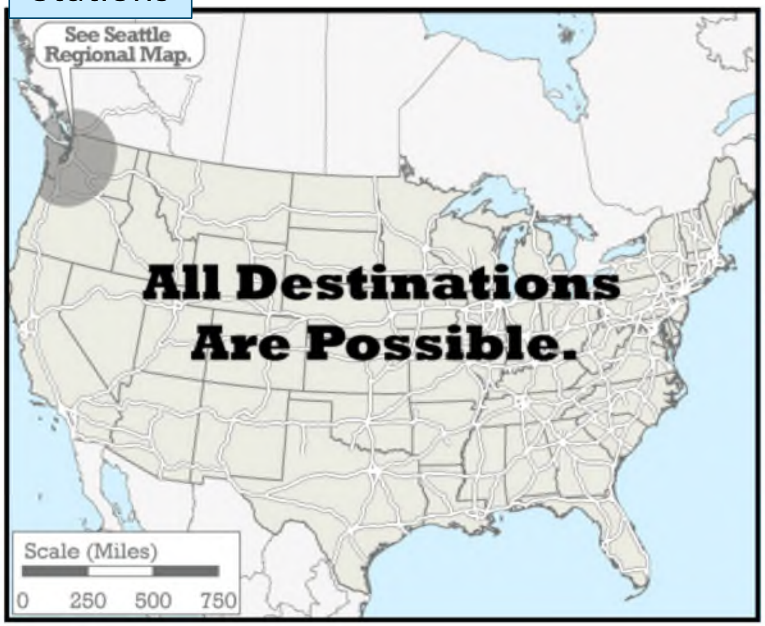
Example of Local Coverage Maps: Los Angeles

Four Levels: (1) No Alt Fuel Stations, (2) sparse, (3) many, (4) same as gasoline

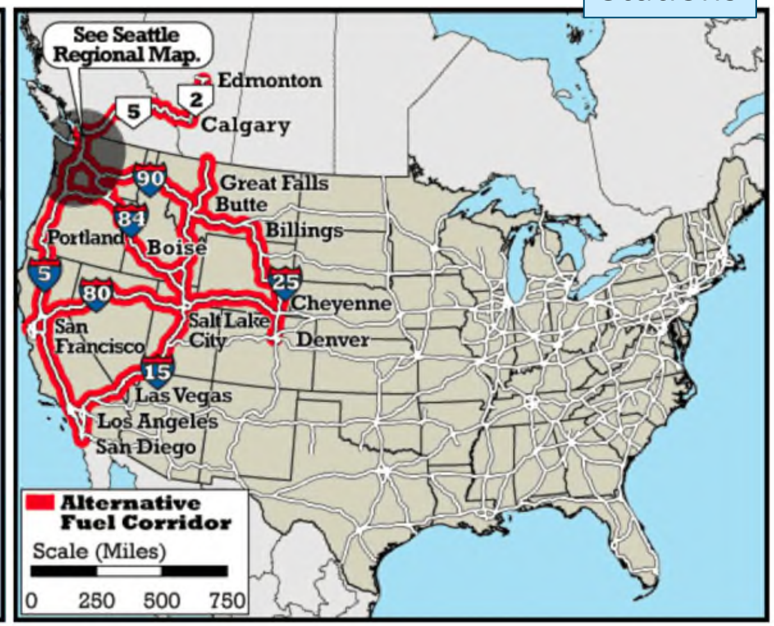
Source: Melaina, Bremson and Solo (2012).

Example of Local Coverage Maps: Los Angeles

Gasoline Stations



Alt Fuel Stations



Four Levels: (1) No Alt Fuel Stations, (2) nearby interstates, (3) many interstates, (4) all interstates.

Source: Melaina, Bremson and Solo (2012).

Study Results: Quantified Stated Preferences for Station Availability and Compared to Rational Behavior Model Results

Stated Preference Estimates

Survey results suggest that household consumers may perceive the following (cumulative) purchase price penalties:

- **Local: $750 to $4,000** for retail station coverage at 1 to 10 percent of existing gasoline stations within metropolitan (urban) areas.
- **Regional: $1,500 to $3,000** for limited medium-distance coverage, defined as 5 to 100 stations within 150 miles of the metro area
- **Interstate: $2,000 to $9,000** for a lack of long-distance coverage along interstates connecting urban areas

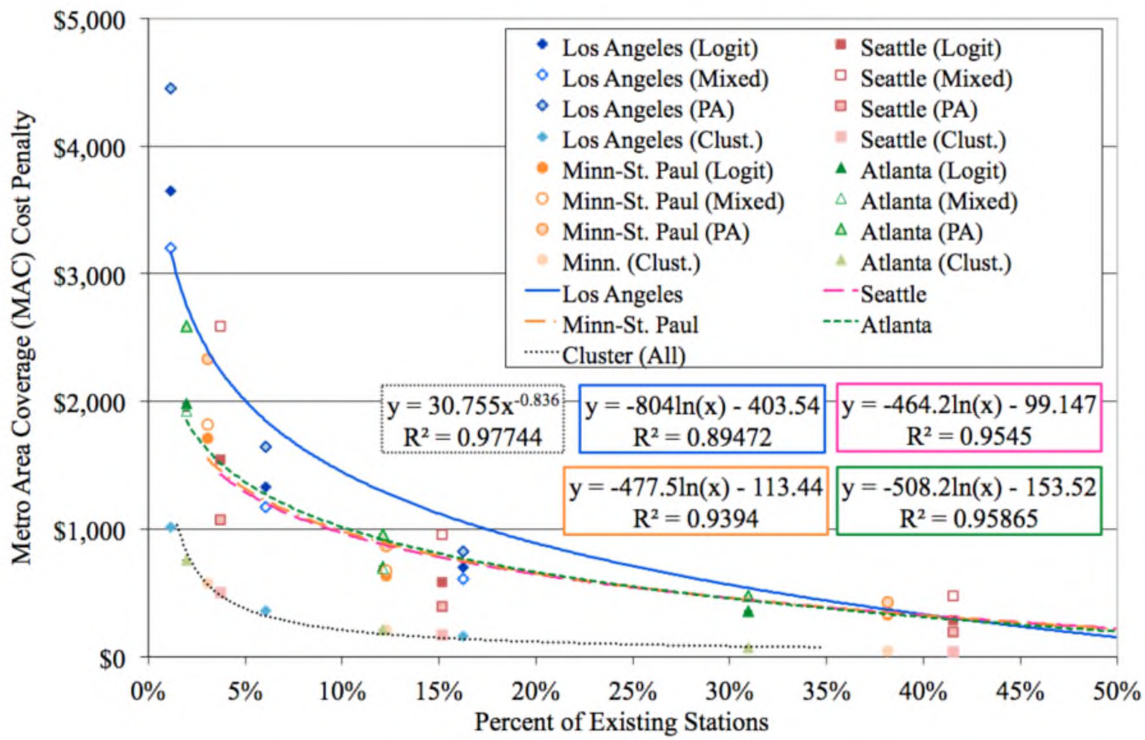
Rational Actor Estimates

A parallel analysis of urban travel time penalties for a "rational" decision maker (additional time needed to drive to stations in a sparse network):

- The "Rational model" based upon a clustering algorithm and travel times suggests **$250 to $1,500** for coverage at 1% to 10% of existing stations.
- This is roughly 3-4 times less than the stated preference penalty for local availability within urban areas.

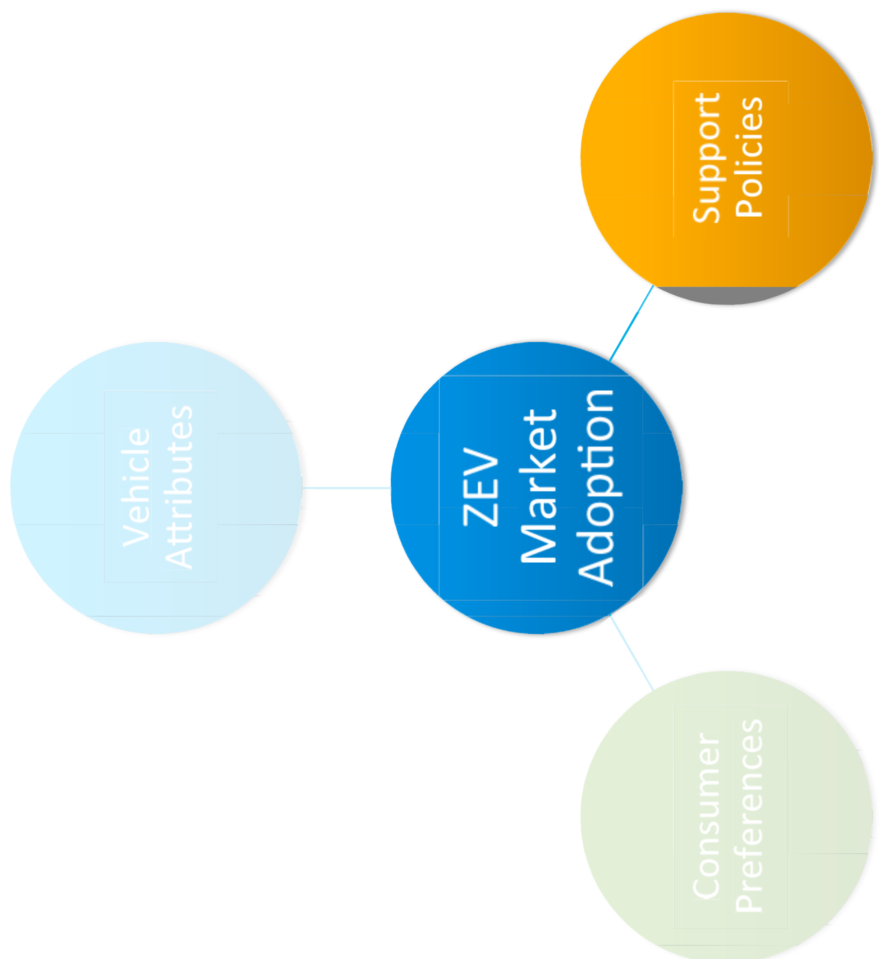
Local Station Availability Penalties

- Cost Penalty Estimates Against the Purchase Price of a New Dedicated AFV for Limited Urban Area Station Availability.
- Graph shows both Survey Results and Cluster Simulations



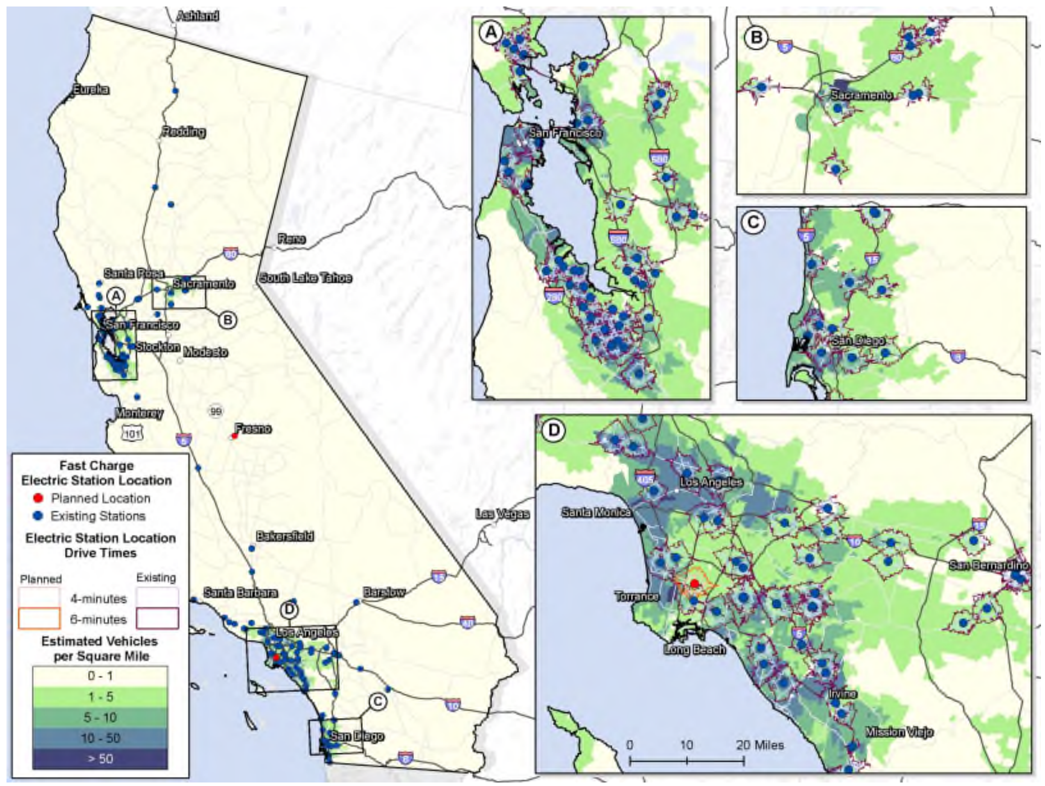
Source: Melaina, Bremson and Solo (2012).

Support Policies



Policy Effectiveness: Sufficient Empirical data?

- As new market data become available, statistical correlations between EVSE deployments and vehicle purchases should emerge
- Statistical fits must take into account a variety of factors, including state and local incentives, inherent consumer vehicle preferences, etc.
- Map at right shows DCFC stations with respect to likely early adopter metric (EAM) results



Source: NREL Infrastructure Market Assessment Report for CEC. Forthcoming

Recommendations for future work

<u>Future Work on Consumer Preferences</u>

New information on consumer responsiveness may be revealed by:

- (1) Examining market trends associated with EVSE infrastructure
- (2) Developing improved survey methods that take into account station availability as a consumer choice factor

<u>Future Work on Policy Support Mechanisms</u>

- Explicit representations of fueling infrastructure may improve market projections and inform market support policies
- Interactions or tradeoffs between vehicle range and EVSE type and availability may influence policy effectiveness


NREL
Questions?
NATIONAL RENEWABLE ENERGY LABORATORY
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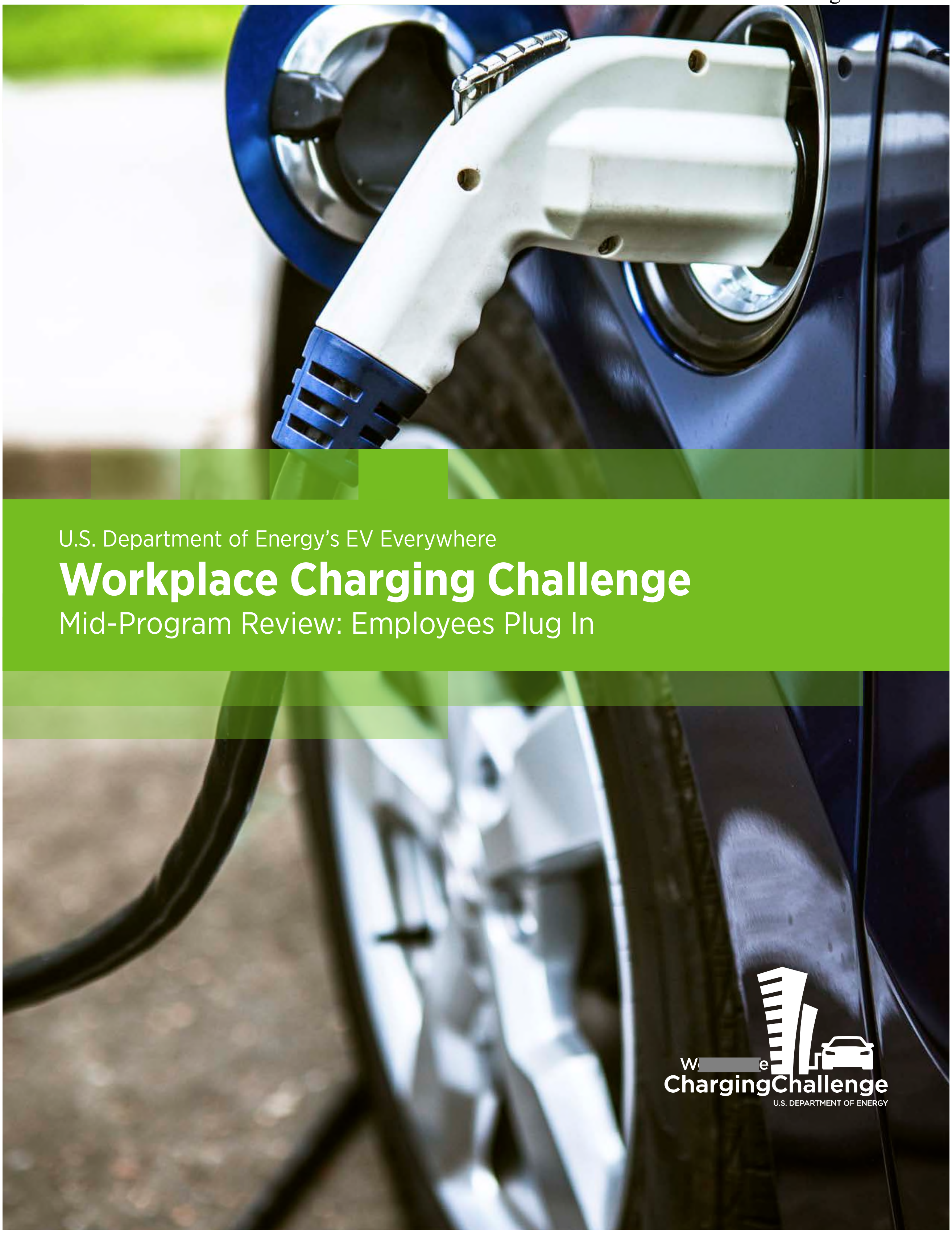


U.S. Department of Energy's EV Everywhere

Workplace Charging Challenge

Mid-Program Review: Employees Plug In

A MESSAGE FROM THE ASSISTANT SECRETARY

Almost three years ago, we kicked off the Workplace Charging Challenge with the goal of having 500 U.S. employers commit to installing workplace plug-in electric vehicle (PEV) charging and joining the Challenge by 2018. I am pleased to share that with more than 250 participants in the Challenge, we are more than halfway there, and the adoption of workplace charging as a sustainable business practice is growing across the country. Thanks to engagement efforts by our internal team, 18 ambassador organizations, our national Clean Cities coalitions, and city and state leaders, the Challenge has expanded its reach in 2015. Now, more than 600 workplaces have installed over 5,500 charging stations that are accessible to nearly one million employees. In addition to our partners, more than 200 other employers also offer charging, showing how the Challenge has acted as a catalyst for the growth of workplace charging even beyond Challenge participants. In fact, the Challenge welcomed the U.S. Department of Transportation (DOT) as the first federal agency partner this year. The DOT's decision to provide charging access to the federal government's workforce underscores its ongoing commitment to leadership in sustainable and innovative transportation alternatives.

This Program Review takes an unprecedented look at the state of workplace charging in the United States—a report made possible by U.S. Department of Energy (Energy Department) leadership and valuable support from our partners as they share their progress in developing robust workplace charging programs.

In 2015, the Energy Department further committed to raising the profile of workplace charging by:

- Establishing the EV Everywhere Utility Partnership by signing a memorandum of understanding with Edison Electric Institute (EEI), which calls upon utilities to promote workplace charging among customers and their own employees
- Promoting the exceptional work of Challenge partners and ambassadors through the Energy Department's social media channels and employer spotlights at workshops across the country
- Recognizing the strong leadership of the Pacific Northwest and welcoming 20 new partners to the Challenge at Drive Oregon's EV Roadmap 8 conference.

To support employers' workplace charging programs, we have:

- Launched a new webinar series to help employers with their workplace charging programs and share experiences among Challenge partners
- Shared technical resources and news through our website and quarterly newsletter
- Collaborated with cities, states, and ambassador organizations to execute workshops aimed at educating employers about the benefits of workplace charging in their communities.

Although 2015 was a year of low gasoline prices averaging $2.42 per gallon, it is more important than ever to support PEV adoption. With new efforts to limit greenhouse gas (GHG) emissions, PEVs will continue to play a major role in increasing environmental and economic sustainability. This is a prime opportunity to make workplace charging a standard across the country instead of an exception.

We would like to thank our partners and ambassadors who are making the transition to PEVs smoother for employees and boosting America's role in the worldwide electrification revolution. With the momentum built since the launch of the Challenge, we are confident that many more U.S. workplaces will decide to make a difference and join the initiative.

Dr. David Danielson
Assistant Secretary for Energy Efficiency and Renewable Energy
U.S. Department of Energy

PLUGGING INTO THE CHALLENGE

In June 2015, the Workplace Charging Challenge distributed a survey[1] to 200 partners with the goal of tracking partners' progress and identifying trends in workplace charging. The 2015 survey responses reflect partners' workplace charging activities between June 2014 and May 2015. A response rate greater than 70% allowed the program to compare it to the 2014 results and highlight how both employers and employees are increasingly valuing workplace charging.

VALUE OF WORKPLACE CHARGING

An innovative employee motivator

According to survey results, employee satisfaction held steady, with 90% of employers indicating that their staff had provided positive feedback on their workplace charging programs. With the addition of workplace charging, PEV-driving employees can nearly double their vehicles' all-electric daily commuting range and feel confident in being able to get where they need to go during and after work.

90% OF PARTNER EMPLOYEES EXPRESS SATISFACTION WITH THEIR WORKSITE'S CHARGING PROGRAM.

Additionally, employees interested in buying a PEV can learn about the benefits of driving electric from their colleagues and may be more likely to consider a PEV, knowing they can conveniently charge up at work.

A valuable tool for reducing oil consumption and greenhouse gas emissions

In the 2015 survey period, partners used an average of 126 kilowatt hours (kWh) per workplace, per day,[2] at employee charging stations. The respondents who provided both charging station counts and electricity utilization used an average of 9.6 kWh per charging station each day, which is representative of 33 miles of electric vehicle miles traveled by a Nissan Leaf. This electricity reduced about 1.3 million gallons of gasoline and about 13 million pounds of GHG emissions at those workplaces between June 2014 and May 2015. Partners who submitted data for both the 2014 and 2015 surveys reported a 76% year-over-year increase in electricity utilization as a result of increased employee demand.

By extrapolating these benefits to include all partner workplace charging stations in operation by June 2015, the Energy Department estimates partners used approximately 11.8 million kWh of electricity over the course of one year. Based on this estimate, Challenge partners will save a combined 1.7 million gallons of gasoline and 17 million pounds of GHGs each year. This is the equivalent of early workplace charging adopters each removing more than nine average gasoline cars from U.S. roads.[3] This catalytic reduction will scale in two dimensions as Challenge partners expand the scope of their efforts and as new partners join the initiative.

A signal of corporate and community leadership

Survey results proved that for a second year in a row, more than half of our partners expanded their PEV promotion activities beyond their own workplaces to help other employers in their workplace charging efforts. Challenge partners are leading change as charging infrastructure leaders in their communities.

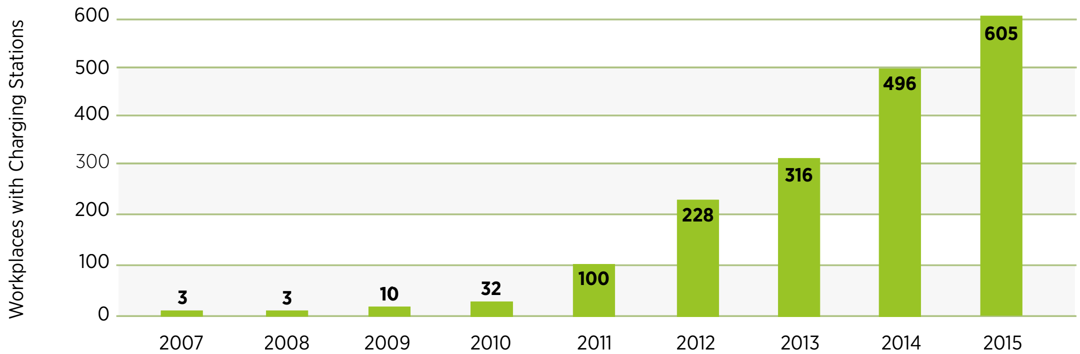
THE NUMBER OF PLANNED AND INSTALLED PARTNER CHARGING STATIONS HAS INCREASED BY 70% SINCE JUNE 2014.

[1] Paperwork Reduction Project (191-5174).

[2] Average calculation reflects only those survey respondents that provided electricity utilization and is based on 250 annual workdays excluding weekends and holidays.

[3] Extrapolation based on the ratio of charging stations at survey respondents' workplaces that reported kilowatt hour (kWh) utilization to charging stations at all workplaces of all survey respondents.

Cumulative Growth in Partner Workplace Locations with Charging Stations



TRENDS

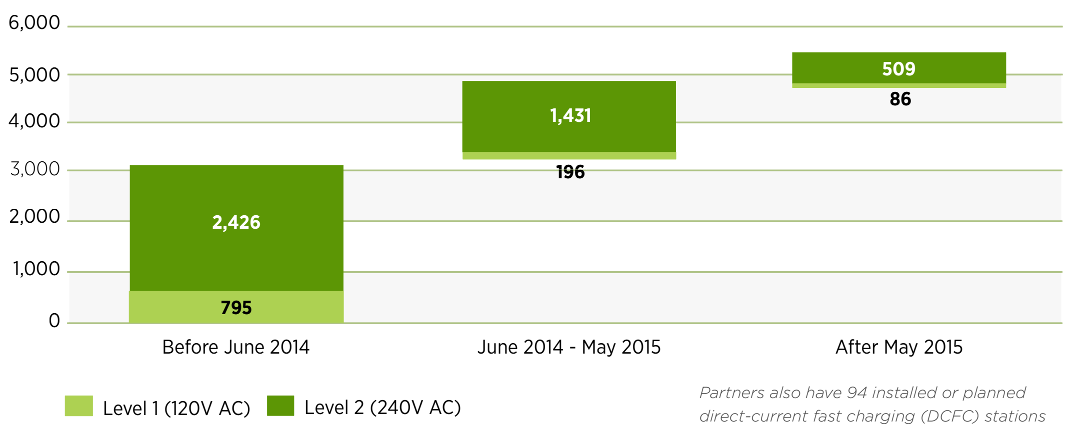
The number of workplaces with charging and the number of stations at those sites is increasing

Partner workplace locations with charging stations increased from 496 in 2014 to 605 in 2015. Further, the number of planned and installed charging stations has increased by 70% since June 2014, demonstrating a growing supply of workplace charging that can provide infrastructure for the increasing number of PEVs purchased by U.S. workers.

PEV ownership is increasing at worksites and across the nation

Challenge partner employees are six times more likely to drive a PEV than the average worker.[4] In total, employees commuting to Challenge partner workplaces now own more than 9,000 PEVs.

Installed and Planned Partner Charging Stations



Partners also have 94 installed or planned direct-current fast charging (DCFC) stations

[4] One in 71 partners' employees drive a PEV, while the national average is one in more than 438 employees. Ratio derived from June 2015 cumulative PEV sales ("Light Duty Electric Drive Vehicles Monthly Sales Updates," Argonne National Laboratory, www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates) divided by 148,739,000 members of the workforce in June 2015 ("Data Tools," Bureau of Labor Statistics, data.bls.gov/cgi-bin/surveymost).

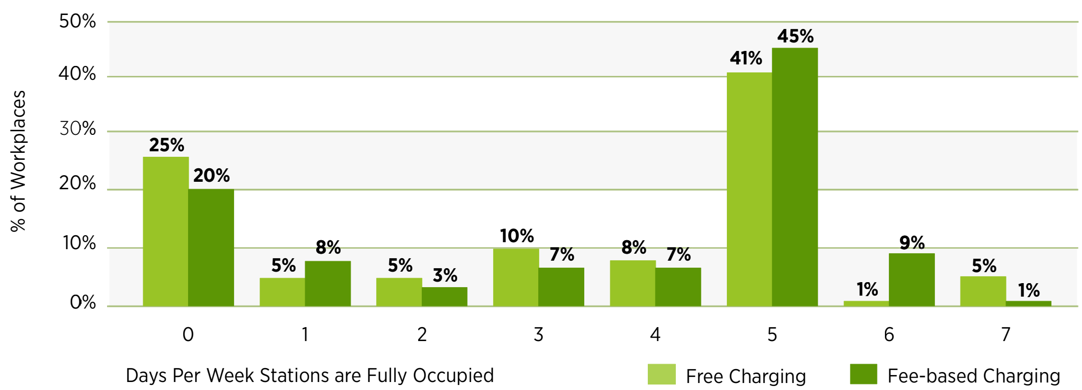
By driving electric, these employees collectively save four million gallons of gasoline and 50 million pounds of GHG each year—the equivalent of removing more than 5,000 average gasoline cars from U.S. roads. The workplace is often referred to as the "second showroom" for PEVs—a place where workers can learn about the benefits of PEVs from their peers. Employers' outreach efforts to educate their staff about PEVs is helping more people realize that driving electric can be a practical and attractive vehicle option.

IN 2015, CHALLENGE PARTNER EMPLOYEES WERE SIX TIMES MORE LIKELY TO DRIVE A PEV THAN THE AVERAGE WORKER.

Stations at workplaces are often fully occupied

Employers observed that the occupancy of charging stations was consistent throughout the week. Eighty-five percent of Challenge partners' PEV drivers plug in at worksites where charging stations are occupied five days a week or more.

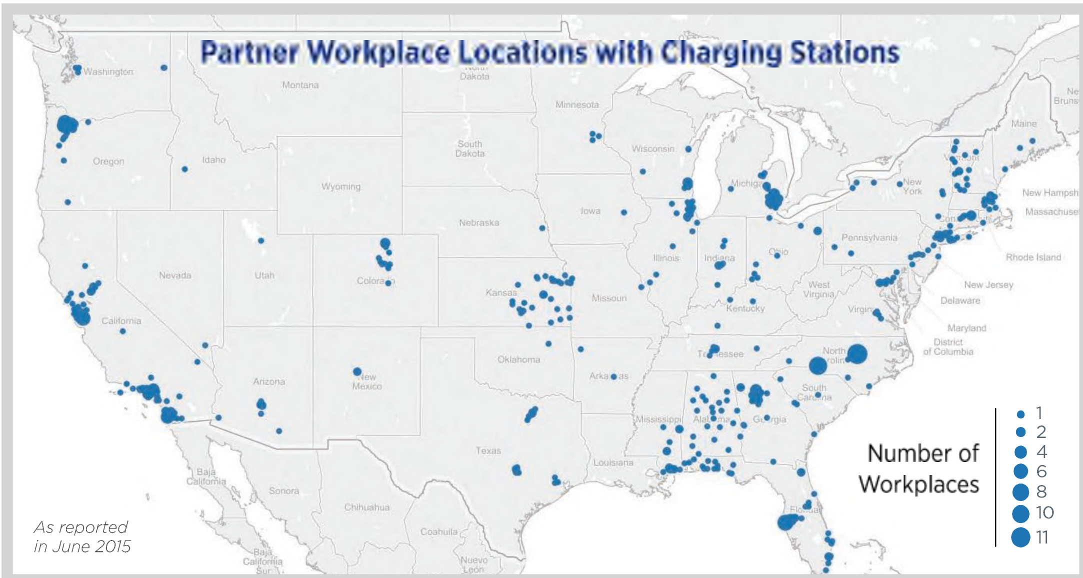
Partner Charging Stations With and Without Fees Have Similar Occupancy Rates



Based on the station occupancy reported by employers, half of workplaces may need to consider adding more stations to meet employee demand. If adding additional infrastructure is not possible, these employers may want to revisit their charging policy to encourage station sharing. Learn more about employee charging station sharing policies at energy.gov/eere/vehicles/workplace-charging-management-policies-sharing.

Most employers offer free charging

Consistent with 2014 survey results, the majority of partners (80%) provide free PEV charging, compared to 20% who charge their employees a fee. Free employee charging can be a factor in an employee's decision to drive electric. However, survey responses show similar occupancy rates of charging stations at workplaces that provide free charging and those that charge a fee. Additionally, as the number of PEV-driving employees increases, employers may need to consider implementing a fee. If an employer institutes a payment system, it is important to develop a fee structure that is not a major barrier to use. In fact, a fee structure may help relieve charging station congestion. Learn more about employee charging pricing policy at energy.gov/eere/vehicles/workplace-charging-management-policies-pricing.



Workplaces with charging stations are distributed among a number of regions across the country

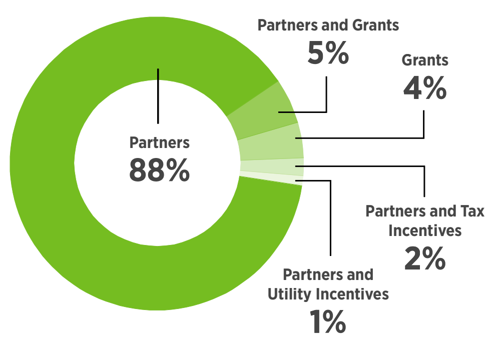
The map above depicts the geographic reach of the program, extending to most major areas of the country. The size of the circles indicates the number of workplaces offering charging in each zip code. Distribution of charging at workplaces in states like Kansas and Alabama is largely due to the leadership shown there by the electric utility sector.

While employers often do not take advantage of them, the majority of workplace stations have been installed in states with charging infrastructure incentives

For workplace charging installed between June 2014 and May 2015, the majority of stations were solely funded by the employer. However, partner worksites with charging infrastructure are far more likely to be located in states with charging infrastructure incentives than states without access to incentives. Of the nearly 5,000 workplace charging stations installed before June 2015, 94% were installed in states with charging station incentives.

In states with charging station incentives, 58 PEVs are registered for every workplace charging station, compared to 41 registered PEVs for every workplace charging station in states without a charging station incentive. It is likely that workplaces are responding to interest in PEVs from their employees, whose purchase decisions are often influenced by financial incentives such as tax credits for both vehicles and charging stations. In addition, many of these states have also made efforts to promote PEVs and lower barriers to their adoption. Learn more about charging station incentives at energy.gov/eere/eveverywhere/ev-everywhere-tax-credits-and-other-incentives.

Funding Mechanisms Used By Partners to Install Charging Stations from June 2014-2015



PARTNER RECOGNITION

Workplace Charging Challenge partners are leading charging infrastructure deployment in their communities and driving PEV adoption among their staff. To help other employers and to measure the progress of the Challenge, partners share their best practices by publishing profiles on the Challenge website, submitting a workplace charging plan, and completing an annual survey. The Energy Department recognizes the following employers for executing all three of these actions for the first time in 2015.

City of Beaverton

The City of Beaverton, Oregon has a goal to meet 100% of the demand from its PEV-driving employees by 2018 at all major worksites. Beaverton hopes to increase employee use of PEVs as well as add more PEVs to its fleet. Other efforts include adopting consistent signage for charging stations, and supporting PEV-related businesses.

DIRECTV

DIRECTV has installed 24 charging stations for employee vehicles, four of which are solar powered, and will install eight charging stations this year. DIRECTV has reduced its U.S. direct emissions and those from purchased electricity by 16% since 2011 and its indirect (Scope 3) emissions by 7% since 2012.

El Camino Real Charter High School

El Camino Real Charter High School in Los Angeles, California, is integrating sustainability throughout the school, both in the physical campus and the curriculum. The school has installed two charging stations for employees, which also generate data that the school uses in its math and science curriculum.

Florida Power & Light Company

Florida Power & Light Company's 70 charging stations are accessible by fleet, employee, and other PEV drivers as part of a pilot program to assess the impact of workplace charging on the electric system. The company is holding workshops to share its experience and engage businesses and their employees across Florida.

Freudenberg-NOK

Freudenberg-NOK aims to be an innovation leader and is committed to reducing emissions. As a producer of advanced sealing technologies used in PEVs, providing employee charging at its headquarters fits clearly into Freudenberg-NOK's Guiding Principles.

Hewlett Packard (HP)

HP employee commuting accounts for close to 30% of the company's carbon footprint from operations. HP recognizes that a shift to PEV commuting can lower its indirect emissions and help it achieve its carbon reduction goals. In 2014, HP provided employees with more than 70 Level 2 charging outlets. Several worksites offer Level 1 charging and one provides direct-current fast charging (DCFC).

Intel

Intel is committed to being at the forefront of sustainable energy initiatives. The company supports employee electric vehicle use by supplying more than 100 charging stations at eight of its campuses in the United States. It is also piloting a new EV4 ETM Charging Station at its Santa Clara, California headquarters, with smart Intel technology and DCFC capability. Understanding the integration of these types of technologies will help advance the development and support the best solutions for implementation.

JEA

JEA is actively engaged with its community to increase the awareness and education of the benefits of driving electric. Workplace charging allows JEA to demonstrate its leadership and assist its customers with achieving their own workplace charging initiatives.

Kohl's

Kohl's is committed to protecting and conserving the environment by seeking innovative solutions that encourage long-term sustainability. Kohl's provides employee charging at four corporate locations, including its headquarters in Menomonee Falls, Wisconsin, and provides free charging for associates and customers at 83 retail locations across 22 states.

Lane Regional Air Protection Agency (LRAPA)

LRAPA is committed to ensuring clean air for everyone in Lane County, Oregon. By joining the Challenge and promoting the use of PEVs, LRAPA is setting an example in the community. Employees and the public are encouraged to charge their vehicles at LRAPA's office. LRAPA has three Level 2 charging stations.

Legrand

Legrand is committed to sustainability and believes that supporting PEV market growth will reduce its GHG emissions. By providing free access to PEV charging stations installed at its facilities, Legrand aims to provide added refueling confidence to employees considering purchasing PEVs. Legrand has installed seven charging stations to date at its three largest facilities and has allocated charging stations to its other North American facilities, to be installed as demand arises.

Lewis and Clark Community College

Lewis and Clark Community College is committed to reaching campus carbon neutrality by 2058. Lewis & Clark views workplace charging as a key component of reducing commuter emissions. With funds from the student body-approved "Student Green Fee," the college installed two charging stations at the main campus and one at the National Great Rivers Research and Education Center.

National Renewable Energy Laboratory (NREL)

NREL staff use workplace charging stations to help meet federal indirect GHG goals, minimize the lab's environmental footprint, and support its sustainable campus vision. The Energy Department's 1,800-car parking garage at the lab's campus includes 36 charging stations, and enables researchers to test various charging scenarios on the utility electrical distribution network.

Nissan

Nissan offers PEV charging to its employees at its headquarters, regional offices, and vehicle assembly plants, with a significant number of the charging units running off of solar power. Nissan has worked with more than 130 major corporations and universities throughout the United States to encourage the installation of PEV chargers on their campuses.

North Central College

North Central College in Illinois has two charging stations that may be used free of charge by students, faculty, staff, and campus visitors. Committed in its efforts to reduce vehicle emissions, the college hopes its charging stations will encourage a trend toward employee and student use of PEVs on its campus. In addition, the college owns two PEVs that utilize the charging stations.

Pacific Gas & Electric (PG&E)

PG&E employees now have an opportunity to charge PEVs at 16 locations. To date, PG&E has installed 511 workplace charging stations. Future plans include installing approximately 200 charging stations per year over the next five years, with 10% of charging stations designated specifically for employee use. PG&E also offers its employees $2,000 to purchase a PEV.

Oak Ridge National Laboratory's (ORNL)

ORNL's Sustainable Campus Initiative includes a roadmap for the development of electric vehicle charging stations, indicating that PEV charging is part of a broad sustainability focus for the laboratory. ORNL has 44 charging stations on campus, 25 of which are solar-assisted. At the end of 2014, almost 40 employees were driving PEVs to work at ORNL.

Prairie State College

Prairie State College has made two Level 2 charging stations with three outlets available for employee, student, and community use. As part of the college's PEV initiative, eight parking spots in front of the main entrance were converted to green parking. The school has been working with other community colleges to further charging station and PEV research.

Salt River Project (SRP)

SRP's mission is to encourage greater use of clean energy transportation. As part of this program SRP installed two workplace charging stations in 2010. In response to increasing employee demand, SRP now has more than 90 Level 2 charging stations in total, with 35 of those stations spread across eight facilities dedicated to employee charging.

SAS Institute

SAS Institute assigns top priority to minimizing energy consumption and related emissions from its operations. The SAS Eco-Commuter Parking Program includes 100 designated PEV spaces with access to 48 charging stations. At the beginning of 2015, employees at SAS headquarters in Cary, North Carolina, represented approximately 4% of PEVs in the state.

Sears Holdings

Sears Holdings first installed two charging stations at their corporate campus in 2012, and installed seven more chargers in 2013. The company hosts a PEV group on an internal social media site that allows PEV drivers to notify each other when chargers are full or available, as well as let management know if chargers are malfunctioning.

SolarWorld

SolarWorld's commitment to sustainability is embedded in every aspect of its business and documented in its annual report. SolarWorld installed its first workplace charging station at its U.S. manufacturing headquarters in 2011. It installed its second station, a DCFC, in 2014. SolarWorld has committed to reducing its company-wide GHG emissions 35% by 2020.

Southern Company

Southern Company offers free charging stations for employees at office locations across Georgia, Alabama, Mississippi, and Florida for its four operating units—Georgia Power, Alabama Power, Mississippi Power, and Gulf Power. More than 350 Southern employees drive electric vehicles.

Suffolk County Community College

Suffolk County Community College is the largest community college in New York, with approximately 27,000 students enrolled at three campuses in Selden, Brentwood, and Riverhead. The college has installed four charging stations at each of its three campuses. The charging stations are used by faculty, staff, students, and the general public.

Thomas College

Thomas College is committed to supporting employee and student sustainability efforts. It encourages employees to drive electric by offering designated PEV parking. In 2013, Thomas College installed two Level 1 chargers that are free for employee use. In November of 2015, Thomas College added an additional two Level 2 chargers for student and employee use.

University of Maine

The University of Maine's 100,000 square-foot Advanced Structures and Composites Center was the first LEED-certified building on the campus. As part of the LEED Gold certification awarded for the Offshore Wind Lab expansion, the center is in process of installing four charging stations adjacent to its main entrance with financial support provided by the university's Class of 1944.

University of North Carolina at Pembroke

The University of North Carolina at Pembroke views workplace charging as one of the commuting transportation strategies that supports the campus' sustainability goal of becoming carbon neutral by the year 2050. GHG emissions from the off-campus production of purchased electricity utilized by PEV drivers plugged in to any one of the campus' four charging stations are offset by the four kilowatts of dedicated solar photovoltaic capacity elsewhere on campus—creating a net-zero installation.

PARTNERS

Workplace Charging Challenge partners commit to assessing employee demand for PEV charging at the workplace and developing and executing a plan to provide PEV charging access for employees. As of November 2015, 255 employers have joined as partners in the Challenge.

Education

Appalachian State University
Bard College
Clarkson University
College of Lake County -
Colorado State University
Eastern Connecticut State University
Eastern Washington University
El Camino Real Charter High School *
Georgia Institute of Technology -*
Gonzaga University
Harvard University -*
Heartland Community College -*
Kankakee Community College -*
Kansas State University *
Kaskaskia College -*
Lewis & Clark College
Lewis and Clark Community College *
Louisiana State University
North Central College *
Northern Illinois University *
Oregon State University
Owensboro Community and Technical College
Pomona College
Portland State University
Prairie State College -*
Purchase College *
Rhode Island College
Stanford University
Suffolk County Community College *
SUNY Empire State College
SUNY New Paltz *
Swarthmore College
Thomas College *
Township High School District 214 *
University at Albany (SUNY Albany)
University at Buffalo
University of Alaska Southeast
University of California Davis
University of California Fullerton
University of California Santa Barbara*
University of California Los Angeles - Smart Grid Energy Research Center
University of Connecticut *
University of Hawaii - Hilo
University of Louisville -
University of Maine *
University of Massachusetts Lowell
University of North Carolina Pembroke -*
University of Pittsburgh
University of Rhode Island
University of Vermont

State and Local

Atlanta Regional Commission
City of Atlanta
City of Auburn Hills -*
City of Beaverton -*
City of Benicia
City of Fort Collins
City of Hillsboro -*
City of Palm Springs *
City of Sacramento -*
County of Alameda -*
County of Broward, FL -*
Lane Regional Air Protection Agency-*
State of Illinois
State of Oregon
Ulster County, NY

Utilities/Energy Companies

Austin Energy *
Avista Utilities*
Clark Public Utilities
ComEd
Consumers Energy (ConEd)
Dominion Resources -*
DTE Energy *
Duke Energy -
Florida Power & Light Company *
Great River Energy *
Green Mountain Power -*
JEA *
Kansas City Power and Light Company
Los Angeles Department of Water and Power
National Grid
New York Power Authority *
NYSERDA *
NRG Energy
Orlando Utilities Commission
Pacific Gas & Electric *
Pepco Holdings
PJM Interconnection
PNM Resources *
Portland General Electric
PPL Electric Utilities
PSE&G (Public Service Electric and Gas Company)
Salt River Project *
San Diego Gas & Electric *
Southern California Edison *
Southern Company *
TECO Energy *
Westar Energy *
Wisconsin Public Service Corporation*
Xcel Energy *

Other

200 Market Associates
3M -*
ABB -*
Advanced Micro Devices
Advocate Health Care
AeroVironment -*
American Honda Motor Co.*
American Lung Association - Colorado
American Spraytech
APEI -*
Argonne National Laboratory
Atomic Auto
AVL-*
Bah-Fo Studio
Baxter Healthcare Corporation -*
Bayer
BECO South
Bentley Systems -*
Biogen Idec -
Black & Veatch
Bloomberg LP -*
BMW North America
BookFactory -*
Bosch Automotive Service Solutions
Brendle Group *
Capital One -*
CFV Solar Test Laboratory *
ChargePoint -*
Cigna *
Cisco -*
Classique Floors *
Clipper Creek -*
Concurrent Design -*
Conrad N Hilton Foundation
Continental Electrical Construction Company *
CravenSpeed
Dell -*
DIRECTV *
Duro-Last *
Eaton
Electric Applications *
Electric Power Research Institute *
Eli Lilly -
EMC Corporation -
EMD Serono *
Envision Solar *
EV4Oregon *
EV Connect
EV Grid
Evolution Marketing
Facebook -*
FCA US -*
FEV -
Ford -*
Fraunhofer Center for Sustainable Energy Systems -*
Freedom Solar
Freudenberg-NOK *
FreeWire
Fuji Electric Corp. of America
General Electric -
General Motors -*
Google -*
Green Cab VT
Green Wheels
Greenlots -
Hannah Solar
Harris Civil Engineers *
Hawthorne Auto Clinic
Hertz
Hewlett-Packard *
Hollywood Woodwork *
IBEW #48
IDEXX Laboratories *
Innova UEV
Intel -*
Intertek
JLA Public Involvement -*
Kaiser Permanente -
KEMET
Ken's Muffler & Automotive
Kia Motors America
Kohl's -*
Law Office of Karen Dalglish Seal
Lawrence Berkeley National Laboratory -*
Legrand *
Leviton
Lynda.com -*
Marshall Auto Body *
Mast Collaborative
Melink Corp -*
Mentor Graphics -
MetLife
Mitsubishi
MOM's Organic Market
NASCAR -*
National Renewable Energy Laboratory *
Neil Kelly Company
NetApp -
Nissan *
Northwest Evaluation Association
Oak Ridge National Laboratory *
Odell Brewing Company *
OpConnect -
Organic Valley *
OSRAM SYLVANIA -*
Owens Corning
Paired Power
Pat's Garage
Pentair Water Pool and Spa *
Phil Haupt Electric -
Port of Portland
Posty Cards
Providence Health & Services -
Puget Sound Solar
Raytheon -*
Realty Trust Group
Rinehart Motion Systems
Rockwood Lithium
Rogue Rovers
Samsung Electronics -*
SAP -*
SAS Institute -*
Schneider Electric -*
Sears Holdings *
SemaConnect -*
Shorepower Technologies -*
Siemens
Sierra Nevada -*
SIT World Learning
SolarWorld *
Spirae *
Sprint *
Straus Family Creamery *
Telefonix *
Territo Electric
Tesla
The Coca-Cola Company -*
The Hartford -*
The Venetian and The Palazzo
Tube Art Group
UL LLC -*
University of Maryland-Baltimore Washington Medical Center -*
Unum
U.S. Department of Transportation
Utah Paperbox *
Utilidata
Verizon -*
Vermont Energy Investment Corp -*
Vernier Software
Volkswagen Group of America
Washington Area New Auto Dealers Association *
WESCO
World Wildlife Fund -
Zappos -*
Zenith Motors
Zero Motorcycles

** partners who completed the survey in 2015*

- partners who completed the survey in 2014

AMBASSADORS

The Challenge's success so far would not have occurred without the efforts of the program's ambassadors. Ambassadors are stakeholder organizations that commit to developing and executing a plan to support and promote deployment of workplace charging infrastructure.

Ambassador recruitment of new Challenge partners:

- **The Edison Electric Institute (EEI)** joined the Energy Department in a partnership to accelerate widespread PEV adoption. As part of this agreement, many EEI member utilities are promoting PEVs among their own employees and helping their commercial customers deploy charging infrastructure at their worksites.
- For the second year, **Drive Oregon** has recruited more new Challenge partners than any other ambassador organization. In July, it recognized 20 new Oregon Workplace Charging Challenge partners at EV Roadmap 8.
- In total, standout ambassadors **Advanced Energy, the California Plug-In Electric Vehicle Collaborative, Drive Oregon, EEI, the Electric Drive Transportation Association, the Electrification Coalition**, and **Plug-In America** helped recruit 26 new Challenge partners in 2015.
- **Clean Cities Ambassadors**, including the Alamo Area, Chicago Area, Greater New Haven, Kansas City Regional, Ocean State, and the Greater Washington Region **Clean Cities Coalitions**, helped sign up 10 new Challenge partners.

Ambassador-produced workplace charging informational resources:

- **Advanced Energy** developed nine new support pieces for use by employers and employees who are interested in workplace charging.
- **CALSTART** developed a workplace charging cost calculator to help employers determine the feasibility of offering workplace charging and released a summary of workplace charging policies and incentives.
- **Drive Electric Minnesota** has developed resources for Minnesota employers, including a guide to funding sources in the state.
- The **Transportation and Climate Initiative** has developed resources to assist with charging station siting and installation.

Ambassador workplace charging outreach efforts:

- The **California Plug-In Electric Vehicle Collaborative** held Drive the Dream 2015 with California Governor Jerry Brown to spur workplace charging among California employers. The Collaborative also held educational webinars focused on small businesses and managing charging stations at the workplace.
- **Clean Fuels Ohio, CALSTART**, and the **International Parking Institute** held workplace charging webinars for employers.
- Through the **Center for Sustainable Energy (CSE)** Experience Electric – the Better Ride program, CSE held a variety of PEV educational events throughout the San Francisco Bay Area, including at workplaces. Among CSE's partners in conducting these ride-and-drive events is fellow Challenge ambassador **Plug In America (PIA)**. PIA is one of the team members behind National Drive Electric Week, which included events on workplace campuses in 2015.
- **Drive Electric Vermont** launched DRIVE THE DREAM VERMONT with Vermont Governor Peter Shumlin to recognize the commitments of Vermont employers who pledged to support workplace charging, PEV fleet purchases, and/or employee incentives to purchase PEVs.
- As part of the Drive Electric Northern Colorado partnership, the **Electrification Coalition** launched a recognition effort for local employers who commit to providing workplace charging. They also held an educational workshop for employers interested in workplace charging.
- **Drive Oregon** and various **Clean Cities Coalitions**, including the Lone Star Clean Fuel Alliance, Alamo Area, Dallas-Fort Worth, Houston-Galveston, Chicago Area, Denver Metro, and Virginia coalitions, held workplace charging workshops during the past year.

JOIN THE CHARGE: BECOME A WORKPLACE CHARGING CHALLENGE PARTNER

The Energy Department's Workplace Charging Challenge is open to employers of all sizes and industry types, in all regions of the United States. Taking the Challenge offers benefits to employers who are considering installing PEV charging stations, as well as those who have already launched workplace charging programs. Becoming a partner in the Challenge allows your organization to gain access to informational resources, peer-to-peer networking, one-on-one technical assistance, and recognition for your workplace charging efforts. More than 60% of partners surveyed reported receiving recognition for their workplace charging efforts. Survey respondents also noted that they are receiving positive staff feedback, with 90% of partners' employees expressing satisfaction with their workplace charging program.
To learn more and join the Challenge, contact WorkplaceCharging@ee.doe.gov.

Sign the Workplace Charging Challenge Pledge

The Energy Department is inviting employers to advance the deployment of PEVs by signing the Workplace Charging Challenge Pledge, a commitment to providing employee charging. Learn more about the Challenge and how to join at energy.gov/eere/vehicles/ev-everywhere-workplace-charging-challenge.

EV Everywhere
U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102015-4836 • December 2015

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WHITE PAPER

MARCH 2017

ELECTRIC VEHICLE CAPITALS OF THE WORLD

DEMONSTRATING THE PATH TO ELECTRIC DRIVE

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EXECUTIVE SUMMARY

Many cities around the world see the transition to electric vehicles as key to improving local air quality and mitigating climate change. Electric vehicles reduce greenhouse gas emissions, improve air quality, and lessen dependence on oil, enabling a transition to renewable energy and sustainable transportation. Large, high-profile cities can play a special leadership role developing and testing innovative policy actions before more widespread adoption. By examining some of the world's preeminent electric mobility cities, or "electric vehicle capitals," in this report, we look to glean lessons on the critical first steps to accelerate a global transition to electric drive.

This report assesses major cities that are leaders in promoting electric vehicles around the world, quantifies their market successes to date, and discusses the underlying contributing factors for each. We identify 14 major metropolitan areas in North America, Europe, and China that led their respective countries in electric vehicle uptake or sales shares in 2015. Only metropolitan areas with a population over 1 million residents are included in this analysis. For each city, we summarize the policy, infrastructure, and consumer awareness actions that have been put in place to grow the market in these world-leading electric vehicle markets. The markets are evaluated at the metropolitan area level to incorporate the urban center and the surrounding commuting area. We compare electric and conventional vehicle life-cycle emission data to assess the new technology's relative climatic impact in these pioneering electric vehicle markets.

Figure ES-1 illustrates electric vehicle sales and sales shares of the 14 electric vehicle capital cities. These are the foremost major markets in terms of their relatively rapid deployment of electric vehicles at the early stage of electric vehicle market growth in 2015. The data points show the share of new passenger vehicles that are plug-in electric vehicles, and the vertical bars summarize new electric vehicle registrations in 2015 to indicate the overall size of the market.

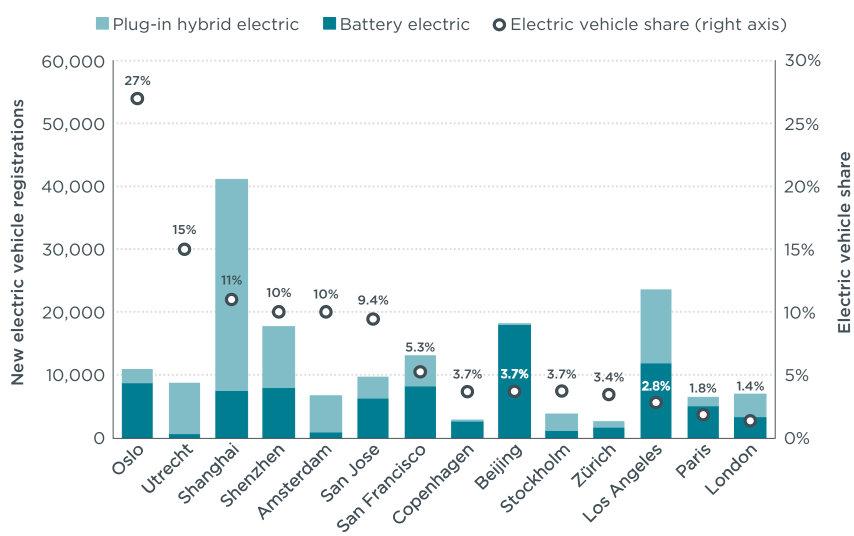

Figure ES-1. Electric vehicle new registrations and share of new vehicles in 2015 in high electric vehicle uptake markets. (*New vehicle registration data from IHS Markit and IHS Automotive*)

Based on this analysis, the top markets by electric vehicle share of new passenger vehicles are Oslo (27%), Utrecht (15%), Shanghai (11%), Shenzhen (10%), Amsterdam (10%), and San Jose (9.4%). For comparison, only 0.8% of new passenger cars sold worldwide in 2015 were electric vehicles (i.e., plug-in hybrid and full battery electric). In terms of total volume, the highest annual sales markets are Shanghai, Los Angeles, and Beijing, which recorded between 18,000 and 42,000 new electric vehicle registrations in 2015. Overall, the 14 electric vehicle capitals presented in this study have from two to over 30 times the global electric vehicle sales rate.

We highlight the following three findings:

> ***Nearly a third of global electric vehicle sales are in just 14 electric vehicle capitals.*** Fourteen metropolitan areas, representing only about 1.5% of the global population, accounted for 32% of new electric vehicles in 2015. These hot spots for electric vehicle growth are demonstrating the first major steps toward the mainstream deployment and integration of new electric vehicle technologies. The foremost 2015 markets within China, Europe, and the United States have annual electric vehicle sales that are in the tens of thousands per year or make up at least one in every 10 new passenger vehicles sold.

> ***Electric vehicle capital cities use a comprehensive suite of electric vehicle promotion actions to spur the market.*** High electric vehicle uptake markets address the prevailing electric vehicle consumer barriers of cost with incentives, convenience with extensive charging infrastructure, and consumer awareness with promotional campaigns. At the same time, these markets' policy actions are tailored to unique local conditions, for example, to their geography (e.g., waiving tunnel tolls in Norway), city layout (e.g., congestion zones in London, carpool lanes in Los Angeles), incentive options (e.g., tax exemption in Europe), or vehicle licensing policies (e.g., exemption from registration lotteries in Beijing and Shanghai).

> ***Electric vehicles deliver a low-carbon transport option.*** Cities that are accelerating the transition to electric drive are achieving significant carbon emission reductions in their transportation sector. Even after incorporating upstream emissions, electric vehicles provide carbon emission reduction benefits of 30% to more than 98% compared to conventional vehicles across the China, Europe, and U.S. markets. Further improvements are expected as the electric grids continue to decarbonize.

These cities demonstrate many best-practice electric vehicle support policies and can act as models for other cities that seek to accelerate their transition to electric vehicles. Many of these policies could be more universally applied around the world, if tailored to a local policy context. Future work would continue to examine questions related to the effectiveness of individual policies, the diffusion of electric vehicle uptake beyond these capital cities, charging infrastructure benchmarks as markets grow, and the prospects for increasingly powering electric vehicles from renewable electricity sources. The importance of the various policy approaches could also shift as lower cost and higher range electric vehicles enter the market. In addition, future work would ideally assess the electrification opportunities more broadly—including increasingly electric-powered car-sharing, transit, and freight movement—as the technology advances.

I. INTRODUCTION

Cities are an important focal point for culture, commerce, and our daily travel patterns. Many cities around the world have struggled to thrive and grow while developing sustainable transportation systems. Some of these cities are seeing the transition to electric vehicles as a key to improving local air quality, mitigating climate change, and growing the economy. Capital cities—be they the formal seat of policymaking or informal leader in a particular market development—play a special role in developing, implementing, and testing innovative policy actions before more widespread adoption of emerging best practices.

Are there "electric vehicle capital" cities emerging, where cutting-edge electric vehicle actions are taking root and broadening the market? This idea of electric vehicle capitals has been introduced in the statements and ambitions of many mayors around the world. The mayors of Oakland, San Francisco, and San Jose, California, have established a joint goal to make the Bay Area region the electric vehicle capital of the United States. The mayor of Los Angeles also has announced the city's intention to compete for the same title (Office of the Mayor of San Francisco, 2011; Office of the Mayor of Los Angeles, 2010). Other U.S. mayors and industry leaders have expressed similar ambitions for their respective cities to become electric vehicle market leaders, including Houston, Texas, and Portland, Oregon (Green Houston, 2010; Adams, 2009).

Several policymakers in Europe have aspired to lead the world in electric mobility. In 2009, the mayor of London launched a plan to make the city the electric car capital of Europe (Jha, 2009), and subsequent mayors have reiterated this commitment (Greater London Authority, 2015 and 2016). Oslo, Norway's numerous electric vehicle activities often put the city front and center in global electric vehicle discussion, and its mayors have committed and reaffirmed the city's pioneering role as the electric vehicle capital of the world (Grundberg & Rolander, 2013; Bymiljøetaten Oslo, 2015). Amsterdam has proclaimed that no other city in the world is as far ahead in the transition to electric transport (Gemeente Amsterdam, 2016). Stockholm also shares the ambition to be the world leader in clean vehicles, envisioning that electric vehicles will play an important role (City of Stockholm, 2012)

The rapid growth of electric vehicles in China suggests that some of the major hubs there are greatly outpacing electric vehicle sales in prominent U.S. and European markets. The Beijing municipal government has launched an action plan to make the city a globally leading electric vehicle market. Electric vehicles are seen as a promising solution to reduce vehicle pollution while sustaining personal mobility and economic growth in many cities in China. Shanghai in particular was declared an international electric vehicle demonstration city by the central government, and this has led to many local policies and promotion activities. Others see Hong Kong as a special beacon city for electric vehicle growth in Asia (Ng, 2016). Pioneering policymakers are working hard to establish their cities as electric vehicle hubs, creating a "race to the top" that could lead to benefits for all.

By examining the cities with the highest electric vehicle uptake around the world, we seek to glean lessons on what it might take to start the global transition to electric drive. In particular, we have collected information on national, state, and local policies and how they have created a favorable policy environment to accelerate electric vehicle adoption. In addition, we investigated the extent of public charging infrastructure and any actions that have helped build out those networks. In the rapidly changing electric vehicle market, these cities demonstrate private and public promotion activities that can be emulated elsewhere.

This paper identifies and analyzes "electric vehicle capitals" around the world that could provide examples of the types of actions that could be more widely embraced to further grow the electric vehicle market. We analyze the top North America, Europe, and China markets that accounted for well over 90% of global electric vehicles sales. To focus the study, we limited our analysis to metropolitan areas with at least 1 million residents and over 1% electric vehicle sales share in 2015. Based on these criteria, we identified high electric vehicle uptake cities by their high electric vehicle sales share and sales volume in major markets, and assessed the prevailing promotional actions in place in each. Additional cities are presented in the Annex, and other markets could be included in future work as the applicable data become available.

The data in this report come from many sources. Vehicle registration data are from IHS Markit for Denmark, Germany, the Netherlands, Sweden, Switzerland, the United Kingdom; Council for Information on Road Traffic for Norway (2016); IHS Automotive for the United States; and EV100 for China. These sources are based on new vehicle registrations, which we consider equivalent to new vehicle sales for this analysis. Although analysis of German vehicle data was included, a comparably high electric vehicle market city was not identified there. Data sources for carbon emissions and charging infrastructure vary by country and are provided in the Annex. Each region is assessed at the metropolitan area level to incorporate the urban center and the surrounding commuting area, as geographic definitions vary widely among countries. Metropolitan area definitions are given in the Annex. In each metropolitan area, we analyzed the vehicle data and reviewed policy, infrastructure, and consumer awareness actions in place.

II. DRIVERS FOR ELECTRIC VEHICLE UPTAKE

Extensive research has shown that high electric vehicle uptake is correlated with a variety of supporting policies and activities. The cities discussed in this paper all have implemented a number of such actions to achieve their electric vehicle goals. These electric vehicle support actions tend to address the prevailing electric vehicle barriers of cost (typically with incentives, exemptions from fees and tolls), convenience (with charging infrastructure, parking, and preferential local access), and consumer awareness (promotional campaigns, fleets, public-private initiatives, and trial projects). For each of the selected cities in this paper, we highlight notable actions in the following five categories.

Financial incentives. Financial incentives are found to be important drivers of electric vehicle sales, and are present in almost every major electric vehicle market (Yang et al., 2016; Vergis, Turrentine, Fulton & Fulton, 2014; Mock & Yang, 2014). There are a number of ways in which governments financially incentivize electric vehicles. The United States offers an income tax credit of up to $7,500 for purchasing an electric vehicle, which is not received by consumers until the end of the tax year. More commonly, governments, such as Sweden and Japan, offer upfront rebates to reduce the purchase price of electric vehicles. Additionally, many jurisdictions offer tax and fee exemptions, both for vehicle purchase taxes and for annual circulation taxes or registration fees. Subsidies vary based on a number of criteria, including vehicle battery capacity or range, and in some cases only battery electric vehicles (BEVs), not plug-in hybrid electric vehicles (PHEVs), are eligible. Additionally, company and private vehicles may be ineligible for different incentive levels. Additional restrictions may help to target funding toward the most hard-to-reach market segments. For example, income and vehicle price thresholds are increasing being used (e.g., DeShazo et al., 2016). Federal or state governments are most commonly responsible for incentive programs, but some city governments provide their own subsidies, and utility companies sometimes provide subsidies for home charging stations and vehicles (Salisbury & Toor, 2016).

Nonfinancial incentives. Beyond financial incentives, many other electric vehicle promotion actions also are linked to electric vehicle uptake. Common forms include special benefits for electric vehicle drivers, such as free parking, access to high-occupancy vehicle (HOV) lanes, access to Low Emission Zones, and exemption from fees for tunnels or congestion areas. By offering and publicizing such programs, governments at all levels can increase electric vehicle uptake (Lutsey et al., 2016; Haugneland & Kvisle, 2013). Sales mandates and government quotas also can lead to greater electric vehicle availability and uptake. California is a prominent example of this policy (Reichmuth & Anair, 2016; Searle et al., 2016). The range of actions depends on the physical and policy context of each city. For example, the rugged terrain in Norway allows for the popular tunnel and ferry fee exemptions for electric vehicle owners, and the vehicle quota system in Shanghai enables the government to give preferential registration to electric vehicles (Dansk Elbil Alliance, 2016; Wang & Liu, 2015). Cities around the world continue to explore various policies in these areas as programs are created and modified and electric vehicles reach mainstream markets.

Charging Infrastructure. The availability of charging infrastructure is linked to electric vehicle uptake around the world. Greater charging availability helps address key consumer barriers regarding the range and the convenience of electric vehicles.

Charging of vehicle batteries tends to be largely done at home, and several studies have shown that availability of home charging infrastructure can increase interest in electric vehicles (Bailie et al., 2015). The deployment of public charging infrastructure has been found in a variety of studies to help encourage electric vehicle purchases (e.g., Bakker & Trip, 2013; Li et al., 2016; Lutsey et al., 2015; Sierzchula et al., 2014; Vergis & Chen, 2014). Expanded charging infrastructure increases electric vehicle user confidence and makes greater range and functionality possible. Charging networks also elevate the visibility of electric vehicle use and can offer broader grid benefits. For these reasons, a number of governments have subsidized and encouraged the construction of public charging infrastructure by private companies and electric utilities. As the market matures, there are a number of models for the future development of public charging networks (e.g., Bakker & Trip, 2015; van Deventer et al., 2015).

Research and campaigns. Electric vehicles are a quickly evolving technology, and governments at the federal and local levels can play a role in steering electric vehicle research, market development, and campaigns to promote electric vehicles. Several countries, such as China and Germany, have designated certain areas as electric vehicle pilot or model regions where best practices in consumer outreach, charging infrastructure deployment, and vehicle-grid integration can be determined (Wang & Liu, 2015; Vergis et al., 2014). Universities also can play a major role in advancing electric vehicle technologies and studying consumer and driver behavior. In the rapidly growing field of vehicle-grid integration, electric power utilities around the world have launched research projects and trials regarding smart charging, the impacts of electric vehicle charging, and new charging infrastructure (Hall & Lutsey, 2017). Additionally, government-run consumer awareness campaigns can be very important in informing consumers about the benefits of electric vehicles and the presence of incentive programs, while also helping to inform the design of new technologies and policies (Greene & Ji, 2016). Research projects and consumer campaigns help support market growth by engaging various stakeholders and promoting awareness and education related to electric vehicle developments and model availability.

Transit and fleets. Another avenue for increasing the number of electric vehicles and their visibility in a city is the electrification of a city's transit and fleets. Electric buses have attracted growing interest in recent years – these buses can significantly reduce noise and localized pollution in addition to promoting clean transportation (Adheesh et al., 2016). Likewise, taxis are a prominent fixture of the transportation landscape in many cities and have duty cycles that could correspond well with electric vehicles; some cities, such as Amsterdam, are working to electrify their entire taxi fleet (City of Amsterdam, 2015). Electrified taxi fleets, as well as electric car-sharing programs, could have the effect of exposing people to electric vehicles and normalizing the technology, in addition to providing immediate environmental benefits.

III. ANALYSIS OF TOP ELECTRIC VEHICLE MARKETS

This section includes profiles of each of the 14 identified high electric vehicle uptake cities around the world and their efforts to promote electric vehicles. The analyses include electric vehicle sales figures, data on electric vehicle charging infrastructure, and the associated emissions from power generation in the respective countries. Furthermore, we summarize government and public-private programs in the categories of financial incentives, nonfinancial incentives, charging infrastructure, research and campaigns, and transit and fleets. In addition to profiling these top electric vehicle uptake cities, we discuss policies and programs in place at the national level that play a significant role in the local market. In the summary tables for each city, we include a qualitative ranking based on how extensive the electric vehicle support activities are in each area. Further details on the data sources and assumptions underlying the analyses are provided in the Annex.

CHINA

The approximately 200,000 new electric passenger cars sold in China represented about 35% of 2015 global electric vehicle sales and accounted for almost 1% of all new passenger vehicles sold in China in that year. The country has a variety of national policies and promotional actions in place that have supported the development of the electric vehicle market. These programs include central government incentives that are valued at up to 54,000 Chinese yuan ($8,000) for the purchase of new electric vehicles (Yang et al., 2016). China is developing a plan to promote additional electric vehicle sales in upcoming years through a New Energy Vehicle credit system or a New Energy Vehicle carbon quota system (Cui et al., 2016).

The central government encourages municipalities to support the advancement of public charging infrastructure by providing policy support, subsidizing construction of charging stations, and issuing guidelines for charging technology standards, city planning, land use policy, and electricity pricing (State Council, 2014). China's state-owned electric utility State Grid Corporation is working to build national networks of fast charging stations (Mitchell, 2015). In 2015, the State Council set the targets of having at least one charging station per every 2,000 electric vehicles and by 2020 achieving a charging infrastructure to support 5 million electric vehicles (Office of the State Council, 2015).

Many cities in China offer additional consumer fiscal rebates and other actions for electric private cars as well as for buses. From 2009 to 2012, the original Ten Cities, Thousand Vehicles program expanded to 25 cities, and the pilot city programs have themselves grown in scope. These pilot cities have used incentives, charging infrastructure, and other promotion activities to increase their electric vehicle readiness (Wang & Liu, 2015). In addition, several major cities in China have restrictions on vehicle registrations and use to help curb congestion and pollution, and electric vehicles sometimes are exempted from such restrictions. The many pilot cities have had varying levels of success, and three markets in China stand out. Shanghai, Shenzhen, and Beijing, which are profiled below, have the highest electric vehicle sales, with these cities accounting for approximately 41% of all electric vehicle sales in China in 2015. Some smaller pilot cities, such as Hangzhou and Wuhu, had sales far above the national average, with electric vehicles accounting for 7.5% and 5.7% of total vehicle sales in 2015 respectively.

SHANGHAI, CHINA

Metropolitan population	24 million	**Total electric vehicle sales**	41,179
Public electric vehicle charge points per million people	146	**Electric vehicle share of new vehicles**	11%
Grid CO_2 emissions (gCO_2/kWh)	740	**Electric vehicle sales share relative to country average**	12x

The Shanghai metropolitan area, where 11% of new vehicles were electric in 2015, has the highest electric vehicle uptake in China. With more than 41,000 new electric vehicles sold in 2015, the Shanghai area had the highest total electric vehicle sales among all metropolitan areas in the world. Shanghai provides additional regional electric vehicle purchase subsidies of up to 30,000 yuan renminbi ($4,400), reduced from up to 40,000 yuan at the beginning of 2016. Electric vehicles are also exempted from the expensive and restrictive license plate auction system where the cost is around 80,000 yuan per license plate (Yang et al., 2016).

Shanghai was declared an International EV Demonstration City by the federal government. An important part of Shanghai's electric vehicle promotion is the EV Demonstration Zone in the city's Jiading District, where the city and federal government help auto companies reach and engage with more consumers and collect consumer electric vehicle data. The Zone includes an electric vehicle rental plan, an electric vehicle service center, and the ability to import with limited customs procedures. The Zone also and includes the promotion of electric vehicles through a car sharing service, a network of charging stations, and free electric vehicle test drives.

Table 1. Summary of electric vehicle support actions in the Shanghai metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidies of up to 54,000 CNY and tax exemptions • Regional subsidies of up to 30,000 CNY	++
Nonfinancial incentives	• Subsidies for a reserved parking space in Jiading District • Exemption from restrictive license plate auctions (80,000 CNY savings)	+
Charging infrastructure	• 21,700 charging points (16,500 private, 3,200 company charging, 800 bus and logistic vehicle) • Estimated 3,513 publically available charge points • State Grid Corp. constructing network of fast charging stations • Up to 30% grant for the installation of charging infrastructure (expired in 2014) • Government plans to build 28,000 public charging points (at least 1:7 ratio of public charging points to NEVs) by 2020 • Goal to build 210,000 charging points by 2020 • 30% capital subsidy for businesses to establish special and public charging infrastructure, integrated PV charging infrastructure, and new charging technology (until 2020)	+
Research and campaigns	• Jiading District EV Demonstration Zone	+
Transit and fleets	• EVCARD: China's first electric car sharing service • Electric buses and taxis are given priority to operate in the city • Pure electric public buses received a 165,000 CNY operation subsidy per year from 2013 to 2015 • Commercial vehicle passing permits to allow purely electric commercial vehicles to operate in urban areas	+

Public charge point data from EVCIPA (2016)

SHENZHEN, CHINA

Metropolitan population	**11 million**	**Total electric vehicle sales**	**17,699**
Public electric vehicle charge points per million people	**—**	**Electric vehicle share of new vehicles**	**10%**
Grid CO_2 emissions (gCO_2/kWh)	**740**	**Electric vehicle sales share relative to country average**	**12x**

The Shenzhen metropolitan area had a 9.9% electric vehicle sales share in 2015, the second highest among China markets, and it had the third highest total electric vehicles sales among all metropolitan areas in China with more than 17,000 passenger cars sold. Shenzhen is the headquarters of BYD, the manufacturer with the second-highest 2015 worldwide electric vehicle sales. Shenzhen is seen as a "first level city" in terms city readiness for electric vehicle adoption, with a number of local programs implemented and significant advancements in charging infrastructure (Shenzhen Municipal People's Government, 2015). Between 2009 and 2015, the Shenzhen government provided 500 million yuan (nearly $74 million) per year of financial subsidies for electric vehicle purchases (Wang & Liu, 2016). In addition to the financial incentives for electric vehicle purchases, the Shenzhen government provides parking benefits and subsidies for tolls, car insurance, and charging infrastructure (Liu, 2015). In 2015, the city of Shenzhen stated that it will spend up to 5 billion yuan for the development of charging infrastructure, subsidies for the purchase of electric vehicles, and policies to increase the overall uptake of electric vehicles (Liu, 2015).

Table 2. Summary of electric vehicle support actions in the Shenzhen metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidy of up to 54,000 CNY and tax exemptions • Regional subsidy up to 60,000 CNY for purchase of passenger vehicles and taxis and purchase tax exemptions • Discounts on tolls and car insurance • Subsidies for the operation of electric public buses	++
Nonfinancial incentives	• One hour of free parking each day • Exemption from vehicle registration lottery	++
Charging infrastructure	• 30% grant for the installation of charging stations • One-time charging subsidy up to 5,000 CNY • Low regulated prices guaranteed for public charging	+
Research and campaigns		
Transit and fleets	• Electrification of city buses, with hundreds of electric buses in operation in 2016, goal of 100% electric vehicles by 2017 • 70% of new fleet taxis must be NEVs • Company cars and government vehicle fleets transitioning to NEVs • Minibus: connects the "last-mile" between homes and normal bus/metro stations (currently 33 routes and 150 buses with the goal of 38 routes and 196 buses by the end of 2016) • e-Bus: An electric bus service that maximizes the efficiency and effectiveness of buses by allowing individuals to book the service and initiate new routes (if there is enough demand, a new route will be added) using an online tool (currently 410 routes with 22,000 passengers per day; 100 new routes planned before the end of 2016)	++

BEIJING, CHINA

Metropolitan population	**22 million**	**Total electric vehicle sales**	**18,065**
Public electric vehicle charge points per million people	**313**	**Electric vehicle share of new vehicles**	**3.7%**
Grid CO_2 emissions (gCO_2/kWh)	**740**	**Electric vehicle sales share relative to country average**	**4.1x**

Electric vehicle sales in Beijing surpassed 18,000 in 2015, accounting for a 3.7% share of new vehicle sales. The Beijing electric vehicle market is promoted through a city-level subsidy worth more than 50,000 yuan for battery electric vehicles. The city's electric vehicle market is unique with more than 99% of its electric vehicle sales being battery electric vehicles, as the Beijing incentives were not provided for plug-in hybrid vehicle models. Electric vehicles are exempt from the traffic restrictions that ban conventional vehicles from the roads of Beijing one day per week based on license plate numbers (Yang et al., 2016). The city of Beijing has implemented a license plate lottery system to greatly limit the number of new vehicles registered in the city. Electric vehicles are exempt from the lottery, and up to 60,000 license plates were reserved for electric vehicles in 2016; in contrast, only about 0.03% of those with conventional vehicles who participated received license plates in the June 2016 lottery (Guo, 2016).

A number of consumer awareness programs complement these incentive and registration policies. Beijing has a New Energy Vehicle Experience Center, supported by the Ministry of Science and Technology and Beijing Municipal Science and Technology Commission, that educates individuals on new energy vehicles and provides test drives in BAIC electric vehicles (China Ministry of Science and Technology, 2014). In addition, from May to November of 2015, the Beijing New Energy Vehicle Promotion Center and the Beijing Auto Museum organized 36 electric vehicle test drive events. Beijing also has several electric vehicle fleet programs, including government programs and private car-sharing programs.

Table 3. Summary of electric vehicle support actions in the Beijing metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal subsidy of up to 54,000 CNY and tax exemptions • Regional subsidies of 31,500-54,000 CNY in 2015, 25,000-55,000 CNY in 2016, and 20,000-44,000 CNY in 2017 for BEV passenger cars based on electric range • Regional subsidies of up to 50,000 CNY for taxis • Electric taxis exempt from fuel tax • Regional subsidies of 300,000-500,000 CNY for BEV buses	++
Nonfinancial incentives	• Exempt from traffic restrictions • Separate license plate quota for electric vehicles, exempt from lottery	+
Charging infrastructure	• 21,000 charge points (3,700 for special use, e.g. buses; 12,000 for private use) • Estimated 6,789 publically available charge points • State Grid Corp. constructing network of fast charging stations • Upper limit on public charging rate of 15% of 1L gasoline market rate per kWh	++

Type of Program	Description	Grade
Research and campaigns	• Consumer awareness campaign: "Electric Vehicle into Community" • Beijing New Energy Vehicle Experience Center allows people to gain insight into new energy vehicles and test drive BAIC electric vehicles • 36 electric vehicle test drive events organized by Beijing New Energy Vehicle Promotion Center and Beijing Auto Museum organized from May to November 2015	++
Transit and fleets	• Electric buses and taxis are given priority to operate • LeShare electric car sharing service	+

Public charge point data from EVCIPA (2016)

DENMARK

In Denmark, the southernmost and smallest of the Scandinavian countries, electric vehicles accounted for 2.3% of the total vehicle sales with more than 4,700 sales in 2015. Denmark has prioritized creating a green and sustainable society with the goal of achieving complete independence from fossil fuels by 2050 (Danish Government, 2016). With the transportation sector's dependence on fossil fuels accounting for approximately one-third of the total fossil fuel use in the country, Denmark's goal of independence from fossil fuels would require an extensive transformation of the sector (Danish Government, 2011).

The national government of Denmark has pushed the adoption of electric vehicles by exempting electric cars from the green tax ("Grønne Afgifter"), additional car taxes, and, until the end of 2015, vehicle registration fees (Danish Government, 2011). Starting in 2016, electric cars will incrementally be charged registration taxes, with full taxes (150% the value of the car) implemented in 2020. In order to ensure that electric vehicle sales do not stagnate with the introduction of registration taxes, a condition of the legislative agreement is that 24,100 electric vehicles are sold by 2020 and sales will be monitored for progress (International Energy Agency [IEA], 2016). The 2015 fourth quarter sales of electric vehicles in Denmark experienced a 280% increase from the third quarter, (Insero, 2016), in advance of the onset of registration taxes on electric vehicles beginning at the start of 2016.

Electric vehicle incentives in Denmark include free parking in certain cities, support of electric vehicle partnerships and tests, tax exemptions on electricity for electric vehicle operators, subsidies for businesses and municipalities for the purchase of electric vehicles, and tax discounts for the installation of charging stations up to 4,000 kroner (Dansk Elbil Alliance, 2016). The Danish Electric Vehicle Alliance (Dansk Elbil Alliance) helps to push the implementation of electric vehicles by bringing together the energy and electric vehicle sectors. Until the end of 2015, the Danish Energy Agency (DEA) administrated extensive funding, at a level of 30 million kroner ($4.4 million) in 2015, for projects to familiarize companies, public bodies, and private consumers with electric vehicles, support charging infrastructure, and develop relevant partnerships (IEA, 2016).

COPENHAGEN, DENMARK

Metropolitan population	1.7 million	**Total electric vehicle sales**	2,793
Public electric vehicle charge points per million people	492	**Electric vehicle share of total vehicle sales**	3.7%
Grid CO2 emissions (gCO2/kWh)	375	**Electric vehicle sales share relative to country average**	1.6x

Copenhagen, the capital of Denmark, had an electric vehicle share well above the national average, with 3.7% of vehicles sold in 2015 being electric vehicles. With approximately 2,800 new electric vehicles, nearly 60% of Denmark's electric vehicle sales were in the Copenhagen metropolitan area. In 2009, Copenhagen released an extensive climate plan with the intention of becoming, by 2025, the world's first carbon neutral capital. To achieve the overall goals, the climate plan set the aim of making public transit carbon neutral and 20%-30% of all light-duty vehicles and 30%-40% of heavy-duty vehicles using alternative fuels (City of Copenhagen, 2009). Copenhagen has supported the transition toward sustainable mobility by providing free and designated parking, pushing the development of charging infrastructure, purchasing only electric or hydrogen powered vehicles for municipality use, and electrifying public transit.

Table 4. Summary of electric vehicle support actions in the Copenhagen metropolitan area

Type of Program	Description	Grade
Financial incentives	Federal Incentives: • Exempt from vehicle registration taxes (up to 180%) until 2016; partially exempt until 2020 • Exempt from annual car tax • Tax refunds on electricity used to charge electric vehicles	+
Nonfinancial incentives	• Designated free parking	+
Charging infrastructure	• 850 total charge points and 60 fast charge points • By 2025: 500-1,000 public charging stations and 5,000 restricted public access charging stations • Tax rebate of up to 18,000 DKK ($2,646) for the installation of a home charger	++
Research and campaigns	• "Meet the electric vehicle" – 12-day trial for businesses to test electric vehicles • "Rent an electric vehicle" – employees of companies in Copenhagen can rent electric vehicles for two weeks to assess their practicality • Financial subsidies for builders and tradesman purchasing electric vans in return for their experiences • "Vehicle X" – using electric vehicles to charge and operate tools and equipment • Two electric buses at the Copenhagen Airport to gain practical experience with electric buses	++
Transit and fleets	• More than 20,000 electric bikes sold in 2014 • DriveNow – car sharing service with a fleet of 400 BMW i3's • Entire bus fleet to be replaced by electric buses starting in 2019 • Municipality only purchasing zero emission vehicles starting in 2011 • 85% of government vehicles must be zero emission by 2015	++

Charge point data from E.ON (2016) and Clever (2016) as of October 31, 2016; may not include some smaller charging networks

FRANCE

Although electric vehicles accounted for only approximately 1.2% of France's total vehicle sales in 2015, France has one of the most efficient new vehicle fleets. France has made great strides to mitigate climate change and improve air quality, especially in urban areas, aiming to achieve a four-fold reduction in greenhouse gas emission by 2050. The transportation sector was the largest emitter of greenhouse gases in France in 2013, emitting 28% of France's total emissions (Ministère de l'Environnement, de l'Énegie et de la Mer, 2015). The development of clean transportation is a main pillar of France's climate policy. France's low-carbon electricity makes it an ideal location for electric vehicle penetration.

With the generous incentive increases in 2016, France has seen a significant uptick in electric vehicle purchases: 15,068 new electric vehicles were registered in the first half of 2016, a 49% increase from 2015, ahead of Norway's 12,216 (AVERE-France, 2016a). The bonus-malus system grants low-emission vehicles up to 6,300 euros and increases the purchase price of high emitting vehicles up to 8,000 euros (Ministère de l'Environnement, de l'Énegie et de la Mer, 2017). In addition, there is up to a 3,700 euro bonus for the scrappage of an old diesel car (AVERE-France, 2016b). The national government offers company tax exemptions for electric vehicles and a 30% tax credit with the installation of a charging station (City of Paris, 2016). Regions have the option to provide 50% to 100% registration tax exemptions for alternative fuel vehicles. At least 50% of the vehicles purchased by the national government and at least 20% of the vehicles purchased by local authorities must be low emission vehicles beginning in 2025. By 2030, France aims to have 7 million charge points installed and by 2017, the country aims to have a charging station every 50 kilometers (Ministère de l'Environnement, de l'Énegie et de la Mer, 2015; AVERE, 2015). The French Environment and Energy Management Agency (ADEME) has provided 50 million euros for the installation of public charging infrastructure since 2013 (AVERE-France, 2015).

PARIS, FRANCE

Metropolitan population	12 million	**Total electric vehicle sales**	6,587
Public electric vehicle charge points per million people	106	**Electric vehicle share of new vehicles**	1.8%
Grid CO2 emissions (gCO2/kWh)	71	**Electric vehicle sales share relative to country average**	1.5x

Paris is the capital and most populous city in France. In 2015, electric vehicles accounted for 1.8% of total vehicle sales in Paris, placing it above the national average but below other European electric vehicle capitals. As transportation is the area's largest source of air pollution and greenhouse gas emissions, the Paris Climate and Energy Action Plan aims for a 60% reduction in greenhouse gas emissions from inner-city transport and a 35% reduction for all transport in outer Paris between 2001 and 2020 (City of Paris, 2012).

To achieve these goals, Paris has implemented new policies to reduce vehicle use by 25% in 10 years, increase and improve public transit, and promote pedestrian and electric vehicle travel (City of Paris, 2012). In addition, the city has set extensive vehicle bans and road closures to improve air quality and reduce harmful greenhouse gas emissions, particularly in the city center. The city provides free parking for electric vehicles, charging station grants, bus electrification, and electric car sharing.

As of September 30, 2016, the Métropole du Grand Paris has provided a subsidy of 25% of the purchase price of low-emission vehicles with the replacement of older vehicles, up to 5,000 euros for cars, 1,000 euros for electric two-wheelers, and 500 euros for electric bikes. (Métropole du Grand Paris, 2016). Autolib', one of the world's largest electric car sharing services, began in Paris in 2011 and in 2016 had more than 3,900 cars, more than 5,900 charge points, and more than 126,000 subscribers (Autolib', 2016). Autolib' cars have access to free parking, are exempt from road and registration tax, and are granted access to bus lanes. Residents of Paris willing to sell or scrap their old, conventional vehicles or motorized two-wheelers receive financial aid for the enrollment to the Vélib bike sharing service or Autolib' or the purchase of a bicycle or electric bike (City of Paris, 2016).

Table 5. Summary of electric vehicle support actions in the Paris metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: Bonus-malus system (up to 6,300 euros grant for electric vehicles), bonus for diesel car scrappage (up to 3,700 euros), company tax exemptions • 25% subsidy for the purchase price of low-emission vehicles, electric mopeds, or electric bikes • 15% subsidy for companies replacing a diesel/gasoline vehicle with an electric vehicle (up to 3,000 euros for light commercial vehicles, 6,000 euros for vans, and 9,000 euros for trucks)	++
Nonfinancial incentives	• Free parking • High polluting vehicles banned from city streets on weekdays	+
Charging infrastructure	• 1,367 total charge points and 32 fast charge points • Federal incentives: tax deduction for installing a charging station • Grants for the installation of a private charging station in apartment complex	++
Research and campaigns	• Electric bus trials by transport operator RATP using 16 BYD buses	+
Transit and fleets	• All 4,500 buses in the Greater Paris network will be clean buses with 80% of them electric by 2025 • Sogarus and SEMPARISENE partnered to provide 30 delivery rounds in the 15th arrondissement using electric vehicles • Autolib', an electric car sharing program • At least 20% of local authority vehicle fleet must be low CO_2 and air pollutant emissions when renewing their fleet • All new public transit buses and coaches acquired after 2025 must be low-emission vehicles • At least 10% of car rental firms and taxi operators fleets must be low-emission vehicles when renewed	++

Charge point data from Etalab (2016), as of September 9, 2016

NETHERLANDS

The Netherlands has been a leader in electric vehicle promotion and deployment, with more than 43,000 new electric vehicle sales. These sales accounted for 9.7% of the country's total new vehicle sales in 2015, second in the world only to Norway. Despite being a relatively small country with a small population, the electric vehicle sales here accounted for more than 8% of the global electric vehicle sales in 2015.

The national government of the Netherlands has taken a comprehensive set of actions to achieve their ambitious national goals of 75,000 privately owned electric vehicles on the country's roads by 2020, and 50% of all new cars sales plug-in electric—with at least 30% of these vehicles fully electric—by 2025 (Dutch Government, 2015). To achieve these national targets, the government has published a series of action plans. The first action plan was published in 2009 and outlined the government's threefold course of action and its contribution of up to 65 million euros to make "the Netherlands the guide and international laboratory for electric driving" (Dutch Government, 2009). These action plans have led to the formation of the Formula E-Team, a national public-private platform that unites and advises businesses, academia, non-profit organizations, and the government to stimulate the development of charging infrastructure and new zero-emission mobility policies. The Formula-E Team has supported the implementation of field trials and demonstration projects and stimulated the development of charging infrastructure and electric vehicle and parts manufacturing.

Zero-emission vehicles in the Netherlands have been exempt from registration and road taxes, and have had reduced taxes for the private use of company cars. The Netherlands has a very extensive public charging network, with 0.8 public charging points per electric passenger vehicle at the end of 2015, and has recently developed the Open Charge Point Interface (OCPI) protocol to support the national agreement on interoperability of charge points (IEA, 2016). The Netherlands has several projects, coalitions, and agreements to support the uptake of electric driving. Among these projects are Project A15, which ran from 2012 through 2015 to promote electric driving powered by locally generated green energy along the A15 motorway; the National Knowledge Platform for Charging Infrastructure, consisting of research and innovation projects to bring down the cost of public charging infrastructure; and the Green Deal to increase publicly accessible electric charging infrastructure, including 5.7 million euros for the installation of charging points.

While the national government has implemented a wide variety of programs to incentivize electric vehicles, local governments also have played a major role in promoting these vehicles. In this analysis, we focus on Amsterdam, the capital of the Netherlands, and Utrecht, a major city with an electric vehicle sales share that is 50% above the national average. We note that additional cities such as Eindhoven, The Hague, and Rotterdam also have similar electric vehicle sales shares of 10.3%, 8.6%, and 7.3% respectively, placing them among the top cities for electric vehicle penetration in the world.

AMSTERDAM, NETHERLANDS

Metropolitan population	**2.4 million**	**Total electric vehicle sales**	**6,645**
Public electric vehicle charge points per million people	**561**	**Electric vehicle share of total vehicle sales**	**9.7%**
Grid CO2 emissions (gCO2/kWh)	**565**	**Electric vehicle sales share relative to country average**	**1.0x**

The electric vehicle share of new vehicle sales in Amsterdam was 9.7% in 2015, placing it among the highest in the world. As the capital and most populous city of the Netherlands, Amsterdam is a model for the transition to sustainability for other cities in the Netherlands and abroad. Amsterdam has set aggressive sustainability targets, aiming to become the first zero-emission European city and to reduce its overall CO_2 emissions by 45% in 2025 relative to 2012 levels (City of Amsterdam, 2015). A significant portion of Amsterdam's air pollution, estimated at up to 50%, stems from motorized traffic (Gemeente Amsterdam, 2016). To achieve its overall emission reduction targets, the city has created a strategy to stimulate, support, and regulate the transition to clean mobility. The city has a widespread public charging network powered by locally generated wind energy. The city encourages further development of the charging infrastructure by accepting applications for the installation of additional public charging stations in desired areas and providing subsidies for the installation of private and semi-private charging stations. Among other programs, there is residential parking permit priority for electric vehicle owners, subsidies for electric taxis and company owned vehicles, a fleet of 350 electric vehicles for car sharing (Car2Go), and extensive deployment of electric taxis (IEA, 2016). Even Amsterdam's Schiphol airport has started the deployment of 35 electric buses charged with solar energy from the largest charging station for electric buses in Europe.

Table 6. Summary of electric vehicle support actions in the Amsterdam metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: electric vehicles exempted from registration and road taxes, reduced tax for the private use of a company car, investments in electric vehicles and charging points that are partially deductible from corporate and income taxes • 5,000 euros for fully electric taxis or company owned passenger and small delivery vehicles • 20% off the purchase price (up to 40,000 euros) per vehicle for large vans, trucks, or buses	++
Nonfinancial incentives	• Priority for electric taxis • Priority for electric vehicles in Low Emission Zones (current for trucks, delivery vans in 2017, taxis and coaches in 2018) • Residential parking permit priority • Free floating parking permits for car sharing companies with fully electric fleets	++

Type of Program	Description	Grade
Charging infrastructure	• 1,341 total charge points and 36 fast charge points • 4,000 charge points planned by 2018 • Public charging stations are powered by locally generated wind energy • Residents/ employees can submit application for new public charging station • 500 euro subsidy for private charging point • 1000 euro subsidy for semi-private charging point	++
Research and campaigns	• Part of European FREVUE Program • EU Sustainable Energy Electric Vehicles for the City (SEEV4City) – storage of sustainable energy using electric vehicles • Part of the Dutch Living Lab Smart Charging • Municipality of Amsterdam and the University of Applied Sciences of Amsterdam performed a study to analyze the most efficient way to install charging infrastructure	+
Transit and fleets	• Car2Go – car sharing company with 350 electric vehicles • All taxis fully emission free by 2025 (Clean Taxis for Amsterdam Covenant) • Currently more than 400 electric taxis • Plans to make public transit system emission free by 2025 • 35 electric buses at Amsterdam Airport Schiphol (largest charging station for electric buses in Europe)	++

Charge point data from Open Charge Map (2016), as of September 9, 2016

UTRECHT, NETHERLANDS

Metropolitan population	**1.3 million**	**Total electric vehicle sales**	**8,791**
Public electric vehicle charge points per million people	**781**	**Electric vehicle share of total vehicle sales**	**14.7%**
Grid CO_2 emissions (gCO_2/kWh)	**565**	**Electric vehicle sales share relative to country average**	**1.5x**

Utrecht is the fourth largest city in the Netherlands and the capital of the province of Utrecht, the smallest of the country's 12 provinces. Although Utrecht is relatively small, more electric vehicles were sold there in 2015 than in any other metropolitan area in the Netherlands. In 2015, Utrecht had the second highest electric vehicle share of the world's large metropolitan areas at 14.7%, second only to Oslo, Norway. The city of Utrecht published its Clean Transport Action Plan in 2015 for 2015-2020 outlining a comprehensive set of actions to become climate neutral by 2030 including a goal to become the city with the highest number of electric cars per inhabitant in the Netherlands (City of Utrecht, 2015). Over the past couple of years, Utrecht has been a hotspot for the development of clean, smart charging networks and vehicle-to-grid integration through various pilot projects and government subsidies.

Table 7. Summary of electric vehicle support actions in the Utrecht metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentives: electric vehicles exempted from registration and road taxes, reduced tax for the private use of a company car, investments in electric vehicles and charging points that are partially deductible from corporate and income taxes • 5,000 euros for electric taxis and delivery vans (until end of 2015) • 10.7 million euros in subsidies for vehicle replacement	++
Nonfinancial incentives	• Environmental zone • Free parking while charging • Bus lane access for clean taxis	++
Charging infrastructure	• 987 total charge points and 46 fast charge points • All charging points will supply only green energy (Utrecht Energy Deal) • 500 euros subsidy for private charging point • 1,500 euros subsidy for semi-public charging points • 160 new charging stations planned in 2017	++
Research and campaigns	• Smart Grid Consortium development of V2G energy storage system • Solar Smart Solar Charging Network Project: deployment of 150 Renault ZOE, installation of 1,000 smart solar-charge stations powered by 10,000 photovoltaic panels, implementation of car sharing program, and development of V2G ecosystem • Part of the Dutch Living Lab Smart Charging	++
Transit and fleets	• Emission free freight transport in the city center by 2020 and the entire city by 2025 (Zero Emission Urban Distribution Green Deal) • 3 all electric buses • 20 electric taxis for transporting school children	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

NORWAY

Norway is widely viewed as the world leader in electric mobility. With approximately 34,000 electric vehicles sales in 2015, more than 22% of Norway's total vehicle sales in 2015 were electric. Almost all of the electricity consumed in Norway is generated from hydropower, making electric vehicles a core part of the country's actions to reduce overall carbon emissions. By 2020, Norway aims to cut greenhouse gas emissions 30% relative to 1990 emission levels and to achieve total carbon neutrality by 2050 (Transportøkonomisk Institutt [TØI], 2013). By 2020, Norway aims to achieve an average CO_2 emission rate of new passenger vehicles below 85 g/km (TØI, 2013). To achieve these ambitious emissions reduction goals, the national government has implemented the world's most generous program of electric vehicle incentives. Among the benefits are exemption from the 25% VAT on purchase or leasing, no import or purchase taxes, no charges on tolls or ferries, low annual road tax, 50% reduced company car tax, no fuel taxes for hydrogen or electricity, free access to bus lanes, free municipal parking, and free charging station use (AVERE, 2012; Norsk elbilforening, 2016). In addition, the government is financing at least two multi-standard charging stations every 50 kilometers on all main roads in Norway by 2017 to allow for long distance trips using electric vehicles (Norsk elbilforening, 2016).

Norway is home to several major electric vehicle markets. The capital, Oslo, stands out and is profiled below. Aside from Oslo, the second-largest metropolitan area of Bergen has a regional population around 500,000 and had the world's highest share of electric vehicle sales with more than 4,600 electric vehicle sales, accounting for 38% of the total vehicle sales in 2015. As many of the surrounding suburbs are on islands, the national incentives of toll exemptions or reductions for the use of bridges, tunnels, and ferries provide a substantial incentive for the inhabitants of the Bergen metropolitan area to purchase electric vehicles. Overall, Norway's urban areas especially benefit, due to the incentives of access to bus lanes and free access to the "toll rings" (Tietge et al., 2016).

OSLO, NORWAY

Metropolitan population	1.2 million	**Total electric vehicle sales**	10,920
Public electric vehicle charge points per million people	2,295	**Electric vehicle share of total vehicle sales**	26.6%
Grid CO_2 emissions (gCO_2/kWh)	9	**Electric vehicle sales share relative to country average**	1.2x

Oslo has the highest electric vehicle share of any major metropolitan area in the world, with electric vehicles accounting for 21% of new passenger vehicles in 2015. Although the Oslo metropolitan area accounts for approximately one-fourth of Norway's population, 40% of Norway's electric vehicles in 2015 were sold in Oslo. Oslo has recently tightened its emission reduction goals, aiming to reduce greenhouse gas emissions in half relative to 1990 levels by 2020 and by 95% by 2030 (Oslo Kommune, 2016). As over 60% of emissions come from transportation, the transformation of the transportation sector is a main pillar of Oslo's plan to cut emissions, as outlined in Oslo's Climate Budget (Oslo Kommune, 2016). To achieve an emissions reduction from transportation of more than 40%, Oslo plans to continue to push electric mobility by electrifying public transportation and the municipality and taxi fleets, freight electrical vehicles, craft and service vehicles, while also increasing charging infrastructure and implementing low-emission and environmentally differentiated congestion zones (Peters & Torvanger, 2016). In terms of passenger traffic, Oslo seems to have shifted its focus from promoting electric vehicles to reducing overall passenger traffic by raising tolls for vehicles entering the city, increasing public transit use, improving bicycle infrastructure, introducing parking restrictions, facilitating carpooling, and encouraging pedestrian traffic with the aim of having a car free city center by 2019 (Tønnesen et al., 2016).

Table 8. Summary of electric vehicle support actions in the Oslo metropolitan area

Type of Program	Description	Grade
Financial incentives	• No purchase or import taxes • Exempt from 25% VAT on purchases and leases • 50% reduction on company car taxes • No fuel taxes for electricity or hydrogen • Low annual road taxes • Exempt from road and ferry tolls	++
Nonfinancial incentives	• Planning low-emission zones • Free municipal parking • Free electricity for normal charging (3.6kW) • Discounted quick- and semi-quick charging for prioritized vehicles (e.g., EL-Taxis and Electric Freight Vehicles (FEV)) • Bus lane access	++
Charging infrastructure	• 2,973 total charge points, 161 fast charge points • Grants for up to 60% (up to 10,000 kroner) of the cost of the installation of additional charging point • 2 million euros for the installation of 400 charging points between 2008-2011, 200 new charging points per year from 2013, 1,200 total by of the end of 2016, and 200 new ones in 2017 • Free public charging for normal charging (3.6 kW) • Cooperation with private quick charging companies to deploy quick charging stations (three deployed in 2016 with many more to come) • Building "a center of excellence for professional users of electric vehicles" in cooperation with the private real estate company Aspelin Ramm • Building dedicated quick and semi-quick charging stations for EL-Taxis together with the taxi industry • Building two large parking garages for electric vehicles	++
Research and campaigns	• Part of European FREVUE, SEEV4, BuyZET, ELAN, and REMIND Programs	+
Transit and fleets	• Zero emissions municipality fleet and public transportation by 2020 • Green purchase of transport services	++

Charge point data from Open Charge Map, 2016, as of September 9, 2016

SWEDEN

Sweden has worked to promote electric vehicles in recent years, and in 2015 it ranked third in new electric vehicle sales percentage in Europe, with electric vehicles accounting for 2.5% of vehicle sales, behind only Norway and the Netherlands. Sweden has adopted a variety of programs to incentivize electric vehicles, including an upfront subsidy of 40,000 kroner (about $4,540) and exemption from circulation taxes (Mock & Yang, 2014). Greater financial incentives for those replacing old, high-polluting vehicles, as well as free parking, have led to high electric vehicle sales in urban areas. In addition to the capital of Stockholm, the city of Gothenburg, home of the Swedish Electric and Hybrid Vehicle Centre, has seen success through its Green Gothenburg campaign and its efforts to electrify 95% of the city's fleet. Sweden is also pushing the frontiers of electric vehicle technology, including working with Siemens to electrify a major highway through the country in order to advance electrification of heavy-duty vehicles (Weller, 2016).

STOCKHOLM, SWEDEN

Metropolitan population	2.2 million	**Total electric vehicle sales**	3,727
Public electric vehicle charge points per million people	257	**Electric vehicle share of new vehicles**	3.7%
Grid CO_2 emissions (gCO_2/kWh)	22	**Electric vehicle sales share relative to national average**	1.5x

The capital of Sweden has seen higher electric vehicle sales than the average of Europe and Sweden, likely stemming from numerous electric vehicle promotion programs over more than a decade. The city has ambitions of becoming the world's leading clean vehicle city and making the city center fossil-free by 2030, with electric vehicles playing an important role in the transformation (City of Stockholm, 2012). The city has partnered with a number of organizations, such as the utility Vattenfall, to transform public and company fleets and to provide public charging stations using clean energy. Furthermore, the city awards electric vehicles free parking permits in the city center, which normally cost 5000 kroner (more than $560) per year (van der Steen et al., 2015). Stockholm will continue to push electric vehicle adoption into mainstream markets and fulfill its ambitious goals.

Table 9. Summary of electric vehicle support actions in the Stockholm metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal incentive of 40,000 kroner ($4,400) • Exemption from annual circulation taxes	+
Nonfinancial incentives	• Free central city parking permits	+
Charging infrastructure	• 565 total charge points, 82 fast charge points • Numerous free chargers with 100% renewable energy	+
Research and campaigns	• Vattenfall inductive charging demonstrations and research • Clean Cars campaign with OEMs and fuel companies to promote zero-emission vehicles	+
Transit and fleets	• Clean Fleets case study – City of Stockholm and 296 organizations purchasing up to 5,000 electric vehicles	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

SWITZERLAND

The small, mountainous country of Switzerland has worked for a number of years to reduce its greenhouse gas emissions and make its transportation sector more environmentally friendly. Switzerland has adopted increasingly stringent emission standards for imported vehicles, and has announced that electric vehicles will cover 50% of vehicle miles traveled by 2050 as part of its New Energy Policy (Swiss Federal Office of Energy [SFOE], 2016; IEA, 2016). The federal government waives the standard 4% car import tax for electric vehicles, but offers no additional financial incentives, leaving such programs to individual cantons. Nonetheless, other actors in Switzerland have been active in promoting electric vehicles. For example, the E'mobile coalition, organized by automakers, utilities, and research institutions, organizes events and publications to support low-emission vehicle uptake (E'mobile, 2016). Additionally, some of Switzerland's picturesque mountain villages, such as Zermatt and Wengen, allow electric vehicles into their otherwise car-free centers.

ZÜRICH, SWITZERLAND

Metropolitan population	1.6 million	**Total electric vehicle sales**	2,496
Public electric vehicle charge points per million people	121	**Electric vehicle share of new vehicles**	3.4%
Grid CO_2 emissions (gCO_2/kWh)	11	**Electric vehicle sales share relative to national average**	1.7x

Switzerland's largest city, Zürich, is known for its innovative transportation solutions, including an extensive tram network and a system that limits traffic volumes in the city center. The city is working to incorporate electric vehicles into its sustainability plans, boasting the highest electric vehicle sales in the country. Zürich's utility, EKZ, also has played a major role in promoting electric mobility in the region and has worked to maximize the environmental benefits of electric vehicles by linking charging with renewable energy. Zürich may not match the sales or programs of larger European capitals, but its transportation electrification programs are pushing the country toward cleaner mobility.

Table 10. Summary of electric vehicle support actions in the Zürich metropolitan area

Type of Program	Description	Grade
Financial incentives	• Exemption (for BEVs) and 80% reduction (for PHEVs) from vehicle taxes in Canton of Zürich	+
Nonfinancial incentives		
Charging infrastructure	• 190 total charge points, 12 fast charge points • National charging station registry LEMnet • Utility EKZ operates fast charging stations in city powered by renewable energy	+
Research and campaigns	• Utility EKZ partnering with IBM to research charging and consumer outreach practices • Research on electric vehicle powertrains, purchasing behavior at ETH Zürich • EKZ Ökostrom-Vignette program guarantees green power for all electric vehicle driving	++
Transit and fleets	• Ongoing electrification of taxi fleet through private-sector initiatives • eMotion Zürich electric car-sharing trial • Replacing diesel trolleybuses with electric buses	+

Charge point data from Open Charge Map (2016), as of September 9, 2016

UNITED KINGDOM

Electric vehicles represented 1.1% of all vehicle sales in 2015 in the United Kingdom, putting the country above the European average. This was approximately double the figure for 2014, and strong growth has continued into 2016 (Society of Motor Manufacturers and Traders, 2016a, 2016b). In recent years, the United Kingdom has initiated a suite of programs to promote electric vehicles, including a subsidy of up to 4,500 pounds and the pioneering Go Ultra Low consumer awareness campaign (Office for Low Emission Vehicles [OLEV], 2016d). The Office for Low Emission Vehicles (OLEV) is investing more than 600 million pounds between 2015 and 2020 to advance the government's goal of making the UK's light-duty fleet fully zero-emission by 2050 (OLEV, 2016a; International Zero Emission Vehicle Alliance, 2015).

Major priorities in the United Kingdom's transportation electrification scheme include the deployment of public and private electric vehicle charging equipment and the electrification of bus and taxi fleets. OLEV offers grants of up to 500 pounds toward the cost of home chargers, provides grants towards workplace charge points, and is working with Highways England to complete an extensive nationwide rapid charge network, a 15 million pound project to ensure there are rapid chargers every 20 miles on the United Kingdom's Strategic Road Network—however, interoperability between private charge networks remains a concern (OLEV, 2016b; Blythe et al., 2015). Recently the government has proposed taking regulatory action to make the provision of electric vehicle charge points mandatory at suitable public locations, simplify the electric vehicle charging equipment usage process for consumers, and introduce smart charging capability to enable future balancing of electricity supply and demand. As with other countries, electric vehicle uptake has been concentrated in specific regions—in addition to the capital of London, the districts of Gloucestershire, Peterborough, and Birmingham have seen electric vehicle sales shares above the national average in 2015, at 9.1%, 4.1%, and 1.5% respectively.

LONDON, UNITED KINGDOM

Metropolitan population	15 million	**Total electric vehicle sales**	7,037
Public electric vehicle charge points per million people	112	**Electric vehicle share of new vehicles**	1.4%
Grid CO_2 emissions (gCO_2/kWh)	428	**Electric vehicle sales share relative to national average**	1.3x

As the capital of the United Kingdom and largest city in the European Union, London is an international center of finance and culture. Increasingly concerned with climate change, air pollution and sustainability, the city has made promotion of electric vehicles a major piece of its environmental policy, including plans to help London become the Ultra-Low Emission Vehicle (ULEV) capital of Europe (Greater London Authority, 2015, 2016). The UK government has given London 15 million pounds as part of the Go Ultra Low City program, with the goal of having 250,000 ultra-low emission vehicles on the road by 2025 (OLEV, 2016a). The city has in turn launched a number of programs to accomplish this ambitious goal, including the ongoing electrification of the taxi and bus fleets; the creation of an Ultra Low Emission Zone in the city center beginning in 2020, although a revised start date of 2019 is under consultation; and planning requirements for charge points at all new developments (Transport for London [TfL], 2016).

Table 11. Summary of electric vehicle support actions in the London metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal grant up to 4,500 pounds at electric vehicle purchase • Electric vehicles exempt from annual circulation tax • Federal grant of an additional 3,000 pounds for zero emission capable taxi (mid-2017-2020)	+
Nonfinancial incentives	• Exemption from congestion charges • Free or reduced parking costs in some boroughs • Central Ultra Low Emission Zone planned for introduction by 2020 (revised start of 2019 under consideration)	+
Charging infrastructure	• 1,652 charge points and 134 fast charge points • City-wide Source London network accessible for small annual fee • Charging point planning requirements for all new developments	++
Research and campaigns	• UK Power Networks grid assessment and demand response trials • Go Ultra Low "Neighborhoods of the Future" project • Go Ultra Low national communications campaign	++
Transit and fleets	• Electrification of bus routes • All single-deck buses will be ZEV by 2020 • All new taxis required to be ZEV capable by 2018 • LoCITY program to encourage cleaner commercial vehicles	++

Charge point data from Office for Low Emission Vehicles (OLEV, 2016c), as of September, 2016

UNITED STATES

More than 115,000 new electric vehicles were sold in the United States in 2015, representing about a quarter of global electric vehicle sales. Although this is a substantial fraction of the global market, electric vehicles represented only 0.7% of all light-duty vehicle sales in 2015 in the United States. The United States has a variety of national policies and promotion actions in place that have supported the development of the market for electric vehicles. These programs include federal tax credits up to $7,500 for the purchase of new electric vehicles, vehicle efficiency standards through 2025 with explicit incentives for electric vehicles, funding for public charging infrastructure, and a program to encourage workplace charging infrastructure deployment. With the goal of making electric vehicles cost competitive and as convenient as conventional vehicles by 2022, the U.S. Department of Energy launched EV Everywhere, an initiative combining research and development, outreach, and education. In addition, many states and cities offer additional consumer fiscal rebates, access to high-occupancy vehicle lanes, exemptions from fees, and preferential parking, among many different actions.

Several major U.S. vehicle markets greatly outpaced the national average electric vehicle uptake in 2015. These markets include many throughout California that were well above the national average. In addition, the areas of Seattle, Washington, Portland, Oregon, Atlanta, Georgia, and Honolulu, Hawaii, had about 2% electric vehicle sales shares in 2015. These high electric vehicle uptake markets tended to have a combination of vehicle and fuel policy, state consumer incentives, local support actions, more extensive public charging infrastructure, and utility actions in place to support electric vehicles (Lutsey et al., 2016). In addition, California's Zero Emission Vehicle regulation has greatly increased electric vehicle model availability in the state, and the policy requires greater electric vehicle penetration over time, up to 15% of new vehicle sales by 2025. The three California metropolitan areas of San Jose, San Francisco, and Los Angeles that are profiled below account for 40% of all United States electric vehicle sales.

SAN JOSE, CALIFORNIA, UNITED STATES

Metropolitan population	2.0 million	**Total electric vehicle sales**	9,753
Public electric vehicle charge points per million people	379	**Electric vehicle share of new vehicles**	9.4%
Grid CO_2 emissions (gCO_2/kWh)	296	**Electric vehicle sales share relative to country average**	13x

The San Jose metropolitan area stands apart as the top electric vehicle uptake market in the Unites States with over 9% electric vehicles share—13 times the national average. New electric vehicle sales in 2015 were about 9,700, a 7% increase over 2014. Encompassing Silicon Valley, the headquarters for many global high-tech companies, the San Jose area has demonstrated that it is a highly attractive early market for electric vehicles (Searle et al., 2016). Along with the standard rich portfolio of California state-level policies, the San Jose area has a variety of local promotion actions to help spur electric vehicle uptake. Local support includes access to multiple high-occupancy vehicle highway lanes, city-owned charging, and free parking for electric vehicles. The city also has a goal for 100% alternative fueled vehicles in its municipal fleet by 2020. The local electric utility, Pacific Gas & Electric, has many supportive actions, including lower electric vehicle charging rates, information and cost tools to assist electric vehicle users. The area has the most extensive public charging infrastructure network in the U.S. with 379 charge points per million residents, which is 4.5 times the national average. The area also includes a much greater amount of workplace electric vehicle charging than elsewhere in the United States.

Table 12. Summary of electric vehicle support actions in the San Jose metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lanes • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 955 charge points and 71 fast charge points • Extensive workplace charging network: More than 1400 workplace charge points available to employees • Low-carbon fuel regulation • State private charging infrastructure incentives and streamlined local charging permitting process	++
Research and campaigns	• State manufacturing incentive • “National Drive Electric Week” city outreach information and events • Utility outreach information and events	+
Transit and fleets	• State electric vehicle fleet programs • Goal to power 100% of municipal fleet with alternative fuels by 2022 (currently 41%)	+

Charge point data from Alternative Fuels Data Center [AFDC] (2016), as of October 19, 2016

SAN FRANCISCO, CALIFORNIA, UNITED STATES

Metropolitan Population	4.6 million	**Total electric vehicle sales**	13,081
Public electric vehicle charge points per million people	339	**Electric vehicle share of new vehicles**	5.3%
Grid CO_2 emissions (gCO_2/kWh)	296	**Electric vehicle sales share relative to country average**	7.5x

The San Francisco metropolitan area is a major electric vehicle hub in the United States, with over 5% electric vehicles share—more than 7.5 times the national average. New electric vehicle sales in 2015 were more than 13,000, a 7% increase over 2014, and the second highest sales fraction among U.S. markets. Along with the many California state-level policies to support, the San Francisco area has a variety of local promotion actions to help spur electric vehicle uptake (Searle et al., 2016). Local support includes access to high-occupancy vehicle highway lanes, city-owned charging, and multiple city outreach and awareness activities for electric vehicles. The city also operates programs to increase the use of electric vehicle in their city and private car-sharing fleets. The local electric utility, Pacific Gas & Electric, has many supportive actions, including reduced electric vehicle charging rates and information and cost tools to assist electric vehicle users. The area has one of the most extensive public charging infrastructure networks in the United States, with 339 charge points per million residents, which is four times the national average.

Table 13. Summary of electric vehicle support actions in the San Francisco metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lane • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 1,916 charge points and 175 fast charge points • Low-carbon fuel regulation • State private charging infrastructure incentive	++
Research and campaigns	• State manufacturing incentive • “Best.Ride.Ever” and “National Drive Electric Week” outreach and awareness events • City information materials and events • Utility outreach information and events	+
Transit and fleets	• More than 300 electric trolley buses and additional hybrid buses • State and city electric vehicle fleet programs • Electric car sharing program	++

Charge point data from AFDC (2016), as of October 19, 2016

LOS ANGELES, CALIFORNIA, UNITED STATES

Metropolitan population	**13 million**	**Total electric vehicle sales**	**23,653**
Public electric vehicle charge points per million people	**208**	**Electric vehicle share of new vehicles**	**2.8%**
Grid CO_2 emissions (gCO_2/kWh)	**296**	**Electric vehicle sales share relative to country average**	**4.0x**

The Los Angeles metropolitan area has the highest electric vehicle sales among metropolitan areas in the United States. With more than 23,000 new electric vehicles in 2015, Los Angeles had an approximate 3% electric vehicles share—more than 4 times the national average. Along with the many California state-level policies to support, the Los Angeles area has a variety of local promotion actions to help spur electric vehicle uptake. Local support includes access to multiple high-occupancy vehicle highway lanes, city-owned charging, and multiple city outreach and awareness activities for electric vehicles. The city also has programs to increase the use of electric vehicles in its city, police, and private car-sharing fleets. The city also has enacted an EV-ready building code requirement whereby new buildings are equipped to enable charging infrastructure. The local utilities offer many supportive actions, including lower electric vehicle charging rates, consumer information, home charger incentives, extensive research into smart charging programs. In addition, there is a major utility pilot plan to deploy $22 million in electric vehicle public charging infrastructure (Edison International, 2016). The area also has an extensive public charging infrastructure network with about 2.5 times the charge points per capita of the U.S. average.

Table 14. Summary of electric vehicle support actions in the Los Angeles metropolitan area

Type of Program	Description	Grade
Financial incentives	• Federal tax credit up to $7,500 per electric vehicle • State rebate up to $2,500 per electric vehicle	++
Nonfinancial incentives	• City parking benefit • Preferential access to high-occupancy vehicle lanes • Preferential utility electric vehicle charging rate	++
Charging infrastructure	• 3,473 charge points and 226 fast charge points • Low-carbon fuel regulation • State private charging infrastructure incentive • Electric vehicle-ready building codes • Streamlined local charging permitting process	+
Research and campaigns	• State manufacturing incentive • "Drive the Dream," "Best.Ride.Ever," and "National Drive Electric Week" city outreach and awareness events • City information materials and events • Utility outreach information and events	+
Transit and fleets	• State and city electric vehicle fleet programs • Growing municipal and police electric vehicle fleets • Electric car sharing program	++

Charge point data from AFDC (2016), as of October 19, 2016

IV. SUMMARY COMPARISON OF ELECTRIC VEHICLE MARKETS

This section summarizes data on electric vehicle sales, public charging infrastructure, policy actions, and carbon emissions across the cities. The electric vehicle sales data in all countries except for Norway are estimated from new vehicle registration data. The charging infrastructure data presented come from multiple sources. The policy action data are qualitative, based on original collection for this report. The carbon emission data include comparisons of lifecycle emissions from electric and conventional vehicles in the regions examined. Further information, underlying data sources, and additional assumptions are presented in the Annex. In several cases data were not available for particular cities.

ELECTRIC VEHICLE UPTAKE

Figure 1 shows the electric vehicle uptake—in new registrations and share of new vehicles in 2015—for the 14 metropolitan areas identified in this study. These 14 markets represented 32% of global electric vehicle sales in 2015. As shown, the top 2015 electric vehicle markets within China, Europe, and the United States have annual electric vehicle sales that are in the tens of thousands per year or that make up about one in every 10 new vehicles. Oslo had the highest electric vehicle share at 27%, followed by Utrecht at 15%, and Shanghai at 11%. Shenzhen, Amsterdam, and San Jose complete the top six in sales share with 9%-10% of new vehicles being electric. The top six cities by electric vehicle share are distributed across four countries on three continents. In terms of total annual new electric vehicle volume, Shanghai leads by a wide margin with 41,179 electric vehicles sold in 2015. Los Angeles, with 23,652 sales, and Beijing, with 18,065 sales, had the next most new electric vehicles being deployed.

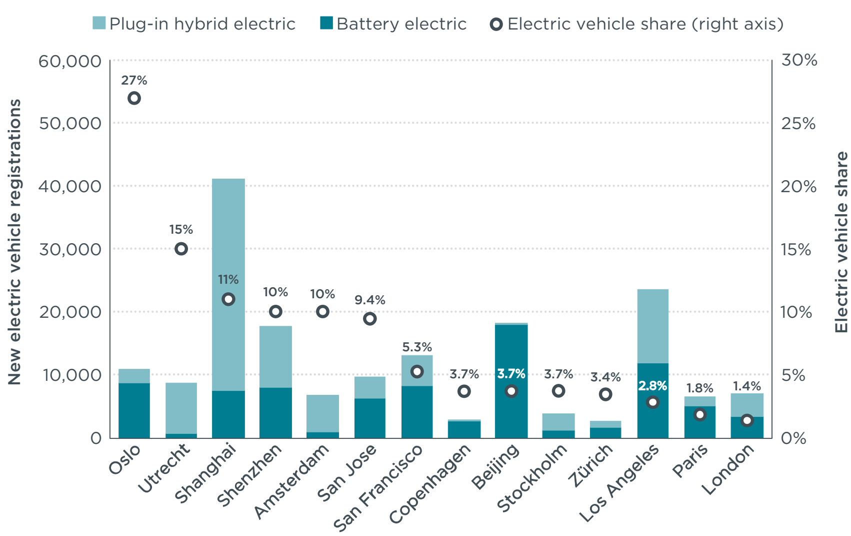

Figure 1. Electric vehicle new registrations and share of new vehicles in 2015 in high electric vehicle uptake markets. (*new vehicle registration data from IHS Markit and IHS Automotive*)

Although Figure 1 shows electric vehicle sales relative to the other capital cities, these cities have varying performances relative to their own countries. The city of Oslo has very high uptake, for example, but its sales fraction is only slightly higher than Norway's national average of 22%. Meanwhile, San Jose has an electric vehicle share more than 13 times that of the United States (and three times that of California), and Shanghai sold electric vehicles at 12 times the rate of China's national average.

Beyond total sales volume and sales fraction, there are additional differences between these cities. In some cities, such as Copenhagen and Beijing, almost all electric vehicles sold were pure battery electric vehicles, while in other cities, like Amsterdam and Utrecht, the vast majority were plug-in hybrid electric vehicles, and in cities such as San Jose and Stockholm, there is a mixture of electric vehicle types. This is reflective of differences in subsidy programs that prioritize the two plug-in electric vehicle types, availability of models in each market, the availability of charging infrastructure, and commuting patterns.

CHARGING INFRASTRUCTURE

As noted in the introduction, public charging infrastructure can be an important component of electric vehicle market growth, and each of the cities examined have substantial electric vehicle charging networks. Figure 2 shows the number of charge points (both total and fast) per million people in most of the metropolitan regions examined in Europe and North America. As shown, Oslo has much more substantial charging network than others, with more than 2,400 total charge points per million people with about 130 fast chargers per million people, with others having less charging available. Detailed, comprehensive data were not publicly available for the China cities; based on best available data, we approximate that the total charge points per million people for Shanghai is 146 and for Beijing is 313. Oslo and Utrecht, the top two cities in electric vehicle sales share, also lead in the availability of public charging infrastructure. Overall, the cities with the greatest electric vehicle uptake tended to have greater charging infrastructure, providing additional evidence that charging infrastructure is a crucial part of a supportive electric vehicle environment.

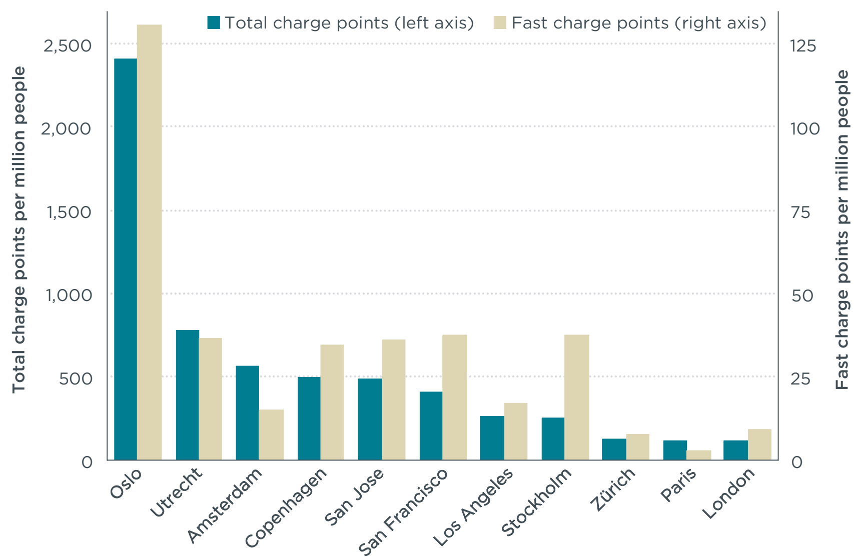

Figure 2. Total electric vehicle charge points and fast charge points per million population.

In each city, the number of Level 2 (AC) charging far exceeded the number of fast chargers, which are defined as having a charging power of 40 kW or greater. Although we use 40 kW for consistency in this analysis, different jurisdictions use anywhere from 22 to 50 kW to define fast charging. However, the ratio varies from more than 20 level 2 chargers for every fast charger in Utrecht and London to about six level 2 chargers for every fast charger in Stockholm. With its large population, Los Angeles leads the 11 metropolitan areas analyzed here in terms of total charge points with 3,473, followed by Oslo (2,829), San Francisco (1,916), and London (1,652). Although detailed comprehensive data were not publicly available for China, one government source states that there are 6,789 publicly available charge points in Beijing and 3,513 in Shanghai (Electric Vehicle Charging Infrastructure Promotion Alliance [EVCIPA], 2016).

ELECTRIC VEHICLE PROMOTIONAL ACTIONS

All of the cities in this assessment have extensive actions and policies in place to further the deployment of electric vehicles. Table 15 shows a breakdown of the extent to which each of the respective cities has implemented actions and policies based on five main categories: financial incentives, nonfinancial incentives, charging infrastructure, research and campaigns, and transit and fleets. Each of the categories is given a ranking of + or ++ based on the extent of action the city has taken for the respective category, with a blank indicating no known policy or action, +, some action, and ++, extensive action. As indicated, each of these metropolitan areas with high electric vehicle uptake has many policies and promotion activities in place.

Table 15. Qualitative evaluation of electric vehicle support actions for high electric vehicle uptake markets

Country	City	Financial incentives	Nonfinancial incentives	Charging infrastructure	Research and campaigns	Transit and fleets
China	Shanghai	++	+	+	+	++
	Shenzhen	++	++	+		++
	Beijing	++	+	+	++	+
Europe	Copenhagen	+	+	++	++	++
	Paris	++	+	+	+	+
	Amsterdam	++	++	++	+	++
	Utrecht	++	++	++	++	+
	Oslo	++	++	++	+	++
	Stockholm	+	+	+	+	+
	Zürich	+		++	+	+
	London	+	++	+	++	++
United States	San Jose	++	++	++	+	+
	San Francisco	++	++	++	+	++
	Los Angeles	++	++	+	+	++

A blank indicates no known policy or action, + some action, and ++ extensive action. Additional details on evaluations are provided in the Annex.

GRID CO_2 EMISSIONS FROM ELECTRIC VEHICLE CHARGING

Electric vehicles, due to their much higher on-road efficiency and use of lower-carbon energy sources, have the potential to offer much lower carbon emissions than conventional vehicles. Figure 3 shows real-world life-cycle carbon dioxide (CO_2) emissions on a per kilometer basis in each of the countries discussed in this paper, including both the vehicle exhaust emission and the fuel cycle emissions to extract and process the energy sources into useful vehicle energy. This figure compares the emissions from the world's most popular electric vehicle, the 2015 Nissan Leaf, charged using electricity from the country's average electricity generation portfolio, with emissions from an average internal combustion engine-powered passenger car sold in 2015 in each of these countries. The conventional vehicles are shown as passenger car averages for China, U.S., and Europe, based on the latest available regulatory CO_2 data. These include an adjustment to account for higher real-world emissions (e.g., International Council on Clean Transportation, 2015; U.S. Environmental Protection Agency and Department of Transportation, 2012). Electric vehicles in all markets analyzed delivered substantially lower carbon emissions than the average conventional vehicle. In some regions (e.g., Amsterdam and Zürich), electric vehicles are more frequently charged using dedicated "green" electricity sources; although the benefits of these programs are not reflected in Figure 3, dedicating clean electricity to fuel electric vehicles would result in even lower carbon transport. Further details on the underlying assumptions are provided in the Annex.

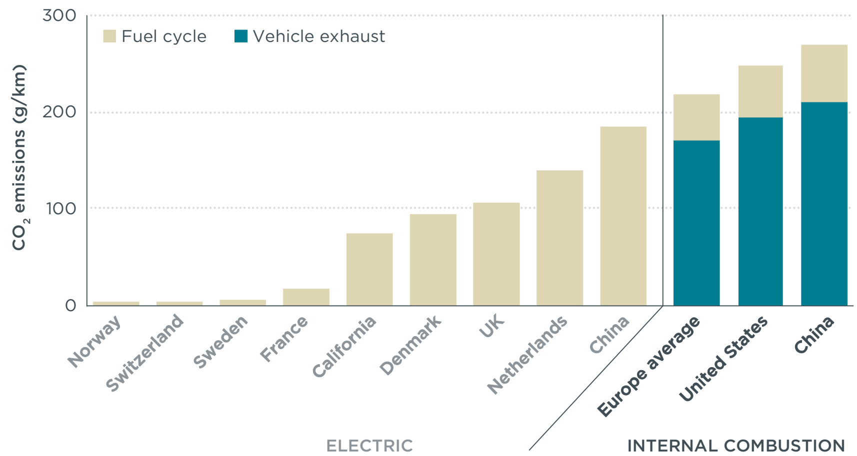

Figure 3. CO_2 emissions from electric and internal combustion engine vehicles in the jurisdictions analyzed assuming the country's average generation portfolio is used to charge electric vehicles.

As shown in the figure, electric vehicles produce fewer emissions than an average internal combustion engine vehicle in every jurisdiction considered. However, the magnitude of this difference varies significantly. Markets like Norway, France, Sweden, and Switzerland that have greater electricity generation from low-carbon renewable and nuclear energy sources result in much lower carbon emissions—more than a 90% benefit compared with average conventional cars in Europe. In California, an electric vehicle produces at least 75% lower CO_2 emissions per kilometer driven than an average conventional car in the U.S. The same electric vehicle produces 50%-60% lower carbon emissions in Denmark and the United Kingdom. In the cases of China and the Netherlands, electric vehicles delivered 30%-40% lower carbon emissions than the average conventional vehicle in those markets. The Netherlands has led efforts to ensure electric vehicles are charged using low-carbon energy, with public chargers being supplied by renewable energy instead of grid electricity (Verbeek et al., 2015). As the electricity supply around the world continues to become steadily cleaner over time, electric vehicles are expected to offer even greater emission reductions in the future (IEA, 2015).

V. CONCLUSION

As electric vehicle technology continues to improve, policymakers seek to mitigate climate change concerns and see electric vehicle uptake as part of the solution. Although global electric vehicle sales are modest at less than 1% of new car sales, many major markets have seen relatively high uptake (ranging from 2 to more than 30 times the global average) due to a variety of supportive policies and extensive charging infrastructure networks. Although these "electric vehicle capitals" each have different market context and differ in their policy approaches, their success today offers a number of lessons, providing valuable information to other governments planning their own transition to electric drive.

Global electric vehicle sales are heavily concentrated in certain metropolitan areas—the 14 metropolitan areas accounting for just 1.5% of the global population and only 5% of annual global passenger vehicle sales represent about a third of the global electric vehicle market. The metropolitan areas with the highest electric vehicle sales in 2015 were in Shanghai (41,179 electric vehicles), Los Angeles (23,652), Beijing (18,065), and Shenzhen (17,699). The metropolitan areas with the highest share of electric vehicles sold in 2015 relative to total passenger vehicle sales were Oslo (27%), Utrecht (15%), Shanghai (11%), and Shenzhen (10%). These electric vehicle capitals are paving the way for the broader global adoption of electric vehicles. Together, they provide clear examples of the set of actions needed for electric vehicles to reach beyond market innovators and early adopters to the mass market.

The 14 electric vehicle capitals discussed in this paper demonstrate how the pathway to increased penetration of electric vehicles includes a wide range of actions, including financial and nonfinancial incentives, charging infrastructure build out, research and development, promotional campaigns to enhance consumer awareness, electrification of public transit and government vehicle fleets, car sharing services, and others. In essence, the common strand among these cities' electric vehicle activities is that they all are actively addressing the key prevailing barriers of cost, convenience, and consumer information.

Although there are similarities in the policy approaches, each of the progressive electric vehicle capitals has a unique approach to increasing electric vehicle adoption, providing numerous examples for other cities to learn from. In Norway, major incentives are implemented by the national government and regional governments and provide strongly supportive policies and programs. The national government's polluter-pay tax system heavily taxes high-emitting conventional vehicles and exempts zero-emission vehicles. The tax system, paired with other electric vehicle incentives (e.g., low annual road taxes, no fuel taxes, no purchase or import taxes, free parking, bus lane access, free charging, extensive public charging network, exemption from road and tunnel tolls), has effectively placed Norwegian cities at the forefront of electric vehicle deployment and integration. The Netherlands has strong national electric vehicle subsides paired with additional regional subsidies in select locations, widespread electric charging infrastructure and development, extensive public transit and taxi electrification, and a broad range of pilot projects and consumer awareness campaigns. In China, there are federal subsidies and tax exemptions in addition to many local registration limitation policies that greatly favor electric vehicles. The United States federal government implements tax credits, and many regional and local governments, like the state of

California, offer electric vehicle rebates, preferential lane access, developed charging infrastructure, and consumer outreach and awareness.

Future work could include a deeper analysis into each of the markets and the relative importance of charging infrastructure, policy, and other promotion actions. Region-specific analysis, for example, isolating China, Europe, and U.S. markets, could use consistent comprehensive datasets to analyze relative effectiveness of the policy actions and charging infrastructure benchmarks over time. Also, beyond the capitals identified here, there are numerous smaller metropolitan areas that also could provide further insight into electric vehicle deployment. Other cities include Bergen, Norway, where electric vehicles are 38% of total vehicle sales; Eindhoven, Netherlands (10%); Gloucestershire, United Kingdom (9.1%); and Hangzhou, China (7.5%). Bergen's numerous islands made bridge, tunnel, and ferry toll exemptions a major driver for uptake. Analysis of Norway in general might be especially helpful in understanding how northern climates in China and North America might overcome potential issues with electric cars in colder climates. Although no German cities are identified here as capitals, they could hold lessons in the future, especially now that Germany has incentives in place and lower-cost, higher-electric range vehicles are entering the market. For example, Cologne and Frankfurt had approximately 1% electric vehicle sales in 2015 before the major mid-2016 Germany incentive program was implemented. Other cities elsewhere in Europe, Canada, and Japan, could also provide further lessons as data become available on the electric vehicle market development in those regions.

Many cities actively work in many ways to shift the transport system to lower carbon modes, and to decarbonize vehicles with new technology. Among these various strategies, it is clear that electric vehicles deliver a low-carbon transport option. The major electric vehicle hubs assessed here are accelerating the transition to electric drive and therefore realizing significant emissions reductions and air quality benefits. Upstream CO_2 emissions from electric vehicles vary substantially across the cities studied in this paper, from essentially zero in hydropower-rich Norway and Switzerland to more than 150 g/km in relatively coal-heavy China. Even after incorporating upstream emissions from electricity production, electric vehicles emit less CO_2 compared to conventional cars in each of markets evaluated. CO_2 reduction benefits range from 30%-40% China and the Netherlands; 50%-75% in the United Kingdom, Denmark, California; and over 90% in France, Norway, Sweden, and Switzerland. Furthermore, electric vehicles are expected to offer even greater emission reduction benefits in the future as electricity grids become cleaner and new initiatives continue to integrate electric vehicle and renewable energy deployment.

During the early stages of market growth, electric vehicle capitals have charted unique paths and emerged as global leaders in terms of electric vehicle promotion actions and uptake. Although electric vehicle policies and actions must be tailored to each region, the metropolitan areas discussed in this analysis provide models for other cities as they transition toward electric mobility. These electric vehicle capitals of the world are already realizing the benefits of their investment in clean transportation. This type of leadership, if continued and expanded, will help accelerate the global deployment of electric vehicles in coming years.

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ANNEX

This section includes additional data sources, as well as information and criteria regarding the qualitative scoring of the electric vehicle support actions and the quantification of the fuel cycle electric vehicle carbon emissions.

COMPARISON OF ADDITIONAL METROPOLITAN AREAS

Although we limited our primary analysis to select metropolitan areas in the United States, Europe, and China with populations over 1 million, there are a number of additional metropolitan areas with substantial electric vehicle sales in 2015, as shown in Figure A1 below. These 29 metropolitan areas represent approximately 44% of world electric vehicle sales in 2015. Although many of these cities were not included in this analysis, further comparison of this broader array of cities is a possible area for future research.

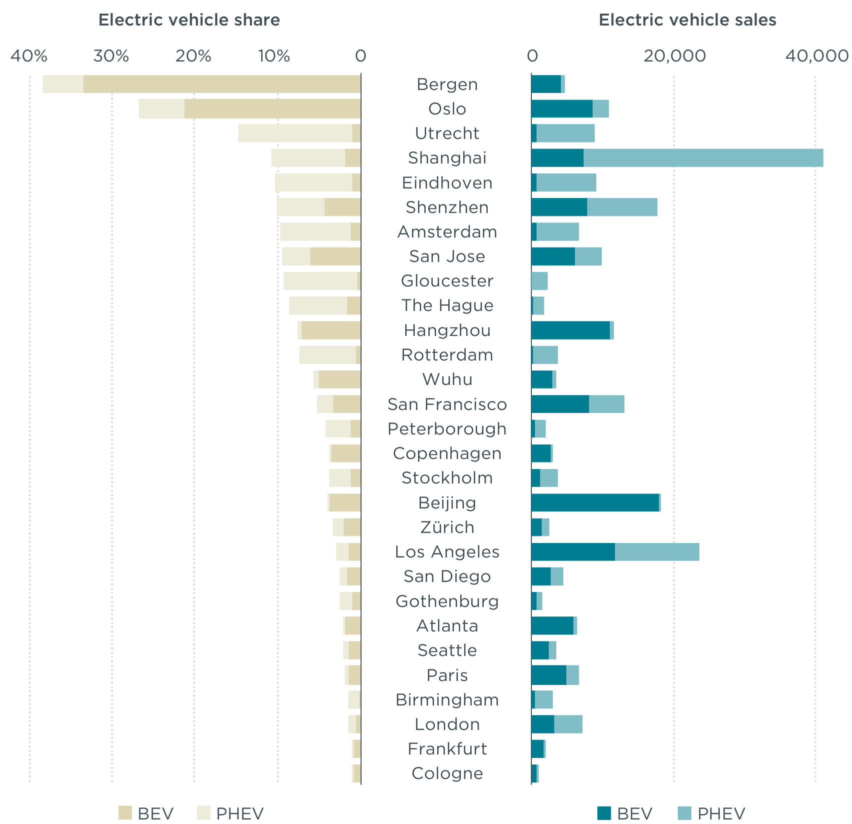

Figure A1. Electric vehicle sales share (left) and sales volumes (right) for 2015 (*new vehicle registration data from IHS Markit and IHS Automotive*).

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Criteria for evaluating electric vehicle support actions. To provide a consistent qualitative analysis, each of the electric vehicle support actions were evaluated with a blank, +, or ++ based on the extent of action taken. These rankings are shown in the right-hand column of the tables outlining electric vehicle support actions for each of the metropolitan areas in the report. The criteria for each category (financial incentives, nonfinancial incentives, charging infrastructure, research & campaigns, and transit & fleets) are defined in Table A1.

Table A1. Criteria used for evaluating the electric vehicle support actions in each city profile

Type of Program	(blank)	+	++
Financial incentives	None	National or regional level incentives with value under $5,000	National and regional level incentive value exceeding $5,000
Nonfinancial incentives	None	One or two actions from the list below	Three or more actions from the list below
Charging infrastructure	< 100 charge points per million people	> 100 charge points per million people	> 400 charge points per million people
Research & campaigns	No significant research projects or consumer awareness campaigns	Notable research project(s) or consumer awareness campaign(s)	Notable research project(s) and consumer awareness campaign(s)
Transit & fleets	None	Substantial electrification in one of the categories below	Substantial electrification in two or more of the categories below

Nonfinancial incentives include local parking benefits, low-emission/environmental zones, congestion charges or exemptions from tolls, high-occupancy vehicle (HOV) or bus lane access, and exemptions from registration restrictions. Transit and fleet activities include government fleet vehicles, municipal buses, taxis, and car sharing services. Where financial incentives are based primarily on tax and fee exemptions rather than subsidies, such as in the Netherlands, we used the values determined in Slowik and Lutsey (2016).

Definitions of metropolitan regions. As noted in the introduction, this paper discusses statistics such as population, vehicle sales, and charging infrastructure at the metropolitan area level rather than at the city level. This helps promote consistency among countries and recognizes that programs instituted at a local level affect people in a wider area through commute and travel patterns. In the United States, our analysis uses the United States Census Bureau Metropolitan Statistical Area (MSA) definition, and in the Europe, our analysis uses the Functional Urban Area (FUA) definition, in most cases. In China, this analysis includes only city definitions, which include large areas that resemble metropolitan areas in other regions. Table A2 below lists the definitions used for each metropolitan area examined in this analysis.

Table A2. Definitions of metropolitan areas used in this analysis

City	Type of urban area	Constituent jurisdictions
Shanghai	Municipality	Shanghai
Shenzhen	Sub-provincial city	Shenzhen
Beijing	Municipality	Beijing
Copenhagen	FUA	Byen København, Københavns omegn, Nordsjælland
Paris	FUA	Paris, Seine-et-Marne, Yvelines, Essonne, Hauts-de-Seine, Seine-Saint-Denis, Val-de-Marne, Val-d'Oise
Amsterdam	Poly-FUA	Alkmaar en omgeving, IJmond, Agglomeratie Haarlem, Zaanstreek, Groot-Amsterdam, Het Gooi en Vechtstreek
Utrecht	FUA	Utrecht (province)
Oslo	FUA	Oslo, Akershus
Stockholm	FUA	Stockholms län
Zürich	FUA	Zürich (Canton), Zug
London	FUA	Greater London, Kent, Essex, Luton, Hertfordshire County, Buckinghamshire County, Berkshire, Surrey
San Jose	MSA	Santa Clara County
San Francisco	MSA	San Francisco County, Alameda County, Contra Costa County, Marin County, San Mateo County
Los Angeles	MSA	Los Angeles County, Orange County

Carbon emissions. In our vehicle life and fuel cycle assessment of electric vehicle CO_2 emissions, we sought to give comparisons that best reflect a comparison with similar internal combustion engine vehicles in each jurisdiction. For consistency, we used a 2015 Nissan Leaf for all electric vehicle calculations and average numbers for passenger cars sold in 2015 in each region. In our calculations, we used the numbers and data sources shown in Table A3.

Table A3. List of values and sources used in carbon emissions calculations

Coefficient	Value	Source
Electric vehicle efficiency	0.30 kWh/mile	Fueleconomy.gov (2016) (real-world)
Transmission & distribution efficiencies	93.5%	United States Environmental Protection Agency and Department of Transportation (US EPA and DOT, 2012)
Charging efficiency	85%	US EPA and DOT (2012)
Upstream fuel extraction emissions factor (electricity)	1.06	US EPA and DOT (2012)
Upstream fuel extraction emissions factor (fuel)	1.28	US EPA and DOT (2012)
NEDC to real-world adjustment factor	1.40	International Council on Clean Transportation (ICCT, 2015a)
EPA test cycle to real-world adjustment factor	1.25	US EPA and DOT (2012)
Carbon intensity of electricity generation, coal	1024 (g/kWh) (EU) 1029 (g/kWh) (China)	International Energy Agency (IEA, 2015)
Carbon intensity of electricity generation, natural gas	471 (g/kWh) (EU) 587 (g/kWh) (China)	IEA (2015)
Carbon intensity of electricity generation, oil/other	820 (g/kWh) (EU) 587 (g/kWh) (China)	IEA (2015)

For simplicity, nuclear power and all forms of renewable energy were assumed to contribute 0 g/kWh of CO_2. As discussed in the text, the power mix reflects electricity generated in each region and does not reflect power imports or exports. Data for power generation mix comes from the Shift Project (2016), which uses data from the World Bank, except for the following: Switzerland, from Bundesamt für Energie (BFE, 2015); United Kingdom, from Department of Energy & Climate Change (2016); and California, from California Energy Commission (2016). Data on conventional internal combustion engine passenger car fleets comes from ICCT (2015a) for Europe; U.S. Environmental Protection Agency (2015) for the United States; and ICCT (2015b) for China.

Public charge point data. In analyzing the density of public charging infrastructure, we use the same regional definitions as used for electric vehicle sales and population, with the boundaries described above. The numbers include "semi-public" charging infrastructure, such as Tesla Superchargers or chargers accessible only at certain times of day. We did not include "level 1" chargers with less than 3 kW of power, and where applicable, fast charging is defined as greater than 35 kW of power. Our charge point data comes from the following sources:

- China: Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA, 2016); Dated August 20, 2016
- Denmark: E.ON (2016); Clever (2016); Accessed October 31, 2016
- France: Etalab (2016); Accessed October 14, 2016
- Netherlands: Open Charge Map (2016); Accessed September 9, 2016
- Norway: Nobil (2016); Accessed October 31, 2016
- Sweden: Open Charge Map (2016); Accessed September 9, 2016
- Switzerland: Open Charge Map (2016); Accessed September 9, 2016
- United Kingdom: Office for Low Emission Vehicles (2016c); Accessed October 18, 2016
- United States: AFDC (2016); Accessed October 19, 2016

Table A4 and the subsequent list of references is used in the Annex for the above methodology data as well as the additional research into the city policies in place to promote electric vehicles.

Table A4. References for electric vehicle promotional actions discussed in each city profile

City	Financial incentives	Nonfinancial incentives	Charging infrastructure	Research and campaigns	Transit and fleets
Shanghai	Yang et al. (2016); Shanghai Municipal People's Government (2016)	People's Government of Jiading District (2014)	Mitchell (2016); Shanghai Municipal People's Government (2013); Ministry of Transport of the People's Republic of China (2016)		Lu (2015); Wang & Liu (2015)
Shenzhen	Yang et al (2016); Liu (2015)	Liu (2015); Shenzhen Municipal People's Government (2015)	Shenzhen Municipal People's Government (2015); Liu (2015)		Shenzhen Transportation Commission (2016); Shenzhen Municipal People's Government (2015); Wang & Liu (2015); China Electricity Council (2016)
Beijing	Yang et al. (2016); Beijing Municipal People's Government Office (2015)	Yang et al. (2016); Bloomberg News (2016)	D1EV (2015); Beijing Times (2015); Beijing Municipal Development and Reform Commission (2015)	Beijing New Energy Vehicle Experience Center (BNEV, 2016a); Ministry of Science and Technology (2014)	Wang & Liu (2015)
Copenhagen	Danish Government (2011); Dansk Elbil Alliance (2016)	City of Copenhagen (2009); City of Copenhagen (2016); Tsang, et al., 2012	Dansk Elbil Alliance (2016); City of Copenhagen (2009); International Energy Agency (IEA, 2016)	Capital Region of Denmark (2016)	Hansen (2015); DriveNow (2016); Arriva (2016); EnergiWatch (2016); City of Copenhagen (2009)
Paris	European Automobile Manufacturers Association (ACEA, 2016); City of Paris (2016a); Métropole du Grand Paris (2016); Ministère de l'Environnement, de l'Énegie et de la Mer (2017); AVERE-France (2016)	City of Paris (2016a); Reuters (2016); Chazan (2016)	Etalab (2016); City of Paris (2016a)	Green Car Congress (2016)	EDF (2015); City of Paris (2012); IEA (2016)
Amsterdam	Netherlands Enterprise Agency (2015); Munnix (2015); City of Amsterdam (2016a, 2016b); IEA (2016)	City of Amsterdam (2016a); City of Amsterdam (2016d); City of Amsterdam (2015)	Netherlands Enterprise Agency (2015); City of Amsterdam (2016a, 2016c); Tietge et al. (2016); Living Lab Smart Charging (2016)	City of Amsterdam (2016a); IEA (2016)	Netherlands Enterprise Agency (2015); City of Amsterdam (2015, 2016a); IEA (2016)
Utrecht	Netherlands Enterprise Agency (2015); Munnix (2015); IEA (2016)	Netherlands Enterprise Agency (2015)	City of Utrecht (2015 a, 2015b, 2015c); Living Lab Smart Charging (2016)	Kane (2016); Eneco (2016); Netherlands Enterprise Agency (2016); IEA (2016)	Netherlands Enterprise Agency (2016)
Oslo	Norsk elbilforening (2016)	Norsk elbilforening (2016); Pütz & Nørbech (2012)	Holtsmark & Skonhoft (2014); Nobil (2012); C40Cities (2014); Norsk elbilforening (2016)	FREVUE (2016)	City of Oslo (2016)
Stockholm	van der Steen et al. (2015); Mock & Yang (2014)	City of Stockholm (2012)	Environmental and Health Administration (2016)	Vattenfall (2015); Environmental and Health Administration (2016)	Sunnerstedt (2013)
Zürich	Swiss Federal Office of Energy (2014, 2016)		EKZ (2016b)	IBM (2011); EKZ (2016a, 2016b)	Interface (2015); Schmitz (2015)
London	Gov.uk (2016); Transport for London (TfL) (2016a)	TfL (2016b, 2016c)	OLEV (2016c); TfL (2016c)	Auendi et al. (2014); OLEV (2016a)	Mayor of London (2016); TfL (2016a); LoCITY (2016)
San Jose	California Air Resources Board (CARB) (2016a); Searle et al. (2016)	Searle et al. (2016); Lutsey et al. (2016)	Searle et al. (2016); Lutsey et al. (2016)	Lutsey et al. (2016); National Drive Electric Week (2016);	Lutsey et al. (2016); CARB (2016b); City of San José (2016)
San Francisco	CARB (2016a); Lutsey et al. (2016)	Pacific Gas and Electric Company (2016); CARB (2016a)	U.S. Department of Energy (2016)	Pacific Gas and Electric Company (2016); National Drive Electric Week (2016)	Dawid (2013); CARB (2016b)
Los Angeles	Lutsey et al. (2016)	Lutsey et al. (2016)	Lutsey et al. (2016)	Lutsey et al. (2016)	CARB (2016b)

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Will Nissan's No Charge to Charge program drive LEAF sales?

Posted July 3, 2014 by Markkus Rovito (https://chargedevs.com/author/markkus-rovito/) & filed under Features (https://chargedevs.com/category/features/), Infrastructure Features (https://chargedevs.com/category/features/infrastructure-features/).


Free Fuel

Nissan and NRG eVgo have pioneered a multi-network consortium to make topping up the bestselling EV a considerable re-LEAF.

By Markkus Rovito

"We have a philosophy about charging at home, at work, and in the community...we always want them to have two of the three."

Brendan Jones, Nissan's Director of EV Infrastructure and Strategy

Image above courtesy of WSDOT (https://www.flickr.com/photos/wsdot/11393844803/in/set-72157638715107663/)*/Flickr*

Nissan and NRG eVgo have pioneered a multi-network consortium to make topping up the bestselling EV a considerable re-LEAF.

When Nissan last graced the *Charged* cover (March/April 2013 issue (http://chargedevs.com/features/a-new-leaf-localized-manufacturing-and-a-focus-on-infrastructure/)), the company was picking itself up and dusting itself off. Its LEAF had taken a shellacking in the press after the all-electric car sold less than 50 percent of the company's goal of 20,000 for 2012. But Nissan's response was all business. It chose to not release LEAF sales goals for 2013 and instead focused on making its new 2013 model LEAF an undeniable deal. The three new LEAF models for 2013 came in with a slightly increased range and significantly decreased prices.

However, the strategists at Nissan knew that improving the LEAF itself was only going to be part of the sale. To break through to more people than just the early-adopting true believers, Nissan wanted to alleviate potential customers' concerns that fuel for the LEAF (electricity) was hard to find. In 2013, Nissan doubled its efforts to spread its CHAdeMO DC fast charging stations across North America and Europe. By April 2014, Nissan had exceeded its expectations by installing – according to the company's own internal data – at least 610 of its DC fast chargers in the United States, with more on the way.

> **"We have a philosophy about charging at home, at work, and in the community...we always want them to have two of the three."**

"We're well ahead of our goal, and we're going to keep adding chargers every day though our network of partnerships," Brendan Jones, Nissan's Director of EV Infrastructure and Strategy, told *Charged*. "We have a philosophy about charging at home, at work, and in the community," he continued. "If our customers have the trifecta, great. But we always want them to have two of the three. We believe you have to build infrastructure in and around where our customers work, live, and travel in their daily lives. When you have heavy consumers of community infrastructure, and you put a fast charger there, people flock to it. The data strongly supports that."

The LEAF ended 2013 with a total of 22,610 sold in the US, and strong momentum from its biggest sales month in December. However, even with Nissan playing a huge role in spreading the CHAdeMO fast-charging standard, it could never single-handedly solve the charging infrastructure problem. And many believe that without sufficient infrastructure, it's unlikely that Nissan will reach the 150,000-LEAF annual capacity that it says its Tennessee assembly plant can scale to.

Last October, in an effort to move more EVs, Nissan launched the "No Charge to Charge" program in the greater Dallas-Ft Worth and Houston areas. The offer gave new LEAF buyers and lessees free access for one year to all of NRG eVgo's local Level 2 and DC fast charging Freedom Stations, which amounted to 23 locations in the Dallas-Ft Worth megalopolis, 17 in greater Houston, and local airport Park 'N' Fly locations. The six-month program stretched from October 1 to March 31, 2014. According to Nissan, through February 2014, LEAF sales grew in the test markets much faster than the overall regional and national rate: up nearly 60 percent in Dallas-Ft Worth, and up about 150 percent in Houston. Such results were enough to convince Nissan to begin to rollout the program – with some important changes – nationwide.

No money, no problem

Beginning on July 1, 2014, Nissan's No Charge to Charge program expands to 10 of the top Nissan LEAF markets in the US: San Francisco, Sacramento, San Diego, Seattle, Portland, Nashville, Phoenix, Dallas-Ft Worth, Houston, and Washington DC. Eligibility is retroactive to LEAF buyers and lessees beginning on April 1, 2014, and the free charging will continue for two years from the day the customer registers for the deal.

Some notable changes to the program are based on Nissan's analysis of customer charging habits and the company's work to unify the major charging networks with the new EZ-Charge card. Jones said, "The Texas pilot was designed to see whether our dealers were structurally adjusted to offer this to consumers, the dealer infrastructure was in place, the public infrastructure was in place, the accounts receivables and payables mechanism worked, and did it resonate? Thankfully, all those proved to be very positive. We could manage it."

So far, the EZ-Charge card will work with public Level 2 and DC fast chargers from ChargePoint, Car Charging Group's Blink Network, AeroVironment (AV), and NRG eVgo.

[**Update:** One of the Nissan's four charging partners, California-based ChargePoint, pulled out of the No Charge to Charge program after this story appeared in print (http://chargedevs.com/newswire/chargepoint-pulls-out-of-nissans-ez-charge-program-spoiling-launch-party/). However, there have been some reports that the companies are renegotiating the terms of the agreement.]

[**Update 2:** The reports were true, sort of. ChargePoint is participating in the EZ-Charge program giving Leaf owners the ability to access multiple charging networks with one single card, but ***not*** participating in the No Charge to Charge program. Although, the company points out that about 60 percent of stations on the ChargePoint network are already free to use.]

"In Texas, NRG controlled the whole market," Jones said. "It didn't have the EZ-Charge card associated with it for interoperability."

Also, while the pilot program was for one year of unlimited charging, the current No Charge to Charge offers two years of time-limited charging sessions. On a DC fast charger, customers will get up to 30 minutes of charging – enough to fill up a LEAF on average from 0 to 80 percent state of charge. With Level 2, customers will receive a free hour of charging, which will net them an additional range of 12-25 miles, according to Nissan's own reports.

"Most customers who arrive at a DC fast charger come in at 35-45 percent state of charge. Their average time on the charger is about 17 minutes."

Nissan used customer habit data from the No Charge Texas pilot, as well as other LEAF-user info gathered for more than two years to determine the free charging time limits that would appease both customers and the charger owner/operators. "Most customers who arrive at a DC fast charger come in at 35-45 percent state of charge," Jones said. "Their average time on the charger is about 17 minutes. So a 30-minute cap on DC fast chargers is more than enough for your average consumer. What it is dissuading to some degree is the extreme situation where somebody sits on the charger longer than 30 minutes, because they go beyond 80 percent and are trying to eke out that last 5 percent, which is where it might take a little bit longer. We don't want that charger hogged up, and lines queuing."

In the case of Level 2, No Charge to Charge covers public Level 2 stations – not workplace or private garage pay stations. "The average dwell time on an L2 charger in most places like grocery stores is right under an hour," Jones said. "We timed it to the average use cases of most people across the country."

For those LEAF users for whom the free Level 2 time is not free enough, the EZ-Charge card still will provide convenience, because it will have payment information stored and allow the user to pay for extra time at the standard rate for each individual charger.

Expanding interoperability

By July 2015, Nissan plans to extend No Charge to Charge to an additional 15 markets, for a total of 25 markets within a year of the program's launch, which Jones said will represent 82 percent of the more than 50,000 LEAFs sold to date in the US. Nissan hasn't revealed what the next 15 markets will be, but Jones did say that they may not necessarily be strictly the next 15 areas with the highest sales.

"Sales are a big criterion, but it is the level of chargers in the market," Jones said. "You take care of customers. You want to make sure that when the LEAF sells, there are enough chargers to maintain customer satisfaction. We have a few holes in some of the markets, so we're going to wait until we fill some of those holes with DC fast chargers. We have aggressive plans, and we'll pull forward some of the launch dates."

As it stands now, Jones said Nissan will announce some additional markets for the program late this summer, and more by the end of the year, with the program launching in certain new markets by January 2015.

In the meantime, Nissan and NRG eVgo, which manages the EZ-Charge card, will be working hard to not only secure the participation of charging station owner/operators, but also to sign up more charging networks on top of the four major networks on board as of now.

"A lot of those networks are reaching out to Nissan and eVgo," Jones said. "There are 10 networks in the US. Who would believe you could have 10 different cards? That's just ridiculous. Now Nissan customers will have one card, and that's what we want. It's a very neutral platform, but Nissan doesn't want to be the one in the middle of the charging business. So we selected eVgo to manage that platform, while they also manage their individual network simultaneously. And everybody plays as an equal partner: Car Charging Group, AeroVironment, ChargePoint, etc."

> "We're simultaneously laying the groundwork for these plans to get to those other markets, and we'll announce plans on a future date for making this scaleable country-wide."

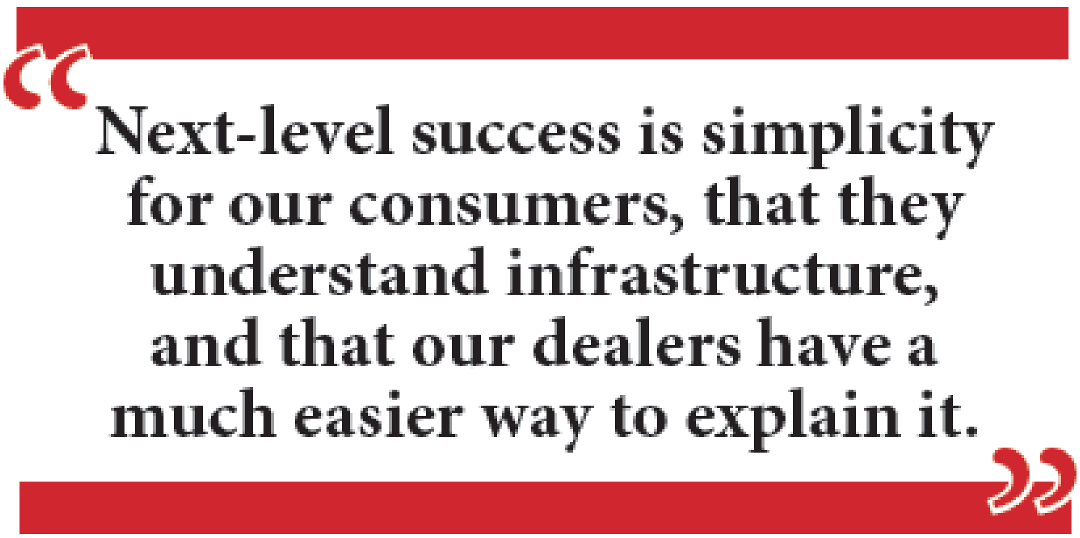
Not only does Nissan want to sign up every charging network for the EZ-Card program, but it also wants to expand the program nationwide after the initial 25 markets go online. "We're not going to leave the other markets just hanging there," Jones said. "We're simultaneously laying the groundwork for these plans to get to those other markets, and we'll announce plans on a future date for making this scalable country-wide."

EZ for all

Regardless of anyone's personal preference for electric automaker and/or charging provider, the success of the EZ-Charge card could spell success for the whole EV industry, because the EZ-Charge card will not be exclusive to Nissan. Any OEM could adopt it. Jones says the No Charge to Charge program's potential for success hinges upon its interoperability between charging networks and EV OEMs.

"I think the charging partners coming together and realizing their customer satisfaction is huge," Jones said. "It's as important to them as it is to the OEM. My hat's off to ChargePoint, AV, the Blink Network, and eVgo for coming together and forming those agreements. That's just a win for customers – not only for Nissan customers, but the industry as a whole. The cards can be used for another OEM, as well, if they choose to use its interoperability. That's great for the EV movement."

In a way, the No Charge to Charge and EZ-Charge card initiatives also pursue the goal of a non-profit group trying to eradicate a disease. Their ultimate success would be to eliminate concern over charging availability and convenience from the EV buyer's mind. Then, Jones said, the OEMs can concentrate more and more on the vehicles, rather than their fuel.



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"Next-level success is simplicity for our consumers, that they understand infrastructure, and that our dealers have a much easier way to explain it," Jones said. "One card gets you access to the DC fast chargers and the L2s in your area. All the miscommunication that has happened in the past goes away, and we can focus on what it's really about – that when buying an EV, your fueling needs are taken care of. We need to get to a place where the fueling takes a back seat to the product. That's true for Nissan and every other OEM. The product needs to lead the way. We'll build the infrastructure behind the scenes and find a way to easily communicate it, and we're heading towards that goal right now."

(http://chargedevs.com/wp-content/uploads/2014/07/Nissan-No-Charge-to-Charge3.jpg)

Spending money to make money

Of course, no one should think that Nissan has embarked on some kind of altruistic crusade. Jones makes it clear that the point of No Charge to Charge is to drive sales. It worked during the pilot program in Texas, and the nationwide rollout of the program certainly means to keep the LEAF in its current position as the best-selling pure EV.

“We’re a sales company, absolutely,” Jones said. “We’re not going to say how big of a sales bump we expect out of this, but it needs to drive sales. We’re confident that it’s going to drive sales. I have a LEAF at home, and two neighbors have also bought one, because our car is present throughout the neighborhood, and they always see it. Think about if a customer goes home and says ‘This is the easiest thing to fuel. I’ve got this card; I’ve got a home charger; I’m done. I thought there was some complexity to this, but there’s not.’ That word of mouth will increase sales.”

The program also helped make sales easier for dealers during the pilot run in Texas. Dealers were able to explain the convenience of the program, show the customers where available chargers were during a test drive, and often demonstrate DC fast charging on the lot. “It really resonated that the customer saw that there was an infrastructure,” Jones said.

Although it’s not giving specific figures, there is certainly some cost to Nissan to implement No Charge to Charge. However, Jones said that Nissan is not actually paying the charging fees that would otherwise be incurred. In most public charging situations (like those on the ChargePoint network), the individual site hosts own the hardware and are responsible for setting the fees. In those cases, ChargePoint and NRG are signing up each site host for the program. The majority of Level 2 sites – according to Jones – are already free to use. “There’s very few instances where an actual profit from the charge station is what makes the site host happy,” Jones said. “There are some, but they’re isolated. Most of them are providing a service to a retail customer. So it benefits the site hosts to be in the program. All indications are that by the time the program launches, we’ll hit the high penetration rate we’re looking for on the amount of L2s available.”

If you live in one of No Charge to Charge’s initial rollout markets, expect to see or hear some advertising that heavily pushes the “free charging” and “network agnostic” angles. Nissan will geo-target its marketing efforts according to the facilities and demands of a particular region. Although common themes should involve the number of chargers available, the convenience of interoperability, and of course, that it’s free!

“We’re excited about it,” Jones said. “We think it’s a step in the right direction.”

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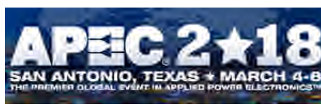

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REPORT

DRIVING OUT POLLUTION:
How Utilities Can Accelerate the Market for Electric Vehicles

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Executive Summary

Widespread adoption of electric vehicles (EVs) is an essential strategy for driving carbon pollution out of the transportation sector.[1] Large-scale deployment of EVs can also help replace dirty power plants with clean energy like wind and solar power. And EVs powered by those renewable resources are virtually emissions-free.

Realizing this potential requires a robust network of charging stations where consumers live, work, and play. Such a network will pave the way for a larger and more diverse EV market. Electric utilities are uniquely positioned to facilitate the creation of this network because they can make use of spare grid capacity to charge EVs, generating significant new revenues. In turn, the growing customer investment in EVs with large, advanced batteries can be leveraged to bring more renewable energy into the system.

With the right policies, the power and scale of the electric industry could be unleashed to transform the way America travels while saving us money and protecting our health, environment, and economy from dangerous climate change.

Putting the transportation sector, which accounts for a third of U.S. carbon pollution, on track to meet the nation's climate goals requires greatly accelerating EV sales.[2] EVs will need to account for 40 percent or more of new vehicle sales by 2030, up from the current less than 1 percent, in order to meet long-term carbon-reduction targets, according to numerous studies.[3]

This is not impossible. In a period of about two weeks, almost 400,000 people put down $1,000 deposits for the next-generation, moderately priced Tesla.[4] However, Tesla may be forced to return many of those deposits, if the charging infrastructure network does not catch up to consumer demand. A major barrier to the growth of the EV market is the lack of charging stations outside of single-family detached homes, where more than 80 percent of current EV owners live.[5]

A substantial investment is needed. By way of example, to meet California's EV deployment goals, it is estimated 125,000 to 220,000 publicly accessible charging ports are needed by 2020, a dramatic increase from the estimated 10,000 the state has today.[6] And hundreds of thousands of additional charging stations at apartment complexes and other multi-unit dwellings will be needed over the same time period to unleash the pent up demand from consumers who do not live in single-family detached homes.

The electric industry is uniquely positioned to accelerate the EV market and help meet air quality standards and climate goals by deploying more charging stations and educating customers on the benefits of driving on electricity.

As noted in a recent National Academies of Science study, only utilities can capture the "incremental revenue from additional electricity that EV drivers consume at home, where roughly 80 percent of the charging takes place," and use it to increase access to electricity as a transportation fuel.[7] This means serving the "garageless" who cannot buy a plug-in electric vehicle because they are not able to plug it in at home, and growing the market in low-income communities that are historically exposed to dangerous air pollution and also the most vulnerable to volatile gas prices. It also means deploying charging stations at workplaces and other visible locations to drive new sales, alleviate "range anxiety" (fear of running out of juice while driving), and make greater use of solar energy that generally peaks when people are away from home. Combined with residential charging, which ensures EVs are plugged in overnight when wind power is abundant, this maximizes the availability of EVs to support the grid.

Researchers at the Pacific Northwest National Laboratory found sufficient spare capacity in the nation's grid to power nearly all of our passenger cars and trucks, if vehicle charging is properly managed.[8] Charging EVs during hours when the grid is underutilized increases utility revenues without commensurate increases in costs, putting downward pressure on electricity rates. This effect is the opposite of the utility "death spiral," whereby increasing costs borne by a decreasing pool of customers causes rate increases that drive away more customers, leaving those who cannot afford distributed (onsite) generation or home energy storage to pay for an aging grid. In fact, a recent study estimates large-scale commercialization of EVs in California would generate net revenues of $2 billion to $8 billion for Southern California Edison (SCE), San Diego Gas & Electric (SDG&E), Pacific Gas & Electric (PG&E) and the Sacramento Municipal Utility District (SMUD), enough to allow those utilities to both invest in charging infrastructure and reduce consumer bills.[9]

Electric utilities can also leverage the growing number of EV batteries already on the road to absorb increasing amounts of wind and solar electricity that may otherwise be dumped if it is not generated at times when there is sufficient demand. The charging of EVs can be managed to avoid hours when the grid is strained and to coincide with

TABLE ES-1: THE THREE PHASES OF UTILITY ELECTRIC VEHICLE MARKET-ACCELERATION POLICY
1. Removing Barriers To Adoption, Ensuring Grid Reliability, And Maximizing Fuel Cost Savings
Clarify that electric vehicle charging companies will not be regulated as utilities
Inform distribution system planning
Provide consistent and fair treatment of electric vehicle load
Adopt appropriate rates to maximize fuel savings and manage charging
Target customer education and outreach programs
2. Closing the Charging Infrastructure Gap and Promoting Equity
Utility-facilitated deployment of charging infrastructure
Increase access to electricity as transportation fuel in disadvantaged communities
Promote broader awareness through mass-market education and outreach
3. Capturing the Value of Grid Services and Integrating Renewable Energy
Implement traditional demand response programs for electric vehicle customers
Implement advanced demand response programs for electric vehicle customers
Integrate V2G and battery second life programs into wholesale and retail markets

hours when renewable energy is plentiful, avoiding the need to either spill valuable clean energy or invest in stand-alone energy storage.

In the future, EV batteries could even put electricity back onto the grid when it is most needed. This can be accomplished both via "vehicle-to-grid" or "V2G" (storing energy in EVs and putting it back onto the grid later) and via "Battery Second Life" (storing energy in used EV batteries redeployed as stationary energy storage and putting it back onto the grid later). American drivers have already purchased, in the form of EV batteries, more than enough energy storage to power all the homes in the District of Columbia on an average day.[10] That sunk investment grows with every EV purchase. Researchers at the National Renewable Energy Laboratory (NREL) estimate massive amounts of energy storage will likely be needed to balance a U.S. electric grid that is 80 percent renewable by the year 2050.[11] That need could theoretically be met entirely with batteries from as few as 10 percent of the EVs on the road in that year.[12] Stand-alone energy storage on that scale could require an investment somewhere between $120 billion and $180 billion.[13] Directing even some portion of that investment away from capital-intensive, utility-scale projects and toward EV drivers to provide energy storage with the batteries they have already purchased could reduce the cost of transitioning to a cleaner grid and accelerate the electrification of the transportation sector.

To realize this potential, we need utility policies to unleash greater investments in charging infrastructure and other programs that expand EV adoption in a manner that supports the grid and returns the value of doing so to EV drivers. Utility policies to accelerate the EV market can be broken down into three phases, as shown in Table ES-1. Phase 1 removes barriers to EV purchases, facilitates a competitive market for third-party charging services, prepares utilities to integrate EV load, and encourages drivers to charge in a manner that avoids adverse grid impacts and maximizes their fuel cost savings relative to gasoline. Phase 2 focuses on infrastructure, equity, and education programs to accelerate the EV market and increase access to electricity as a transportation fuel. Phase 3 develops managed charging programs so that EVs can facilitate the integration of renewable energy and provide other grid services, and returns the value of such services to EV drivers to further accelerate the market.

Phase 1 presents the most pressing issues, but the foundations for Phase 2 and Phase 3 must be laid today in order to realize the long-term benefits of widespread EV adoption. Now is the time for utilities and utility regulators to act. Short-term delays could result in a near-impossible task in the future, as it takes decades to turn over the nation's vehicle fleet. It is estimated that traffic pollution causes more than 50,000 premature deaths annually in the lower 48 states, which is more than 1.5 times the deaths from traffic accidents on an annual basis.[14] The electric industry should move quickly to bring forward the environmental and economic benefits of moving America off oil—once and for good.

A. Introduction

Achieving long-term greenhouse gas (GHG) reduction targets in the United States and internationally requires large-scale deployment of electric vehicles (EVs), including both pure battery electric vehicles and hybrids that can be plugged into the grid, increasingly fueled by renewable electricity. Electric utilities are singularly positioned to provide ubiquitous access to charging—while supporting the grid and facilitating its transition to variable resources like wind and solar energy, benefiting all customers, and returning value to EV drivers.

Studies show that putting the transportation sector on track to meet long-term GHG reduction goals requires greatly accelerating the sale of EVs—currently less than 1 percent of new sales—in the near term.[15] Fortunately, the initial U.S. market launch of EVs has been highly successful. Over the first five years of sales, from 2011 to 2015, about 388,000 EVs were sold; that is comparable to the number of conventional hybrid electric vehicles (which cannot be plugged into the grid) sold during their first five years on the U.S. market.[16] Electric vehicles have also enjoyed extremely high levels of customer satisfaction: 98 percent of Tesla Model S owners, 85 percent of Chevrolet Volt owners, and 77 percent of Nissan LEAF owners report they would definitely purchase the same vehicle again.[17] Over the next couple of years, the number of models will almost double, and these next-generation models promise improved range and performance. Battery costs have been falling more rapidly than previously predicted and will continue to drop. In a period of about two weeks, almost 400,000 people put down $1,000 deposits for the next-generation, moderately priced Tesla Model 3.[18]

However, without major new market-transformation policies, the EV market could stall before it reaches a critical tipping point. To achieve mass commercialization, EVs must overcome three key barriers: higher initial purchase prices, concerns over lack of charging stations and range, and low consumer awareness. Utilities can accelerate the mass commercialization of EVs by reducing the cost of ownership through appropriate rate design and compensating EV drivers for valuable grid services, deploying charging infrastructure that can act as a grid resource and reduce range anxiety, and conducting customer education and outreach.

The electric industry is one of the few that have the power to challenge the market dominance of the oil industry. Utility-scale investment is also needed to facilitate the expansion of the nascent competitive EV charging service industry. Since they provide the fuel, utilities and independent EV charging service companies play a critical role in determining the success of the EV market. With the right programs to manage charging, widespread EV adoption could benefit the entire utility system and its customers.

Electric vehicles are not the only form of fuel-switching that can reduce overall emissions, but substituting electricity for petroleum fuels has the greatest potential to reduce emissions of any electrification opportunity. Likewise, no other single customer-side resource combines the attributes of a typical EV that could be utilized to support the grid. A 2016 Nissan LEAF can store as much electricity as the average American home uses in a day, equal the instantaneous demand of several homes, and be recharged while its owner is sleeping, eating, working, or doing anything other than driving.

Utility programs that maximize the storage, power, and flexibility of EVs can benefit all utility customers. Charging EVs when there is spare grid capacity avoids the need for new capital investments and provides additional revenue without a commensurate increase in costs, thereby putting downward pressure on electricity rates. By providing valuable grid services that facilitate the integration of variable renewable resources like wind and solar, widespread EV adoption can also lower the costs of de-carbonizing the electricity sector. Achieving this promise requires the rapid adoption of major new utility programs and policies that can drive out pollution while benefiting the power grid and its customers.

B. The Need for Utility Electric Vehicle Programs

1. ELECTRIC VEHICLES AND CLEAN POWER ARE NEEDED TO SOLVE GLOBAL WARMING AND AIR POLLUTION

Numerous independent studies have come to the same conclusion: reducing global warming pollution to 80 percent below 1990 levels by 2050 will require a dramatic shift to electric vehicles powered by renewable and other zero-carbon energy sources.[19] Because just 15 million to 17 million passenger vehicles are sold each year in the United States, it will take decades to transform the existing U.S. stock of 250 million vehicles. To meet long-term GHG emissions reduction targets, studies have estimated EVs will need to account for 40 percent or more of new vehicle sales by 2030.[20]

Electric vehicles are also increasingly needed to meet clean air standards in the most polluted areas of the country. It is estimated that traffic pollution causes more than 50,000 premature deaths annually in the lower 48 states, which is more than 1.5 times the deaths from traffic accidents on an annual basis.[21] In California, regulators have concluded that broad deployment of zero- and near-zero-emissions technologies in the South Coast and San Joaquin Valley air basins will be needed between 2023 and 2032 to comply with current federal health-based air quality standards. The regulators also project that by 2040, all passenger vehicles sold in California will need to be zero-emissions vehicles.[22] Major metro areas outside of California with dangerous levels of air pollution, such as Houston and Dallas, are increasingly looking to EVs to comply with federal air quality standards.[23] In light of the pressing need to combat dangerous air pollution, 13 North American and European governments, including those of Germany, the United Kingdom, California, Connecticut, Maryland, and New York, signed a pact to ensure that all new vehicles sold be zero-emissions vehicles by 2050.[24]

2. UTILITY INVESTMENT IN CHARGING INFRASTRUCTURE IS NEEDED TO EXPAND THE ELECTRIC VEHICLE MARKET

It is becoming increasingly clear that a new model is needed to deliver the robust charging network necessary to accelerate EV adoption. Market research shows that consumers' top four reasons for rejecting EVs were all related to lack of infrastructure or range.[25] Survey analysis by the National Renewable Energy Laboratory (NREL) shows that the lack of infrastructure for alternative-fuel vehicles is as much of a barrier to adoption as incremental vehicle price.[26] To date, the limited charging infrastructure that exists beyond single-family homes has generally been deployed by government, automakers, and start-up charging service companies. This model is unlikely to deliver the comprehensive network needed to meet long-term emissions reduction goals. Electric utilities are singularly positioned to close the charging infrastructure gap. Utilities can work with third-party charging service providers to leverage existing customer relationships and their knowledge of the electric grid to capture the value of grid services provided by EVs and increased revenues from well-managed residential charging, which meets the vast majority of fueling needs.[27]

Recent studies have concluded that expanding charging infrastructure is critical to increasing EV adoption. As explained by the "network effect" of market diffusion, consumer valuation of EVs increases with the number of charging stations, but investors are less willing to build stations when the EV market is small (this is also known as the classic "chicken or the egg" problem). Researchers from Cornell University analyzed network effects associated with quarterly EV sales in 353 metro areas. They found that "the increased availability of public charging stations has a statistically and economically significant impact on EV adoption decisions."[28] Another recent study of global EV markets concluded that of all the factors examined, charging infrastructure was the best predictor of a country's EV market share.[29]

Recent investments by automakers further illustrate the importance of infrastructure in driving increased sales. BMW, Volkswagen, and Nissan have pledged to help finance more than 1,000 publicly available stations in key U.S. markets. In Japan, Nissan, Honda, Toyota, and Mitsubishi have agreed to fund one-third of the cost of installing 12,000 public charging stations (with the balance provided by the government). According to Nissan's market research, sufficient charging infrastructure would double the number of Leading, Environmentally-friendly, Affordable, Family (LEAF) car owners who would repurchase an EV.[30] Nissan also saw a marked increase in LEAF sales in 2013 when the company deployed a large number of direct current (DC) fast charging stations at dealerships across North America and Europe.[31] Similarly, Tesla officials report their DC fast charging network has been critical to growing sales of the Model S sedan.[32]

However, deploying charging infrastructure is not the core business of automakers. After all, automakers did not enter the gas station business to sell gasoline-powered vehicles. Likewise, while state and federal programs have supported much of the existing charging network, public funding alone will likely not be sufficient to meet the scale of the challenge.

Even California, which has been a strong supporter of infrastructure deployment and has almost 30 percent of the nation's publicly available charging ports, still falls far short of what is needed to scale up the EV market.[33] According to a study by NREL, to support 1 million EVs, California would need 125,000 to 220,000 publicly accessible charging ports (including those deployed at workplaces), a dramatic increase from the estimated 10,000 the state has today.[34]

To meet emissions reduction goals, we need to rapidly increase our investment in infrastructure. Unfortunately, private financing of the installation and operation of charging stations alone does not appear to be sufficient. A recent study commissioned for the state of Washington found that "charging station business models that rely solely on direct revenue from EV charging services currently are not financially feasible" and that viable business models must "capture other types of business value in addition to selling electricity."[35] The challenge is especially acute for DC fast charging stations, which have high capital costs and can be subject to demand charges meant to recover investments needed to meet peak electricity demand.

Utilities are uniquely situated to capture the system-wide benefits of a comprehensive charging network. As noted in a recent National Academies of Science study, utilities can capture the "incremental revenue from additional electricity that EV drivers consume at home, where roughly 80 percent of the charging takes place" and use that revenue to both deploy charging stations and reduce rates and bills for all customers.[36]

Increasing access to electricity as a transportation fuel is a natural fit for the electric industry. A multi-state survey conducted by researchers at the University of California, Davis reveals EV drivers believe utilities should lead the deployment of charging infrastructure.[37] Building upon their history of helping to transform the market for energy efficiency and renewable energy, utilities are also well situated to deploy infrastructure, especially in segments where the need is greatest, such as:

Apartment Complexes and Other Multiunit Dwellings

Drivers are unlikely to purchase plug-in vehicles if they cannot plug in at home, where cars are parked for 12 hours out of every day and the vast majority of driving needs can be met with overnight charging.[38] Unfortunately, less than half of U.S. vehicles have reliable access to a dedicated off-street parking space at an owned residence where charging infrastructure could be installed.[39] More than 80 percent of EV drivers live in single-family detached homes.[40] It is essential for the EV market to move beyond the suburbs to meet long-term climate and air quality goals. Installing charging stations at apartment buildings and other multiunit dwellings could unlock the potential for a broader, younger, and more diverse market for the next generation of EVs. Utilities can leverage existing customer relationships, knowledge of the electric grid, and economies of scale to deploy charging stations in this critical but underserved market.

Workplaces and Other Long-Dwell-Time Locations

Adding charging stations to workplaces can both extend range for drivers and increase EV visibility, which can spur additional vehicle sales. Nissan credits a workplace charging initiative with a fivefold increase in monthly EV purchases by employees at Cisco Systems, Coca-Cola, Google, Microsoft, and Oracle.[41] Likewise, the U.S. Department of Energy (DOE) recently concluded that employees of companies participating in its Workplace Charging Challenge were 20 times more likely to drive an EV than the average worker.[42] Workplace charging can also increase electric miles driven, especially for drivers of plug-in hybrid vehicles with shorter all-electric ranges, reducing their reliance on petroleum. Utility-facilitated deployments of grid-integrated charging infrastructure at workplaces and other long-dwell-time locations such as park-and-ride commuter lots also ensure EVs are available in the afternoon to serve as a form of energy storage to absorb peak production from solar energy (see Section 4).

Public Fast Charging

Nine days out of ten that a car is driven, it is driven less than 70 miles, which is well within the range of today's pure battery electric vehicles, but the lack of fast charging infrastructure needed to make that one-in-ten trip remains a significant obstacle to the purchase of pure battery EVs.[43] Drivers' purchase decisions are often disproportionately influenced by rare use cases; for example, the off-road capability of SUVs remains a driving force behind their market dominance, even though that capability is almost never used. Consumer research shows the lack of "robust DC fast charging infrastructure is seriously inhibiting the value, utility, and sales potential" of typical pure-battery electric vehicles.[44] Unfortunately, without extremely high utilization rates, it is difficult for private firms to recoup installation costs and cover operating expenses, including utility demand charges that are meant to recover grid investments needed to serve customers with high power requirements.[45] As the keepers of the electric grid, utilities are singularly situated to facilitate the deployment of fast charging stations that incorporate strategies to minimize the need for additional grid investments, including managing the demand of both charging stations and other loads, as well as on- and off-site energy storage. Utility-funded researchers are also in the process of developing more efficient utility fast charging stations that require less power to deliver the same amount of electricity.[46] Utilities are also uniquely able to fund the deployment of fast charging stations needed for widespread EV adoption with additional revenues derived from the residential charging that will occur as a result of greater adoption and use of EVs.

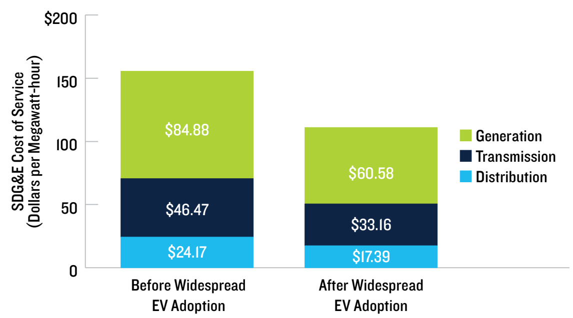
3. WIDESPREAD AND WELL-MANAGED ELECTRIC VEHICLE CHARGING CAN BENEFIT ALL UTILITY CUSTOMERS

Charging electric vehicles predominantly during off-peak electricity hours (when the electric grid is underutilized and there is plenty of spare capacity in the generation, transmission, and distribution system) allows utilities to avoid new capital investments while capturing additional revenues, lowering the average electricity cost for all their customers. This effect is the opposite of the utility "death spiral," whereby increasing costs borne by a decreasing pool of customers causes rate increases that drive away more customers, leaving those who cannot afford distributed generation or home energy storage to pay for an aging grid.

Researchers at the Pacific Northwest National Laboratory found sufficient spare capacity in the nation's electric grid to power virtually the entire light-duty passenger vehicle fleet, if vehicle charging load is integrated during off-peak hours and at lower power levels.[47] As the grid becomes more dominated by renewable energy generation that varies depending upon the weather, time of day, and season, the amount of spare capacity may grow even larger. The same researchers also modeled impacts on the marginal cost of utility service associated with transformative transportation electrification for two utilities, Cincinnati Gas & Electric and San Diego Gas & Electric (SDG&E). The results of a 60 percent plug-in hybrid penetration scenario in SDG&E territory are illustrated in Figure 1.

These results do not reflect all the complexities of SDG&E's systems, but the directional shift (~20 percent reduction in the cost of service) is significant. All customers would benefit from this shift in the form of lower electricity bills.

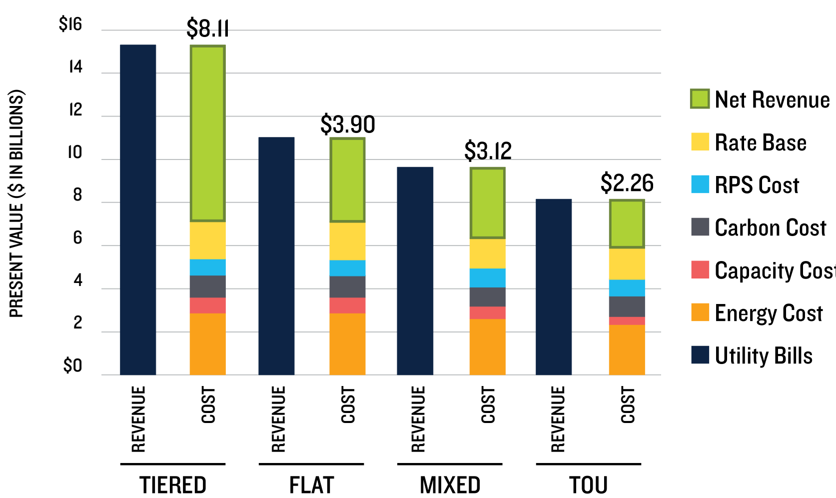
FIGURE 1: SDG&E COST OF SERVICE BEFORE AND AFTER WIDESPREAD ELECTRIC VEHICLE ADOPTION



(Adapted from Kintner-Myer et al., 2007)[48]

Using standard regulatory cost benefit tests, recent analysis conducted by Energy and Environmental Economics (E3) demonstrates that the body of utility customers is likely to benefit from the additional revenue provided by properly managed EV charging. Figure 2 presents results from the Ratepayer Impact Measure test, a restrictive test that fails to account for systemic benefits, for a typical California utility under typical rate structures. It reveals that, by 2030, EVs will contribute $2 billion to $8 billion more in revenue to SCE, SDG&E, PG&E and SMUD than they cost to serve, putting downward pressure on rates for all customers.

FIGURE 2: PRESENT VALUE OF EV ADOPTION IN CALIFORNIA THROUGH 2030, BY RATE SCENARIO



Notes: Based on California utility system, assuming charging occurs predominantly when the system is underutilized. Net revenues are positive under "Tiered," "Flat," and "TOU" (time-of-use) rate structures and a "Mixed" TOU/Tiered scenario. Under TOU rates, EV owners are rewarded for charging during hours of the day when the cost of energy is at its lowest, resulting in smaller, but still significant, net revenues.

(Environmental and Energy Economics, *California Transportation Electrification Assessment—Phase 2: Grid Impacts*)[49]

To capture the potential of widespread EV adoption to benefit all customers, utilities should implement rate designs and programs to ensure EV charging occurs predominantly when there is excess capacity in the grid. SDG&E has already demonstrated that the combination of time-of-use rates and education and outreach can push 80 percent of EV charging to the hours between midnight and 5 a.m., the "super off-peak" period on the utility's EV tariff (see Figure 7).[50] Such time-of-use rates are likely sufficient to integrate EV load in the early market. However, analysis conducted by SMUD shows that more sophisticated forms of load management, such as the use of dynamic price signals or advanced demand response, will likely be needed to minimize costs and allow for net benefits as the EV market scales up.[51]

4. ELECTRIC VEHICLES CAN PROVIDE VALUABLE GRID SERVICES

Already highly valued by grid operators and utilities, flexible resources that keep the grid stable by ensuring electricity demand and supply remain perfectly in sync will become increasingly valuable as variable resources like wind and solar replace fossil and nuclear generation. With the right policy framework, utilities can leverage the growing customer sunk investment in EV batteries to capture this value and use it to drive additional EV sales. Rewarding EV customers for facilitating the transition to renewable energy could prove a sustainable replacement for federal and state purchase incentives that are likely to be phased out as the EV market moves beyond the early-adopter segment.

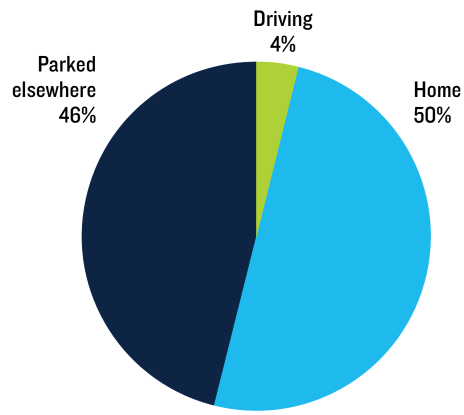
Electric Vehicles Represent a Unique Opportunity to Support the Grid

American drivers have already purchased approximately 11 gigawatt-hours (GWh) of advanced battery storage in the form of EV batteries, more than enough to power all the homes in the District of Columbia on an average day.[52] This sunk investment grows with every new EV purchase and represents a unique opportunity to support the electric grid. There is no other single customer-side "smart appliance" that combines the potential for immense flexibility with significant capacity for both power and storage.

Peak demand for electricity generally occurs during the early-evening hours when people return home from work, turn on the lights, crank up air conditioners, watch television, and do all the other things that require electricity—most of which can be done only when people are at home and awake. In contrast, EVs can be charged whenever they are not being driven, which is 96 percent of the average day, as shown in Figure 3, provided they have access to charging stations.

The average American drives 35 miles per day.[54] Using a standard 120-volt wall outlet and the "level 1" charging cords that are provided with every EV, 35 miles' worth of electricity can be delivered in nine hours of low-power

FIGURE 3: ESTIMATED PERCENTAGE OF TIME EVs SPEND BY LOCATION



(Adapted from Langton & Crisotomo, *Vehicle-Grid Integration, California Public Utilities Commission*)[53]

charging that can easily be accomplished during off-peak hours for the electricity grid. Using "level 2" charging equipment, which plugs into a 240-volt outlet (like those used by clothes dryers), 35 miles of electricity can be delivered in two hours. This provides an immense amount of flexibility, considering the typical EV is parked for 23 hours a day. That flexibility means an EV battery could satisfy typical driving needs while supporting the electric grid and providing EV drivers with significant value.

The Types of Grid Services Electric Vehicles Could Provide

Imagine a vehicle that stops charging when demand for electricity peaks in the early evening and begins again late at night when most people are asleep and electricity is cheap. Now picture that EV being driven to work in the morning, charging up on excess solar generation during the afternoon, being driven home, selling electricity back to the grid when demand peaks in the evening, and then recharging again at midnight when there is an oversupply of cheap wind energy. Imagine further that after many years of service, when the battery in that EV has lost enough capacity that it no longer provides the range its driver requires, it is redeployed as a form of stationary energy storage that could be charged and discharged whenever or wherever most needed to support the grid. All of these functions are already being proved in the real world. They can be categorized as follows:

1. Traditional Demand Response: Turning charging off.
2. Advanced Demand Response: Turning charging on or off and/or changing the rate of charging.
3. Vehicle-to-Grid, or V2G: Putting electricity stored in EVs back onto the grid.

4. Battery Second Life: Putting electricity stored in used EV batteries redeployed in stationary applications back onto the grid.

These four functions can potentially provide the full range of services required to keep the grid stable at all levels. Supply of electricity must instantaneously and precisely match demand to prevent blackouts. Yet both demand and supply of electricity change by the second, minute, hour, day, and season. Grid operators must maintain this equilibrium, even as they integrate greater levels of variable renewable resources, like wind and solar.

This holds true across the entire electric grid, which comprises both a transmission and a distribution system operated by different entities. The transmission system moves electricity from power plants in bulk, often across state lines. It is kept in balance by independent system operators (ISOs), such as the California ISO, and regional transmission organizations (RTOs), such as PJM Interconnection, which operate wholesale energy markets. The distribution system delivers electricity from the transmission system to retail customers in homes and businesses. Its reliability is ensured by local utilities. Utilities, ISOs, and RTOs rely on the transmission and distribution system grid services to keep the whole system in balance.

Transmission System Grid Services

"Day-Ahead Resources," typically bid into wholesale markets one day before deployment, must be able to turn on within minutes, reach full power within 30 minutes, and be maintained for about four hours. These resources are typically used only 5 to 20 days per year, often to meet peak demand from air conditioners during heat waves. "Ancillary Services" (including "Frequency Regulation" and "Spinning Reserves") meet the instantaneous needs of the grid, requiring an immediate response for up to 30 minutes. These are called upon several times per day for around 50 days a year. For more than a century, procuring "Day-Ahead Resources" and "Ancillary Services" meant building expensive fossil-fuel power plants, called "peakers," that sat idle most of the year; a single typical peaker natural gas plant costs about $120 million to build at $1,200 per kW of capacity.[55]
In some regions, peaker plants are supplemented by "Pumped Hydro Storage" facilities that pump water uphill and use gravity to power turbines at a later time. This is by far the most widely deployed form of energy storage currently operating, but it is expensive and it has a large geographic footprint.[56]

Distribution System Grid Services

Local utilities often rely on customer-side resources to defer upgrades to equipment such as neighborhood transformers. To date, this has meant rewarding participating utility customers for occasionally turning things off ("Traditional Demand Response") or firing up diesel generators during peak-demand hours. In the future, "Advanced Demand Response" programs could reward customers for allowing things to be automatically turned off, on, down, and up in a manner that still meets their needs. Customer-side energy storage resources could also provide "Power Quality" (keeping local voltage, frequency, and power stable to protect critical equipment), "Energy Arbitrage" (storing electricity during hours when it is cheap, and either using it later or selling it back to the grid when it is expensive), and "Demand Charge Mitigation" (managing on-site consumption to minimize "demand charges" on utility bills, which recover investments needed to accommodate peak demand).

As shown in Table 1, the four categories of EV functions can provide the full spectrum of grid services at both the transmission and distribution system levels.

Utility-scale projects take years to finance, permit, and construct and can be difficult to site where they are most needed. In contrast, EVs can be scaled precisely and deployed strategically to provide the full spectrum of grid services required at the transmission level by ISOs and RTOs operating wholesale markets, and at the distribution level by local utilities that interact directly with retail customers. The challenges associated with relying on vehicles, the primary purpose of which is to

TABLE 1: GRID SERVICES THAT ELECTRIC VEHICLES COULD POTENTIALLY PROVIDE, BY GRID SEGMENT

Electric Vehicle Function	Potential Grid Services, by Grid Segment	
	Transmission	**Distribution**
Traditional Demand Response: Powering charging down or off	Day-ahead resource, spinning reserve	Grid upgrade deferral, demand charge mitigation
Advanced Demand Response: Powering charging down, off, on, or up	Day-ahead resource, spinning reserve, frequency regulation, one-way energy storage	Grid upgrade deferral, demand charge mitigation, energy arbitrage
Vehicle-to-Grid ("V2G"): Discharging energy stored in EVs back to the grid	Day-ahead resource, spinning reserve, frequency regulation, two-way energy storage	Grid upgrade deferral, power quality, demand charge mitigation, energy arbitrage
Battery Second Life: Deploying used EV batteries as stationary energy storage	Day-ahead resource, spinning reserve, frequency regulation, two-way energy storage	Grid upgrade deferral, power quality, demand charge mitigation, energy arbitrage

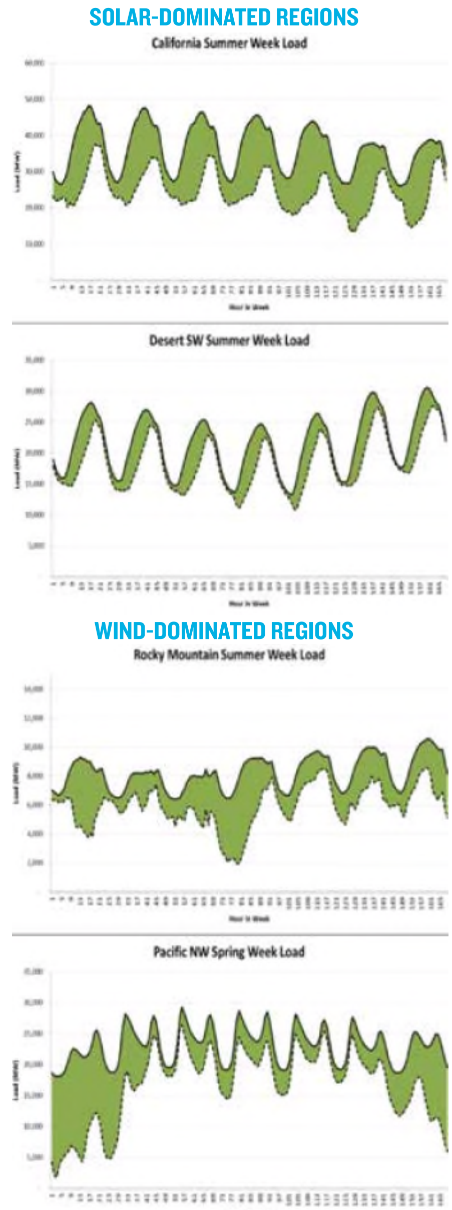
provide mobility, to also provide grid services can be largely mitigated with sufficient scale; with a large enough fleet, the fact that some vehicles are not available at any given moment becomes increasingly irrelevant because enough other vehicles will be available at that time.

Electric Vehicles Can Provide a Variety of Grid Support and Storage Services to Meet Unique Regional System Needs

Integrating higher levels of renewable energy, chiefly wind and solar, will increase the demand for flexible grid resources that could be provided by EV batteries across the nation, but resources and needs will vary regionally. As shown in Figure 4, in solar-dominant California and the desert Southwest, solar generation can create an oversupply of electricity during the afternoon but does little to help meet peak demand during evening hours. Both Traditional Demand Response and Advanced Demand Response can help avoid exacerbating that evening peak, and the latter can also help absorb excess solar generation during the afternoon by ramping up EV charging. V2G and Battery Second Life (see Table 1) provide the additional benefit of selling excess solar energy stored during the afternoon back to the grid to supply peak demand during the evening (Energy Arbitrage). This regular pattern of excess solar generation during the afternoon will be most common in the spring and fall, when the biggest source of demand for electricity resources—heating or cooling of buildings—is at its lowest. Solar could provide as much as one-quarter of the regional electricity supply at these times.[57]

Wind energy generation often peaks during early-morning hours, when demand for electricity is typically at its lowest point because the vast majority of the population is asleep.[58] EVs can be conveniently refueled while their drivers are still in bed and electricity is cheap. In 2009, BMW and the European utility Vattenfall demonstrated the potential for EVs to function as a form of Advanced Demand Response in which overnight charging was ramped up and down to match variable wind generation, integrating renewable generation while effectively lowering the emissions of the vehicles.[59] However, the wind does not always blow at night, nor does it blow every day. Such varying intervals typical of onshore wind generation as well as seasonal variation in hydropower resources are shown in Figure 4 in the Rocky Mountain (top right) and Pacific Northwest (bottom right) regions. A similar pattern is likely to emerge for the wind-rich Midwest, South, and Northeast (counting both onshore and offshore generation), which also contain a sizable share of hydropower resources. In such regions, energy must often be stored for longer periods of time, requiring EV grid services such as Advanced Demand Response and V2G to be supplemented with stationary forms of energy storage, including Battery Second Life.

FIGURE 4: MODELED STORAGE NEEDS OF FOUR EXEMPLARY SUBREGIONS OF THE U.S. WESTERN GRID WITH 27 PERCENT RENEWABLES IN 2022



(Energy and Environmental Economics, Inc., *Investigating a Higher Renewables Portfolio Standard in California*)[60]

Note: Top line is the net generation for a 27 percent renewables scenario over a one-month period. The bottom line is the net load. The green-shaded area represents the oversupply of electricity that will be wasted if it cannot be stored and used later to power EVs or put back onto the grid when demand for electricity peaks. That need for energy storage could be met with Advanced Demand Response, V2G, or Battery Second Life programs.

The Potential Value of Electric Vehicle Grid Services

The full range of EV grid support functions is already being demonstrated in projects that are providing considerable value, especially in highly remunerative but limited ancillary services markets. However, leadership by regulators and the utilities under their jurisdiction is needed for EVs to capture the full value of facilitating the transition to a grid dominated by variable renewable resources.

PG&E and BMW have partnered in a novel pilot project that combines Traditional Demand Response and Battery Second Life to provide a flexible grid resource with a capacity of at least 100 kW. They are offering a $1,000 incentive to encourage 100 EV drivers to participate in an 18-month pilot study. Participants could earn an additional $540 by responding to day-ahead requests to curtail charging during hours when the grid is pushed to its limits. The $540 figure was derived using the tool approved by the California Public Utilities Commission to determine the value of investments deferred as the result of demand response programs. If the response rate is not high enough to reduce demand by the full 100 kW, BMW will return energy to the grid from used EV batteries redeployed in a stationary second-life application to make up the balance.[61] In addition, the pilot is meant to build a technical foundation and customer interface that could be used in future Advanced Demand Response and V2G programs. BMW is also using this real-world test to determine whether sufficient value can be derived from stationary storage to justify pre-engineering battery packs to be easily redeployed in Battery Second Life applications.

In the PJM Interconnection regional wholesale market, which serves approximately 50 million people in the mid-Atlantic and Midwest states, the University of Delaware and NRG Energy have a demonstration V2G project underway, in which a fleet of EVs is charged at optimal times and returns power to the grid to provide Frequency Regulation, earning annual revenues of about $1,800 per vehicle.[62] By managing the charging and discharging of the vehicles' energy, the project is able to meet the PJM minimum 100-kW capacity required to participate in the ancillary services market.[63] A similar V2G pilot at an Air Force base in Southern California, with 32 EVs that provide up to 655 kW of power to California ISO's ancillary services market, is returning annual revenues of around $2,500 per vehicle.[64] Table 2 shows per-vehicle estimates of value for pilot projects currently underway.

Questions remain as to the willingness of automakers to allow their vehicles' batteries to be used for V2G. Likewise, the scalability of V2G remains to be seen. While today's Frequency Regulation markets are highly remunerative, they could be saturated with as few as 136,000 EVs in the PJM market or 45,000 EVs in the California ISO region if one assumes V2G-enabled vehicles are able to return electricity to the grid at the same rate at which they charge using typical level 2 equipment plugged into 240-volt outlets.[69] The market for Frequency Regulation could double or triple as more variable solar and wind energy is integrated into the generation mix. Over the longer term, however, one-way storage is likely to emerge as the greatest opportunity for drivers to earn value since it allows utilities to call upon EVs as a "dispatchable" resource to absorb low-cost wind and solar, balance the grid, and improve the utilization of the system.[70]

Researchers at NREL have estimated that 100 to 152 GW of energy storage will likely be needed to balance a U.S. electric grid that is based on 80 percent renewable resources by the year 2050.[71] That need could theoretically be met entirely with EV batteries from as few as 10 percent of the EVs on the road in that year.[72] Stand-alone energy storage on that scale could require an investment somewhere between $120 billion and $180 billion.[73] Directing even some portion of that investment away from capital-intensive, utility-scale projects and toward EV drivers to provide energy storage with the batteries they have already purchased could reduce the cost of transitioning to a cleaner grid and accelerate the electrification of the transportation sector.

TABLE 2: ESTIMATED VALUE OF SELECT ELECTRIC VEHICLE PILOT PROGRAMS

Project	Electric Vehicle Function	Market	Grid Services	Estimated $/ Vehicle
BMW/PG&E Pilot	Traditional Demand Response	California ISO	Day Ahead Resource, Spinning Reserve	$360 per year[65]
Hypothetical at 40% Renewable Penetration	Advanced Demand Response	Retail	One-way Storage (storing renewable energy and using to drive later)	$850 over vehicle lifetime[66]
Univ. of Delaware & NRG Demonstration	V2G	PJM	Frequency Regulation	$1,800 per year[67]
U.S. Dept. of Defense	V2G	California ISO	Frequency Regulation	$2,520 per year[68]

C. The Three Phases of Utility Policy to Accelerate the Electric Vehicle Market

Realizing the environmental, consumer, and grid benefits of EV adoption requires regulators to move quickly to develop new programs and policies to accelerate the market. Based on experience in the major early EV markets, the necessary utility policies can be separated into three phases, introduced in Table ES-1, repeated below, and discussed in detail in the subsections that follow.

1. REMOVING BARRIERS TO ADOPTION, ENSURING GRID RELIABILITY, AND MAXIMIZING FUEL COST SAVINGS

Phase 1 removes barriers to consumer adoption, facilitates a competitive market for third-party charging services, prepares utilities to integrate EV load, and encourages drivers to charge in a manner that avoids adverse grid impacts and maximizes savings relative to gasoline. Example policies include:

Clarify that Electric Vehicle Charging Companies Will Not Be Regulated as Utilities

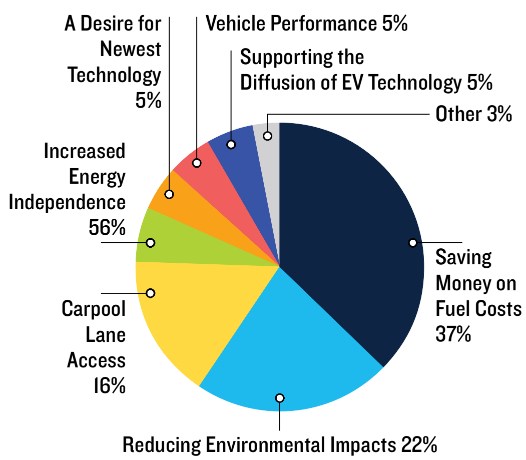
Regulatory treatment of independent EV charging companies is a fundamental issue that must be decided at the state level. State codes often define the term electric utility very broadly, potentially subjecting EV charging service providers to the jurisdiction of state utility regulators. In most instances, such companies will simply act as customers of utilities and will be subject to the terms of service, rates, and other policies adopted by state commissions. Sixteen states have adopted policies to make it clear that such companies are not subject to the full extent of utility regulatory authority. Policymakers should make it clear that companies acting as customers of utilities will not be regulated like public utilities, but they should also avoid creating sweeping exemptions that could hinder future efforts to ensure the environmental performance and integrity of the electric grid.

Inform Distribution System Planning

A fundamental tool to minimize the costs of integrating vehicle charging is timely utility notification when a customer buys an EV. In California, one of the world's largest EV markets with more than 200,000 vehicles, costs associated with integrated EV load so far have been *de minimis*—only 0.1 percent of EVs have required a service line and/or distribution system upgrade.[76] A detailed analysis of California's distribution systems also reveals that, with the right policies, a mass market for EVs could be achieved without significant new investments.[77] However, the instantaneous demand of a single EV can be comparable to that of an entire home, which could result in local distribution system impacts if not properly managed.[78] For example, the cost of replacing a transformer on an emergency basis can be twice that of a planned upgrade.[79] Therefore, regulators and utilities need to know where EVs

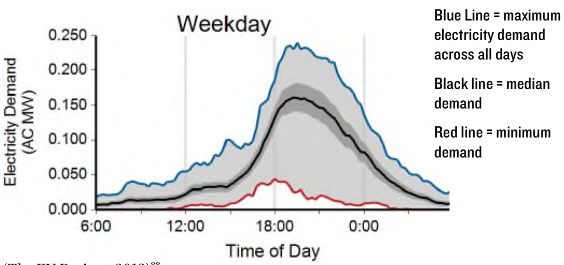
TABLE 3: THE THREE PHASES OF UTILITY POLICY TO ACCELERATE THE ELECTRIC VEHICLE MARKET
1. Removing Barriers to Adoption, Ensuring Grid Reliability, and Maximizing Fuel Cost Savings
Clarify that electric vehicle charging companies will not be regulated as utilities
Inform distribution system planning
Provide consistent and fair treatment of electric vehicle load
Adopt appropriate rates to maximize fuel savings and manage charging
Target customer education and outreach programs
2. Closing the Charging Infrastructure Gap and Promoting Equity
Utility-facilitated deployment of charging infrastructure
Increase access to electricity as transportation fuel in disadvantaged communities
Promote broader awareness through mass-market education and outreach
3. Capturing the Value of Grid Services and Integrating Renewable Energy
Implement traditional demand response programs for electric vehicle customers
Implement advanced demand response programs for electric vehicle customers
Integrate V2G and battery second life programs into wholesale and retail markets

FIGURE 5: MOST IMPORTANT REASON TO ACQUIRE AN ELECTRIC VEHICLE (FROM SURVEY OF 16,000 EV OWNERS)



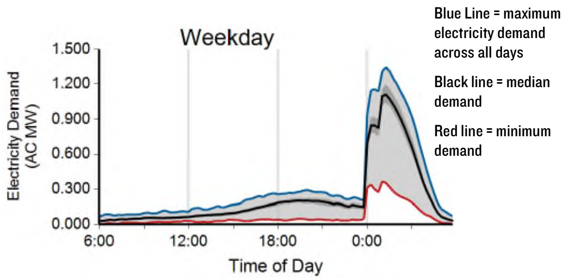
(Center for Sustainable Energy, *California Plug-in Electric Vehicle Owner Survey Dashboard*)[84]

FIGURE 6: RESIDENTIAL EV CHARGING IN DALLAS/FORT WORTH REGION BY TIME OF DAY



(The EV Project, 2013)[88]

FIGURE 7: RESIDENTIAL EV CHARGING IN SAN DIEGO REGION BY TIME OF DAY



(The EV Project, 2013)[89]

are charging if they are to manage the load. Four states have adopted some form of notification requirements.[80] Notification is also essential to facilitate targeted customer outreach regarding EV rate options, policies, and programs. Existing utility rules generally require customers to provide notification whenever they add significant new load, but customers are often unaware of this requirement and contact their utility only if something goes wrong.[81] Utilities must proactively identify EV owners. Potential sources of actionable information include automakers, auto dealers, charging equipment installers, local building permit offices, smart meter data, and state departments of motor vehicles (DMVs). Legislative changes are sometimes necessary to allow access to DMV data, which is the most comprehensive source.[82]

Provide Consistent and Fair Treatment of Electric Vehicle Load

Utility regulators should resist calls to implement EV-specific charges or fees. Existing utility rules are generally sufficient to recover costs associated with integrating vehicle load. There is no reason to treat EV load less favorably than comparably demanding loads such as hot tubs and air conditioners, which lack the corresponding environmental benefits.

Adopt Appropriate Rates to Maximize Fuel Savings and Manage Charging

Generally applicable utility rates may not be well suited for EV load. While time-of-use rates are not always the answer, they are generally a good fit for EVs. These rates do double duty: ensuring consumers can maximize their fuel cost savings, and incentivizing minimal adverse grid impacts. Numerous surveys reveal fuel cost savings are the most important motivator of EV purchase decisions, as shown in Figure 5.[83]

To illustrate the potential fuel savings from driving on electricity to consumers accustomed to buying gasoline, the DOE has an online tool that translates the cost of driving an EV into “eGallons,” which are equivalent to the cost of driving a similar conventional vehicle on gasoline. On a national average basis, electricity costs $1.22/eGallon.[85]

However, utility customers do not buy “average” electricity; prices can vary by utility territory, customer class, season, time of day, marginal consumption, and peak demand. Many of the nation’s largest EV markets have higher-than-average electricity prices and rates that increase with marginal consumption. For example, residential customers in PG&E territory pay $3.31/eGallon on the default rate for marginal consumption above a certain threshold, whereas customers charging off-peak on PG&E’s EV rate pay only $0.97/eGallon.[86]

Time-of-use rates are also an important tool to encourage drivers to charge during off-peak hours when the electricity grid has spare capacity. Without a price signal, drivers will generally plug in and charge immediately upon arriving home after work, exacerbating system-wide evening peak demand, as shown in Figure 6 for the Dallas/Fort Worth area. This stands in marked contrast to the charging pattern of EV drivers in San Diego (Figure 7), who meet 80 percent of their refueling needs during the "super-off-peak" period from midnight to 5 a.m. on SDG&E's time-of-use rate. Were EVs in Dallas on similar rates, instead of exacerbating peak demand and driving the need for additional investments, they would be charging while their drivers are asleep and when Texas' considerable wind generation is often at peak production.[87]

Target Customer Education and Outreach Programs

At a minimum, utilities should prepare their customer service agents and modify their websites to answer common questions from new or prospective EV owners regarding home charger installation, availability of public charging, benefits of off-peak charging, fuel cost savings on applicable rates, and other issues. This can help ensure grid safety and reliability, and promote a positive consumer experience in the early market. However, a more proactive approach is needed to avoid adverse grid impacts and maximize fuel cost savings that motivate EV purchase decisions.

Even in California, where utilities have been very active with respect to vehicle electrification, the majority of customers remain unaware of the potential savings of switching to time-of-use rates. Utilities should identify and reach out to customers who would benefit financially by switching to more appropriate rates. Rate options and other programs for EV customers must be coupled with targeted customer education and outreach.

2. CLOSING THE CHARGING INFRASTRUCTURE GAP AND PROMOTING EQUITY

Phase 2 focuses on robust policies and programs that can accelerate the EV market and increase access to electricity as a transportation fuel. Example policies include:

Utility-Facilitated Deployment of Charging Infrastructure

As noted in Section B, the lack of access to charging infrastructure remains a significant obstacle to widespread EV adoption. Electric utilities are singularly positioned to close the charging infrastructure gap by capturing the value of additional grid services and increased revenues from system-wide charging. Utility involvement is also necessary to ensure that the charging network is expanded in a manner that supports the grid to the benefit of all customers.

Utility leadership is especially needed in the 10 states that have adopted zero-emissions vehicle (ZEV) programs in order to meet federal air quality standards. Combined, they require about 3.3 million ZEVs by 2025, which will require a comprehensive charging network where drivers live, work, and play.

Utilities are beginning to move forward with infrastructure investments. A recent decision issued by the California Public Utilities Commission (CPUC) found agreement among charging companies, automakers, utilities, and nonprofit organizations that "utilities should have an expanded role in EV infrastructure support and development in order to realize the potential benefits of widespread EV adoption."[90]

This decision allowed the CPUC to evaluate separate applications submitted by SDG&E, SCE, and PG&E to install more than 60,000 charging stations at public, workplace, and multiunit residential locations. In January 2016, the CPUC approved a modified version of the SDG&E proposal and the first phase of the SCE proposal. In March 2016, a widely supported settlement agreement was proposed in the PG&E proceeding, building on the guidance provided by the CPUC in its decisions approving the SCE and SDG&E programs.[91] Meanwhile, the Washington Utilities and Transportation Commission approved a $3 million EV infrastructure deployment pilot proposed by Avista, which serves rural areas in the eastern Washington and northern Idaho. Kansas City Power and Light is also investing $20 million to install more than 1,000 public and workplace charging stations, and Georgia Power and Light has a $12 million "Get Current. Drive Electric" charging program to install 60 public charging stations with both DC fast chargers and Level 2 stations. Utilities in other states have taken notice; the majority of respondents to a recent survey of utility professionals across the nation stated their utilities are pursuing EV infrastructure deployment as a new and emerging revenue stream.[92]

Increase Access to Electricity as Transportation Fuel in Disadvantaged Communities

To increase access to electricity as a transportation fuel in communities with the greatest need for cleaner air and lower fuel bills, utilities can target charging infrastructure investments in low-income communities and communities of color. Communities of color represent the fastest-growing consumer segment in America, and their buying power will be critical in using EVs to meet long-term air quality standards and GHG emission reduction targets.[93] As noted in the Greenlining Institute's 2011 report "Electric Vehicles: Who's Left Stranded?" communities of color are more concerned about air pollution, making them a natural but largely untapped market for ZEVs.[94] The SDG&E and SCE programs approved by the CPUC both include requirements to deploy at least 10 percent of charging stations in "disadvantaged communities," as identified by the California

Environmental Protection Agency's CalEnviroScreen 2.0, which scores census tracts using 12 types of pollution and environmental factors and seven population characteristics and socioeconomic factors.[95] The settlement proposed in the PG&E proceeding requires that at least 15 percent of the charging stations be deployed in disadvantaged communities, with a stretch goal of 20 percent, and also sets aside $5 million for additional equity programs in those communities.

Promote Broader Awareness through Mass-Market Education and Outreach

To expand the EV market, a general lack of consumer awareness must be overcome and common misperceptions, often fueled by misleading press coverage, must be corrected.[96] Consumers in the market for a new car need to be educated about the benefits of vehicle electrification and applicable utility rates, incentives, and programs. Utilities are better positioned to conduct this type of broad customer education effort than individual automakers seeking to promote specific vehicles, or charging service providers seeking to promote specific business models.

3. CAPTURING THE VALUE OF GRID SERVICES AND INTEGRATING RENEWABLE ENERGY

Phase 3 leverages the growing customer investment in EV batteries to provide valuable grid services that can facilitate the integration of renewable energy, and return the value of such services to EV drivers to further accelerate the market. Example policies include:

Implement Traditional Demand Response Programs for Electric Vehicle Customers

Traditional Demand Response programs that either curtail or reduce the rate of charging can provide value to both the grid and EV drivers without compromising transportation needs. Such programs can be deployed today with readily available technology. As noted in Section B(4), PG&E and BMW are demonstrating this functionality in the San Francisco Bay Area, but they are not alone. Pepco (a utility serving Maryland and the District of Columbia), Eversource (a utility serving the Northeast), and SCE have all launched pilot programs to test EV charging as a form of Traditional Demand Response.[97]

Implement Advanced Demand Response Programs for Electric Vehicle Customers

Advanced Demand Response programs not only curtail or reduce EV charging when necessary, but turn on and ramp up charging to absorb excess renewable generation. Although EV Advanced Demand Response does not feed power back to the grid, it is a form of energy storage that takes power off the grid for use at a later time (like ice storage used for cooling needs), and it should not be excluded from energy storage procurement mandates. Rather, it should be valued for the services it provides.

SDG&E's charging infrastructure deployment program, recently approved by the CPUC, includes a price-based form of Advanced Demand Response that aggregates EV charging load by deploying banks of grid-integrated charging stations at multiunit dwellings and workplaces. It is partially meant to test EV Advanced Demand Response as a form of energy storage. Participating customers charge on a real-time rate that reflects hourly wholesale market prices and are billed on their normal home energy bill. Customers can actively manage their charging by providing basic parameters (e.g., when they want the vehicle to be fully charged) or allow the system to minimize costs by absorbing cheap electricity (e.g., excess solar in the afternoon or excess wind at night) and avoiding expensive electricity during evening peak hours.

In the future, leveraging the "smarts" and communications capabilities embedded in EVs themselves may prove a cost-effective solution for Advanced Demand Response. The Electric Power Research Institute, utilities, and automakers are developing an Open Vehicle Grid Integration Platform that uses non-proprietary communications protocols and takes advantage of the connectivity in vehicles to manage EV load in response to grid conditions.[98]

Integrate V2G and Battery Second Life Programs into Wholesale and Retail Markets

As noted in Section B(4), leveraging EV drivers' sunk investment in advanced batteries to provide energy storage that both absorbs excess renewable generation and feeds electricity back to the grid during hours of peak demand could reduce the cost of integrating wind and solar resources and accelerate the EV market. However, if utilities, automakers, and other relevant parties do not act now to demonstrate V2G and Battery Second Life programs at scale, the opportunity could be lost. Significant investments in large-scale energy storage projects are already being made.[99] Grid operators, utilities, and regulators should prioritize V2G and Battery Second Life programs because they could provide value to utility customers that would otherwise go to private interests and prove more cost-effective by leveraging sunk investments. They also have a unique potential to simultaneously reduce emissions in the electricity and transportation sectors.

Conclusion

With more than 450,000 modern EVs in the United States alone, policymakers and utilities need not rely upon conjecture to place transportation electrification on the right path to meet air quality, climate, and equity goals while supporting the grid and facilitating progress toward other clean energy goals. If regulators and the utilities under their jurisdiction fail to take timely action, the expansion of the EV market could stall and EV charging could strain the grid, necessitating otherwise avoidable costs. However, with the right policies and programs, utilities could provide widespread benefits to all customers, reduce exposure to dangerous air pollution and the worst effects of climate change, and provide consumers with a viable alternative to the volatile world oil market.

Regulatory directives will be crucial to this effort, but simply commanding utilities to do the right thing is not always sufficient; the utility business model for transportation electrification should be aligned with societal interests. This has been proved repeatedly with respect to energy efficiency; states in which regulators have decoupled the recovery of authorized expenditures from actual volume of electricity sales in order to remove the disincentive for utility investments in energy efficiency consistently triple their efficiency savings, reducing bills for all customers.[100] But removing disincentives does not go far enough. Regulators should consider performance-based earnings opportunities to encourage utilities to accelerate transportation electrification in a manner that supports the grid and facilitates the integration of renewable energy, in addition to the three phases of utility EV market acceleration policy outlined in Section C.

While they are generally aware of the potential benefits associated with widespread transportation electrification, many utility executives remain focused on other, short-term issues that go straight to today's bottom line. Consequently, even in utilities with robust transportation programs, EVs remain a secondary priority. Funding for transportation teams can be erratic and is often dependent on the particular interests of company executives. Regulatory incentives should be realigned to ensure that the most profitable option for utility shareholders minimizes adverse system impacts, facilitates the integration of renewable generation, and maximizes system benefits and consumer savings relative to gasoline. This would provide a clear and durable signal to utility leadership to accelerate the pace of transportation electrification.

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Division 5-23

Request:

Refer to Schedule PST-1, Chapter 5, page 5 regarding the Charging Station Demonstration Program, and construction and ownership by the Company of a new distribution service and required electrical infrastructure (such as new electrical panel, conduit, and wiring) at the premises for each charging site.

a. Will the Company install a new distribution service even if it is not needed to support a charging station?

b. Will the host customer be assessed an additional monthly fixed charge for the new distribution service?

c. If a station is not operated by the Company, will a customer be assessed a demand charge (if a demand charge is included in the tariff under which the customer takes service)?

Response:

a. Narragansett Electric intends to establish a dedicated meter at every new charging station location to provide EV charging. Narragansett Electric will only upgrade or install a new distribution service and associated infrastructure if needed to serve the electrical capacity at the site host's location in consideration of the addition of estimated EV charging load.

b. With a new dedicated electric service to serve a electric vehicle supply equipment owned and operated by the site host, the electric vehicle supply equipment would have its own electric service account with the site host as the customer of record. The account would be billed all rates and charges under the applicable rate schedule assigned to the account based upon the anticipated electric load pursuant to Narragansett Electric's available tariffs. The Charging Demonstration Program will pay the cost associated with the construction of all infrastructure, except in instances where the site host wishes to construct facilities with a cost that exceeds Narragansett Electric's approved site design. In this instance, Narragansett Electric would require the site host to pay for the incremental cost.

c. Yes.

(This response is identical to the Company's response to Division 1-23 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

Division 5-24

Request:

Refer to Schedule PST-1, Chapter 5, page 5 regarding DC fast charging under the Charging Station Demonstration Program.

a. Please describe how the Company determined that DC Fast Charging should be installed at four public locations at the current time.

b. Please provide all data and analysis that the Company has in its possession regarding the utilization of the existing DC fast chargers in Rhode Island.

c. Did the Company consider providing a rate discount equal to the demand charge to encourage third parties to install additional DC Fast Charging stations? If yes, please explain why this approach was not selected.

d. Did the Company consider providing a charging station rebate (or other up-front incentive) to encourage third parties to install additional DC Fast Charging stations? If yes, please explain why this approach was not selected.

Response:

a. The widespread use of electric vehicles in Rhode Island will require the existence of adequate charging infrastructure, including publicly-accessible DC Fast Charging. Research shows that DC Fast Charging is highly convenient for drivers, and that the existence of Fast Charging increases the likelihood of EV purchases.[1] Rhode Island currently has a total of eight locations where DC Fast Charging is available, but only one location with more than two charging ports. Please see Attachment DIV 5-24 for a list of the DC Fast Charging locations in Rhode Island. To support the state's ambitious ZEV goals, more Fast Charging locations with enough ports to charge a larger number of vehicles at once will be required.

Narragansett Electric made the proposal to own and operate four stations at this time to establish this infrastructure over the next several years, as new EVs are being launched and ZEV targets scale up substantially. Narragansett Electric determined that four DC Fast Charging stations would be enough locations from which to learn about DC Fast Charging site development and operation at different types of sites, while ensuring that

[1] For example, see a 2015 presentation by Nissan North America, provided as Attachment DIV 5-22-3, which indicates that DC Fast Charging is drivers' preferred form of public charging (slide 4), and that the existence of sufficient infrastructure would double the number of Nissan Leaf drivers would who would re-purchase the vehicle (slide 5).

this new, highly-convenient type of charging is visible and accessible to EV drivers and prospective drivers in different parts of the state.

Narragansett Electric did not propose more sites to manage the cost of the overall program.

b. Narragansett Electric does not operate stations at any of the eight locations where DC Fast Charging is offered today in Rhode Island. Narragansett Electric has no data on the utilization of these stations.

c. Yes, Narragansett Electric considered providing a rate discount equal to the demand charge for DC Fast Charging customer accounts; however, Narragansett Electric selected the approach described in Section 2.3 of Schedule PST-1, Chapter 5 (Bates Pages 108-109) for further development of DC Fast Charging stations in Rhode Island. Narragansett Electric's proposal is for a per-kW credit equal to the applicable distribution demand charge for a three-year period beginning with the start of service. Narragansett Electric considers its proposal to be an appropriate starting point for this Pilot, to moderate the overall value of the discount for individual participants and the cost of the discounts that would be recovered from all customers.

d. Narragansett Electric's Massachusetts electric affiliates, Massachusetts Electric Company and Nantucket Electric Company, proposed a charging station rebate for DC Fast Charging in D.P.U. 17-13. In Rhode Island, Narragansett Electric proposed a different approach to demonstrate the effectiveness in a limited-time bill credit as a means to encourage DC Fast Charging development to compare the results of these approaches across the two service territories. A bill discount based on billing demand may potentially be a more effective form of incentive to ensure the continued operation of DC Fast Charging, compared to an upfront rebate. Narragansett Electric considered experience from renewable energy incentive programs that have evolved toward "performance-based" incentives (e.g., per-kWh of renewable generation), rather than upfront (per-kW of renewable capacity installed).

(This response is identical to the Company's response to Division 1-24 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

List of DC Fast Charging Locations in Rhode Island

Station Name	Street Address	City	State	ZIP	Station Phone	EV DC Fast Count (Ports)	Groups With Access Code	Access Days Time	EV Network
East Greenwich Square - Tesla	1000 Division St	East Greenwich	RI	2818	877-798-3752	8	Public	24 hours daily	Tesla
MARRIOTT	9 Commerce Dr	Middletown	RI	2842	888-758-4389	2	Public	24 hours daily	ChargePoint Network
DD - Warwick	1678 Post Rd	Warwick	RI	2888	877-455-3833	2	Public - Card key at all times	24 hours daily; EVgo network subscription and key fob required	eVgo Network
DD - Greenwich	2611 S County Trl	East Greenwich	RI	2818	877-455-3833	2	Public - Card key at all times	24 hours daily; EVgo network subscription and key fob required	eVgo Network
Providence Hilton Garden Inn	220 India St	Providence	RI	2903	877-455-3833	2	Public - Card key at all times	24 hours daily; EVgo network subscription and key fob required	eVgo Network
BMW WARWICK	1515 Bald Hill Rd	Warwick	RI	2886	888-758-4389	2	Public	24 hours daily	ChargePoint Network
Langway Nissan of Newport	295 W Main Rd	Middletown	RI	2842	401-619-5050	1	Public - Call ahead	Dealership business hours	
WHOLE FOODS MKT	151 Sockanosset Cross Rd	Cranston	RI	2920	888-758-4389	1	Public	24 hours daily	ChargePoint Network

Data downloaded from https://www.afdc.energy.gov/locator/stations/, accessed January 15, 2018.

Division 5-25

Request:

Refer to Schedule PST-1, Chapter 5, page 8 regarding Discount Pilot for DC Fast Charging Station Accounts.

a. Please confirm that the demand charge will essentially be waived for three years for service for dedicated DC Fast Charging.

b. For each of the existing DC Fast Charging stations, please provide the customer's rate schedule, the customer's total annual bill, the demand charge portion of the total bill, and the load factor. If such information cannot be provided due to confidentiality reasons, please provide the data in as much detail as possible (such as in a histogram with ranges for each category).

c. Will the Company consider a phasing-in of the demand charge once the three-year period is over?

Response:

a. Narragansett Electric's proposal is for a per-kW credit set at the same rate as the applicable distribution demand charge for a three-year period beginning with the start of service. A participating site host/customer would be billed the full distribution and transmission demand charges on their DC Fast Charging station bill, and would receive a per-kW credit equal to the distribution demand charge and applied to that month's billing demand as defined in the applicable rate class tariff.

b. Narragansett Electric is aware of one service account in Rhode Island that is dedicated to DC Fast Charging. The information for that account is provided in the table below. Other DC Fast Charging locations appear to operate charging stations on the site host's general electric account, so Narragansett Electric cannot analyze the Electric Vehicle Supply Equipment's contribution to those site hosts' bills and load factors.

Rate Schedule	[redacted]
Total Annual Delivery Service Charges	
Distribution Demand Charges	
Transmission Demand Charges	
Total Demand Charges	
Load Factor	

Prepared by or under the supervision of: Carlos Nouel

c. As described in the response to part a. above, a participating site host/customer would continue to be billed the applicable demand rates for distribution service and transmission service approved by the Public Utilities Commission for all customers receiving service on the same rate schedule, and in addition would receive a separately-identified credit on its DC Fast Charging station bill. Therefore, a phasing in of the distribution demand charge is not necessary under the manner by which Narragansett Electric is proposing to provide the bill credit to participating DC Fast Charging stations. In coordination with other stakeholders, Narragansett Electric will determine whether to change the structure of the credit or eliminate the credit at the end of the three-year period, based on the impact of the program, station utilization patterns, market maturity, and load data. If the Company determines that some form of bill assistance continues to be needed, the Company will submit a proposal to the Public Utilities Commission.

(This response is identical to the Company's response to Division 1-25 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

Division 5-26

Request:

Refer to Schedule PST-1, Chapter 6. For each of the four Electric Heat Initiative components, please identify whether the component could be implemented through the Company's energy efficiency programs instead of through a separate PST initiative, and what the advantages or disadvantages of doing so would be.

Response:

The motivation for implementing heat electrification activities in both the energy efficiency (EE) and Power Sector Transformation (PST) programs is to achieve greater speed and scale, commensurate with Rhode Island's stated emissions targets and policy goals. This motivation is articulated in Chapter Six of the PST Plan (p. 121):

> The Rhode Island Executive Climate Change Coordinating Council (EC4) issued on December 31, 2016 its "Rhode Island Greenhouse Gas Emissions Reduction Plan" (the EC4 Plan). The 2050 pathway envisioned by the EC4 report implies an annual conversion rate of approximately 13,000 customers per year to heat pumps every year between now and 2050. Adoption rates are currently far lower than this. [T]he 2018 energy efficiency program plan (EE Program) proposes incentives for approximately 60 fuel-oil customers per year. Yet given the shortfall between that number and the vision laid out in the EC4 Plan, this [Electric Heat] Initiative dedicates additional resources to accelerate adoption of air- and ground-source heat pumps by the customers with the highest energy costs and largest emissions footprints. In the process, this Initiative helps to animate an active third-party ecosystem in Rhode Island of efficient heat electrification.

Prior to finalization of the PST Phase One Report in November 2017, Narragansett Electric introduced a limited heat electrification program in RIPUC Docket No. 4684 (the 2018-2020 Energy Efficiency and System Reliability Procurement Plan), and subsequently in RIPUC Docket No. 4755, the 2018 Energy Efficiency Program Plan. During the PST Technical Meetings, various stakeholders, while noting that heat electrification has a role in the EE programs, also articulated their support for including heat within the PST framework. Following that input from stakeholders, the Company submitted a broader electric heat initiative through the PST framework as a complementary step to achieving market transformation of the renewable thermal market.

The main advantage of implementing all electric heat components through the EE program would be procedural simplicity: all electric heat programs would be funded and evaluated through existing channels. This procedural simplicity, however, would come at a cost.

Implementation through EE alone is not sufficient to achieve the market dynamism contemplated by stakeholders and by the State's 2050 emissions targets. Specifically, there are three key advantages to pursuing complementary heat electrification through the PST framework.

The first advantage is to provide a venue for crafting more transparent and targeted incentives for beneficial electrification. The PST framework proposes incentives linked to reducing emissions, rather than focused on reduced kWh and demand load, which is the goal of EE incentives. The proposed delivery of beneficial electrification beyond the EE process is intended to invite a process for establishing appropriate utility incentive structures for electrification.

The second advantage is creating a venue for new partnerships and business models. Situating a complementary program within PST will allow new and creative approaches to animating the renewable thermal market, such as shared facility investment and novel financing options that are not possible through the EE program.

The third advantage is to reach a broader customer base than what can be achieved through the EE program alone, which is offered only to a small number of customers because of budgetary limitations. As a first step, the PST heat initiative expands the program significantly and includes offerings tailored to both income eligible customers and to large institutional and commercial customers interested in ground-source heat pumps.

For these reasons, although it is possible to implement certain components of the Electric Heat Initiative through the EE program on a limited basis, doing so would not promote the scale and transformative impact that PST stakeholders and state policy goals envision.

(This response is identical to the Company's response to Division 1-26 in Docket No. 4780.)

Prepared by or under the supervision of: Mackay Miller

Division 5-27

Request:

Refer to Schedule PST-1, Chapter 7 regarding energy storage. Please discuss how the Company will evaluate potential locations to maximize quantifiable benefits.

Response:

The Company has not yet developed specific qualification requirements for maximizing quantifiable benefits at potential locations. However, the Company believes the following list of benefits will be in included (not limited to) in the evaluation of any potential energy storage location.

- Co-located intermittent generation
- Distribution profile on local feeder
- Site Host's load profile
- Site Host's Mission – Community, Environmental, and/or Educational goals
- Site Host's willingness to support project
- Number of potential visitors per year
- System permitting or zoning restrictions
- Available space for demonstration
- Ability to electrically interconnect system

(This response is identical to the Company's response to Division 1-27 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

Division 5-28

Request:

Refer to Schedule PST-1, Chapter 8 regarding the Company's proposed Solar Program.

a. Please discuss whether the low income bill reductions under the Company's proposed Solar Program would likely be the same, less than, or greater than bill reductions under a comparable investment in the Community Renewables program.

b. Please discuss whether the Company considered additional support for the Community Renewables program instead of the proposed Solar Program. If yes, please discuss the decision to propose the Solar Program rather than investments in the Community Renewables program.

Response:

a. The low income bill reduction under the proposed Solar Program would vary considerably among participants based on their existing usage and potential to reduce energy usage, as the program will use proceeds to fund additional energy savings measures at the residences of Income Eligible customers.

The Company understands the RI Commerce Corporation's Renewable Energy Fund (REF) is proposing a Community Renewables proposal. This proposed Community Renewables program is designed to provide a fixed savings (it has been proposed to be $500 per low income subscriber) for low income subscribers from a community solar project developer. As the savings from the Company's proposed program would be variable, but would last the life of any efficiency measures installed, the Company believes the value from its program would be greater over the long term.

b. The Company did not consider additional support for the proposed Community Renewables program in lieu of the proposal the Company submitted.

(This response is identical to the Company's response to DIV 1-28 in Docket No. 4780.)

Prepared by or under the supervision of: Carlos Nouel

Division 5-29

Request:

Regarding the proposed metric for the Complex Capital Projects Capital Cost Incentive:

a. Please explain whether the incentive would apply to all of the projects included in the Company's ISR plan, or only a subset. If only a subset, please explain how such projects would be determined.

b. Please provide portfolios of complex capital projects for FY 2015, 2016, and 2017, including the project names, sizes, and brief descriptions.

c. Please provide baseline estimates of cost for portfolios of complex capital projects for FY 2015, 2016, and 2017.

d. Please provide a list of planned complex capital projects for FY 2018.

Response:

a. The Company is proposing an incentive that would apply only to the larger, more complex projects. As part of the Company's project management process, when a project is first initiated, the Company calculates a complexity score. This score is used to determine if a Project Manager is required. The incentive would apply to all projects that required a Project Manager.

b. The Company is interpreting size to refer to the project cost. Attachment DIV 5-29 shows the complex capital projects that closed in Fiscal Year 2015, Fiscal Year 2016, and Fiscal Year 2017. It includes the project names, actual capital dollars, baseline capital dollars, source of baseline capital data, and brief descriptions.

c. Please see Attachment DIV 5-29.

d. Based on the Company's December 2017 schedule updates, the table below shows the complex capital projects that are projected to close in Fiscal Year 2018.

Fin Sys Proj No.	Project Name
C024176	03304 Hopkinton Substation (Dist Sub) - Chase Hill
C036522	09312 Kilvert St 87 - Install TB#2 (DSub)
CD01101	15721 Kent County # 22 Add T5, Tie Breakers and 22F6 Feeder Position
C046386	BITS Wakefield Sub Upgrades (D-Sub)
C052708	Volt Var-Substation (Putnam Pike Sub)
C046352	URI Volt/Var Mgmt Pilot Project

(This response is identical to the Company's response to Division 1-29 in Docket No. 4780.)

Prepared by or under the supervision of: Meghan McGuinness and Timothy R. Roughan

Project	Project Description	PowerPlan Project Decription	Closure Year (includes the one where all work orders are closed, but Funding Project is opened)	Baseline - CAPEX Sanction Amount Data Source	Sanction CAPEX (baseline data, $1000)	Actual CAPEX ($1000)
C036230	Langworthy Substation (D-Sub)	This project upgrades Langworthy substation to add capacity and to phase this station with the rest of the distribution system in the area.	FY15	USSC-12-444vdtd Jan 1 2014	$1,574	$1,682
C033535	Johnston Sub 12.47 kV Expansion	Johnston Sub 12.47 kV Expansion of New yard. This project is being moved forward because of the failure of the #2 Transformer at Johnston and the subsequent loss of 12.47 kV supply to the old switchgear.	FY16	USSC0110W259 v3 dtd June 20th 2015	$4,284	$4,590
C034002	Johnston Sub 12kV Expansion Getawa.	Johnston Sub 12.47 kV Epansion Getaways - This is an associated project to C33535 for the relocation of feeder from the old 12 kV switchgear to the new switchgear. It will cover the underground getaway relocation cost.	FY15	USSC0110W259 v3 dtd June 20th 2015	$326	$318
CD00659	Eldred Sub Asset Replacement(D-Lin	Install conduit and cable for 2-modular feeders at Eldred substation as shown on the Distribution Plan. Remove existing conduit and cable.	FY16	USSC-1 1-045v4 dtd 3/4/2014	$148	$244
C036232	Langworthy Substation (D-Line)	This project upgrades Langworthy substation to add capacity and to phase this station with the rest of the distribution system in the area.	FY16	USSC-12-444vdtd Jan 1 2014	$116	$172
C046832	CLARKE St Feeder Upgrades (D-Line)	Upgrade 65J12 feeder utilizing a MITS design with a 3.75/4.68 MVA transformer. Reinforce feeders as shown in scope document.	FY17	USSC-12-085 v3 dtd Dec 9th 2014 - did not include resanction paper	$389	$425
CD01243	Pontiac substation Flood Restoratio	Install new cable getaways for 27F1, 27F2, 27F5 & 27F6 Feeders.	FY17	USSC-12-433 v3 dtd 9/9/14 - did not look at resanction paper	$473	$593
C024180	Coventry MITS (Dist Line)	Getaway associated with new "MITS" modular feeder in Coventry. Install 2000 c.f. of 477 Al open wire to supply "MITS" from 3309 line.	FY17	USSC0408P37 dtd June 13th 2012	$775	$678

Project	Project Description	PowerPlan Project Decription	Closure Year (includes the one where all work orders are closed, but Funding Project is opened)	Baseline - CAPEX Sanction Amount Data Source	Sanction CAPEX (baseline data, $1000)	Actual CAPEX ($1000)
C046398	Memorial Blvd Easton's Beach inst d	This is an asset replacement project to relocate 2 - 25 kV circa 1965 direct buried cables from a ROW where it interferes with the cities Newport¿s drainage ditch to a duct and manhole system located in the road. The project involves installing 3,200 ft of 9 way duct bank along Memorial Blvd (Easton's Beach). Installing 2 - 25 kV. 3 - 1/C, 500 kcmil CU, CN, XLPE cables. Retiring in place 2- 25 kV, 3c 250 kcmil CU, Plastex covered, C-L-X, direct buried cables.	FY17	USSC-14-123 v2 dtd Nov 10th 2015 - did not include resanction paper	$1,390	$1,440
C046831	CLARKE 65J12 Feeder Upgrade (D-Sub)	Upgrade 65J12 feeder utilizing a MITS design with a 3.75/4.68 MVA transformer	FY17	USSC-12-085 v3 dtd Dec 9th 2014 - did not include resanction paper	$2,130	$2,172
CD01242	Pontiac substation Flood Restoratio	This project is required to address reliability concerns at Pontiac substation and to follow up on commitments made to the Rhode Island Public Utility Commission to address flood related issues as a result of the historic flooding.	FY17	USSC-12-433 v3 dtd 9/9/14 - did not look at resanction paper	$2,811	$3,080
C054788	ValleySub 102 NERC CIP v3.25	This project is designed to bring all newly-identified BES substations (specifically Valley Sub 102) into compliance with NERC Critical Infrastructure Protection (CIP) Standards - version 4. The scope of work includes installing physical and cyber access controls to bring the substation into compliance with current CIP version 4 requirements. Costs include engineering, physical security perimeters, electronic security perimeters, and phone lines.	FY17	Electronic DoA dtd May 2 2014. DOA was used from orignal electronic sanction (PowerPlan system), not the re-sanction amount	$250	$317

Project	Project Description	PowerPlan Project Decription	Closure Year (includes the one where all work orders are closed, but Funding Project is opened)	Baseline - CAPEX Sanction Amount Data Source	Sanction CAPEX (baseline data, $1000)	Actual CAPEX ($1000)
C024179	Coventry MITS (Dist Sub)	Install a modular feeder on Tiogue Ave in Coventry utilizing a Modular Integrated Transportable Substation (MITS) design.	FY17	USSC0408P37 dtd June 13th 2012	$2,970	$2,106
CD01104	Kent County 2nd Transformer (D-Line	To address load at risk at Kent County substation this project installs a second 115/13.2kV, 24/32/40 MVA power transformer at this station. This project is the D-line work associated with the substation.	FY18	USSC-12-355 v4 dtd Feb 23rd, 2016	$212	$167
C049981	Nsnvlle 127W41 New Customer Load	In 2014 a new commercial customer's expected load will exceed the only area Nasonville 127W41 distribution feeder SN rating. Additionally, new load will reduce the W41 feeder support to other area customers. The proposed project increase the W41 feeder SN rating, provides additional capacity for other commercial loads, and transfers a portion of load from W41 onto the extended W42 feeder at Victory Hwy near Oakland Ave in Burrillville, RI.	FY18	Originally, the project was less than $1M so there is only electronic DOA in PowerPlan. Project was resanctions. Amounts reflect original sanction	$700	$1,696
C023852	Inst Ductline Governor St. Prov.	Install 2800' of 12-way manhole and duct system.	FY18	USSC-13-239 dtd 8/20/2013	$1,571	$1,528
CD00972	New Highland Drive Substation - DSu	This project will cover Distribution Substation costs associated with the New Highland Drive Substation.	FY18	USSC 12-287 v4 dtd July 23rd, 2014	$13,133	$12,132

Division 5-30

Request:

Please provide the rationale behind the $2.5 million cap on the value of savings that might be retained by the Company from the Complex Capital Projects Capital Cost Incentive.

Response:

Narragansett Electric sought to propose an incentive structure for complex capital projects that would balance customer and Narragansett Electric's interests. Narragansett Electric believes that it is reasonable to propose an upper bound to the incentive beyond which all further savings would be returned to customers. The $2.5 million cap was chosen because it represents a significant revenue opportunity for Narragansett Electric that will motivate its performance while also providing 50 percent of the savings to customers until the threshold is reached, and 100 percent of the savings to customers for savings above the cap.

(This response is identical to the Company's response to Division 1-30 in Docket No. 4780.)

Division 5-31

Request:

Please provide information on the per-mile construction costs for previous overhead distribution line projects.

Response:

The Company's cost-per-mile-of-construction metric was developed in September 2017 as a full process cost view in support of the Company's focus on end-to-end process alignment. It falls under the electric standard construction work stream, which has, as its primary focus, electric distribution line construction. To make the data most useful, the Company included all electric distribution line work performed on a daily basis – large and small. Therefore, the data is not run exclusively for certain projects, but rather for all distribution line work.

To produce results, the Company has created a composite mile algorithm. This calculation includes all electric overhead distribution line work orders that are completed each month, and factors in all assets that are installed on these work orders. The assets are aggregated into six categories, and a variety of assumptions and calculations are performed to generate a total number of composite miles for that month. All costs are included, with the exception of contribution-in-aid-of-construction (CIAC) reimbursements (which would artificially lower the cost calculation for this purpose). The result is a fully loaded cost-per-mile.

The Company's intent is to produce this metric monthly at a Company level and evaluate trends to monitor cost efficiency. In addition, the Company has begun to produce this data in a yard/platform view to allow us to manage cost efficiencies at a yard level across the companies. When the Company produces the yard-level view, it included only direct costs (labor, material, invoices), as this view is used by supervisors to manage costs.

The table below presents data for all platforms in Rhode Island, capturing the following information (left to right):

Yard: The platform where the work was performed
Last Month: The previous month's direct costs per mile
Trend: Captures whether last month's value was lower (L) or higher (H) than the month prior
Miles: The composite miles of construction installed in all work orders completed in the current month
Direct Cost: The total direct cost for all work orders completed in the current month
FY18: The running total value for direct cost per mile for this platform this fiscal year

Yard	Last Month	Trend	Miles	Direct Cost	FY 18
Chopmist OH	$398,324	H	0.4	$175,986	$216,006
Lincoln OH	$223,286	L	0.7	$153,350	$251,465
Middletown OH	$276,029	H	0.2	$48,214	$199,758
North Kingston OH	$253,435	L	1.5	$371,632	$268,781
Providence OH	$259,956	H	2.2	$560,245	$272,736
Westerly OH	$246,776	L	1.4	$339,607	$172,216

(This response is identical to the Company's response to Division 1-31 in Docket No. 4780.)

Division 5-32

Request:

For each of the most recent five years, please provide the portion of total costs that each of the following categories represents: generation capacity (FCM), transmission, distribution, and energy supply. Please provide these costs on a monthly basis, if possible.

Response:

Attachment DIV 5-32 provides Narragansett Electric's total generation and transmission expenses, by month, for calendar years 2013 through the month of 2017 for which this information is available. Because Narragansett Electric is billed a bundled rate by its Standard Offer Service wholesale suppliers, it is unable to provide separate amounts for generation capacity costs.

The table below provides an estimate of Narragansett Electric's distribution costs derived from its Earnings Reports filed for calendar year 2012 in RIPUC Docket No. 3617 and 2013 through 2016 in RIPUC Docket No. 4323. Since calendar year 2017 just ended, Narragansett Electric has not submitted its Earnings Report for 2017. These costs include distribution costs, interest, taxes, and return on equity. Distribution costs include the costs of energy efficiency programs.

Historic Annual Distribution Costs ($ millions)

2012	**2013**	**2014**	**2015**	**2016**
$322	$379	$412	$412	$406

(This response is identical to the Company's response to Division 1-32 in Docket No. 4780.)

Total Transmission and Generation Expense[1] - Calendar Years 2013 through 2017

	CY 2013		
	Month	Transmission Expense (a)	Generation Expense (b)
(1)	January	$9,912,389	$37,541,422
(2)	February	$12,394,003	$32,510,615
(3)	March	$10,743,254	$25,158,863
(4)	April	$8,564,850	$20,660,602
(5)	May	$13,591,191	$20,307,384
(6)	June	$14,470,516	$25,995,293
(7)	July	$15,118,089	$40,395,205
(8)	August	$10,437,097	$30,482,034
(9)	September	$12,890,824	$23,608,627
(10)	October	$9,602,681	$22,413,780
(11)	November	$12,279,253	$26,491,907
(12)	December	$11,279,290	$40,408,076
(13)	Total	**$141,283,438**	**$345,973,807**

CY 2014		
Month	Transmission Expense (c)	Generation Expense (d)
January	$11,853,522	$58,464,972
February	$11,796,005	$48,896,041
March	$14,733,257	$33,054,054
April	$9,901,258	$24,793,720
May	$11,398,624	$22,759,866
June	$15,583,791	$27,198,813
July	$15,062,346	$37,842,404
August	$12,673,850	$32,924,471
September	$15,876,833	$25,760,015
October	$9,616,424	$23,105,330
November	$11,681,660	$30,011,895
December	$12,650,361	$46,525,525
Total	**$152,827,931**	**$411,337,107**

	CY 2015		
	Month	Transmission Expense (e)	Generation Expense (f)
(14)	January	$12,945,813	$81,829,131
(15)	February	$13,058,290	$74,882,089
(16)	March	$15,837,906	$42,498,871
(17)	April	$8,510,920	$22,936,553
(18)	May	$12,351,441	$20,094,276
(19)	June	$14,654,838	$25,310,855
(20)	July	$15,538,894	$32,051,906
(21)	August	$15,657,975	$31,021,738
(22)	September	$15,213,923	$22,574,623
(23)	October	$9,748,123	$19,394,043
(24)	November	$18,651,059	$23,907,621
(25)	December	$12,914,533	$38,156,451
(26)	Total	**$165,083,715**	**$434,658,158**

CY 2016		
Month	Transmission Expense (g)	Generation Expense (h)
January	$13,860,223	$46,639,717
February	$12,194,962	$42,107,887
March	$12,872,710	$26,430,442
April	$12,489,269	$18,822,459
May	$14,840,051	$16,076,755
June	$15,485,423	$19,534,240
July	$14,950,031	$26,961,056
August	$17,842,946	$26,217,349
September	$12,983,844	$17,553,675
October	$10,859,253	$15,433,533
November	$13,014,694	$17,612,681
December	$12,190,432	$28,163,226
Total	**$163,583,840**	**$301,553,021**

	CY 2017		
	Month	Transmission Expense (i)	Generation Expense (j)
(27)	January	$15,199,636	$30,378,981
(28)	February	$13,812,551	$25,746,157
(29)	March	$14,547,548	$22,267,644
(30)	April	$12,960,885	$14,335,013
(31)	May	$17,130,512	$14,240,929
(32)	June	$20,489,900	$23,685,363
(33)	July	$18,260,968	$27,592,005
(34)	August	$17,070,271	$25,678,708
(35)	September	$17,090,118	$22,139,612
(36)	October	$13,473,591	$20,845,461
(37)	November	N/A	$23,047,016
(38)	December	N/A	N/A
(39)	Total	**$160,035,982**	**$249,956,889**

Source:
Column (a); RIPUC Docket No. 4485, 2014 Electric Retail Rate Filing, Schedule JAL-11, Page 4, Column (e)
Column (b); RIPUC Docket No. 4485, 2014 Electric Retail Rate Filing, Schedule JAL-2, Page 4, Column (e)
Column (c); RIPUC Docket No. 4554, 2015 Electric Retail Rate Filing, Schedule JAL-11, Page 4, Column (e)
Column (d); RIPUC Docket No. 4554, 2015 Electric Retail Rate Filing, Schedule JAL-2, Page 6, Column (e)
Column (e); RIPUC Docket No. 4599, 2016 Electric Retail Rate Filing, Schedule ASC-12, Page 4, Column (e)
Column (f); RIPUC Docket No. 4599, Revised 2016 Electric Retail Rate Filing, Schedule ASC-2 Revised, Page 4, Column (e)
Column (g); RIPUC Docket No. 4691, Revised 2017 Electric Retail Rate Filing, Schedule ASC-12, Page 4, Column (e)
Column (h); RIPUC Docket No. 4691, Revised 2017 Electric Retail Rate Filing, Schedule ASC-2 Revised, Page 4, Column (e)
Column (i); per monthly NEP and ISO Bills - November 2017 and December 2017 expenses not yet available
Column (j); per monthly Standard Offer Service invoice and ISO-New England Bills - December 2017 expenses not yet available

[1] Reflects costs associated with provision of Standard Offer Service
Does not include GIS and Renewable Energy Standard (RES) Costs

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Division 5-33

Request:

Refer to Workpaper 9.1 – Peak Demand Reduction Targets.

a. Please provide the Company's internal peak forecast in machine-readable format.

b. Please provide the methodology behind and the input data for the forecast in machine-readable format.

c. Please provide the methodology and calculations for the EE reduction and PV reduction forecasts in machine-readable format.

Response:

a. Attachment DIV 5-33-1 provides the internal peak forecast in machine-readable (electronic) format.

b. Attachment DIV 5-33 -2 provides the methodology for the forecast. Please refer to Pages 5-10 of the attachment for an explanation of the methodology used. Attachment 5-33-3 contains the input data for the forecast in machine-readable (electronic) format.

c. Attachment DIV 5-33-2 describes the methodology used for the energy efficiency reduction and photovoltaic reduction forecasts. Please refer to Pages 6-9. Attachment DIV 5-33-4 contains the energy efficiency and photovoltaic reductions in machine-readable (electronic) format.

(This response is identical to the Company's response to Division 1-33 in Docket No. 4780.)

Prepared by or under the supervision of: Meghan McGuinness and Timothy R. Roughan

RHODE ISLAND
SUMMER (Independent) Peaks

AFTER Solar & Energy Efficiency Reductions

YEAR	Actuals (MW)	Actuals (% Grwth)	Normal 50-50 (MW)	Normal 50-50 (% Grwth)	Extreme 90-10 (MW)	Extreme 90-10 (% Grwth)	Extreme 95-5 (MW)	Extreme 95-5 (% Grwth)	WTHI ACTUAL
2003	1,670		1,803		1,950		1,991		80.1
2004	1,628	-2.5%	1,839	2.0%	1,993	2.2%	2,036	2.3%	78.5
2005	1,805	10.8%	1,772	-3.6%	1,925	-3.4%	1,968	-3.4%	83.1
2006	1,985	10.0%	1,803	1.8%	1,941	0.8%	1,979	0.5%	85.9
2007	1,777	-10.5%	1,852	2.7%	2,006	3.4%	2,050	3.6%	80.9
2008	1,824	2.6%	1,817	-1.9%	1,964	-2.1%	2,006	-2.1%	82.9
2009	1,713	-6.1%	1,816	0.0%	1,988	1.2%	2,036	1.5%	80.3
2010	1,872	9.3%	1,798	-1.0%	1,968	-1.0%	2,016	-1.0%	84.5
2011	1,974	5.5%	1,817	1.1%	1,985	0.9%	2,033	0.8%	84.8
2012	1,892	-4.2%	1,822	0.3%	1,977	-0.4%	2,021	-0.6%	83.5
2013	1,965	3.9%	1,817	-0.3%	1,985	0.4%	2,032	0.6%	84.7
2014	1,653	-15.9%	1,811	-0.4%	1,980	-0.2%	2,028	-0.2%	80.4
2015	1,738	5.1%	1,850	2.2%	2,035	2.8%	2,087	2.9%	80.4
2016	1,803	3.8%	1,778	-3.9%	1,946	-4.4%	1,994	-4.5%	82.6
2017	1,688	-6.4%	1,723	-3.1%	1,893	-2.8%	1,941	-2.7%	81.7
2018	-	-	1,706	-1.0%	1,878	-0.8%	1,926	-0.7%	-
2019	-	-	1,691	-0.9%	1,864	-0.7%	1,913	-0.7%	-
2020	-	-	1,679	-0.7%	1,855	-0.5%	1,905	-0.5%	-
2021	-	-	1,672	-0.4%	1,849	-0.3%	1,900	-0.2%	-
2022	-	-	1,668	-0.2%	1,847	-0.1%	1,899	-0.1%	-
2023	-	-	1,666	-0.1%	1,848	0.0%	1,899	0.0%	-
2024	-	-	1,668	0.1%	1,852	0.2%	1,904	0.3%	-
2025	-	-	1,673	0.3%	1,860	0.4%	1,913	0.5%	-
2026	-	-	1,681	0.4%	1,870	0.5%	1,923	0.5%	-
2027	-	-	1,687	0.4%	1,878	0.4%	1,932	0.5%	-
2028	-	-	1,692	0.3%	1,885	0.4%	1,940	0.4%	-
2029	-	-	1,696	0.2%	1,891	0.3%	1,947	0.3%	-
2030	-	-	1,699	0.2%	1,897	0.3%	1,953	0.3%	-
2031	-	-	1,702	0.1%	1,901	0.2%	1,958	0.2%	-
2032	-	-	1,703	0.1%	1,904	0.2%	1,962	0.2%	-

	Normal 50-50	Extreme 90-10	Extreme 95-5
Compound Avg. 10 yr ('07 to '17)	-0.7%	-0.6%	-0.5%
Compound Avg. 5 yr ('12 to '17)	-1.1%	-0.9%	-0.8%
Compound Avg. 5 yr ('17 to '22)	-0.7%	-0.5%	-0.4%
Compound Avg. 10 yr ('17 to '27)	-0.2%	-0.1%	0.0%
Compound Avg. 15 yr ('17 to '321)	-0.1%	0.0%	0.1%

WTHI

NORMAL	82.2
EXTREME 90/10	85.0
EXTREME 95/5	85.8

RHODE ISLAND

2018 Electric Peak (MW) Forecast

Long-Term: 2018 to 2032

[Narragansett Electric Company]

December 2017

Rev. 0, 12/31//2017

Advanced Data & Analytics
Business Processes

nationalgrid

REVISION HISTORY & GENERAL NOTES

Revision History

Version	Date	Changes
Rev. 0	12/31/2017	- ORIGINAL

General Notes:

- Input data through **August 2017**; Projections from 2018 forward;
- Economic data is from Moody's vintage **August 2017**.
- Energy Efficiency data is vintage **August 2017.**
- Distributed Generation data is vintage **August 2017.**
- Peak MW and Energy GWH source is ISO-NE/MDS meter-reconciled data (1/2003 to 6/2017); internal unreconciled **preliminary** data (7/2017 to 8/2017).
- Peak load data is metered zone load.
- Peak day & times in this report refer to those for the Company and not for ISO-NE peak.
- The term "Weather-Normal" and "Extreme" 90/10 ("1 in 10") and 95/5 ("1 in 20") weather are based on 20 year average.
- Narragansett Electric Company (NECO) is now shown individually (previous versions had NECO included in the same report as the Massachusetts jurisdiction Companies).
- The modeling process now employs a "reconstructed" for DERs historical data set for input

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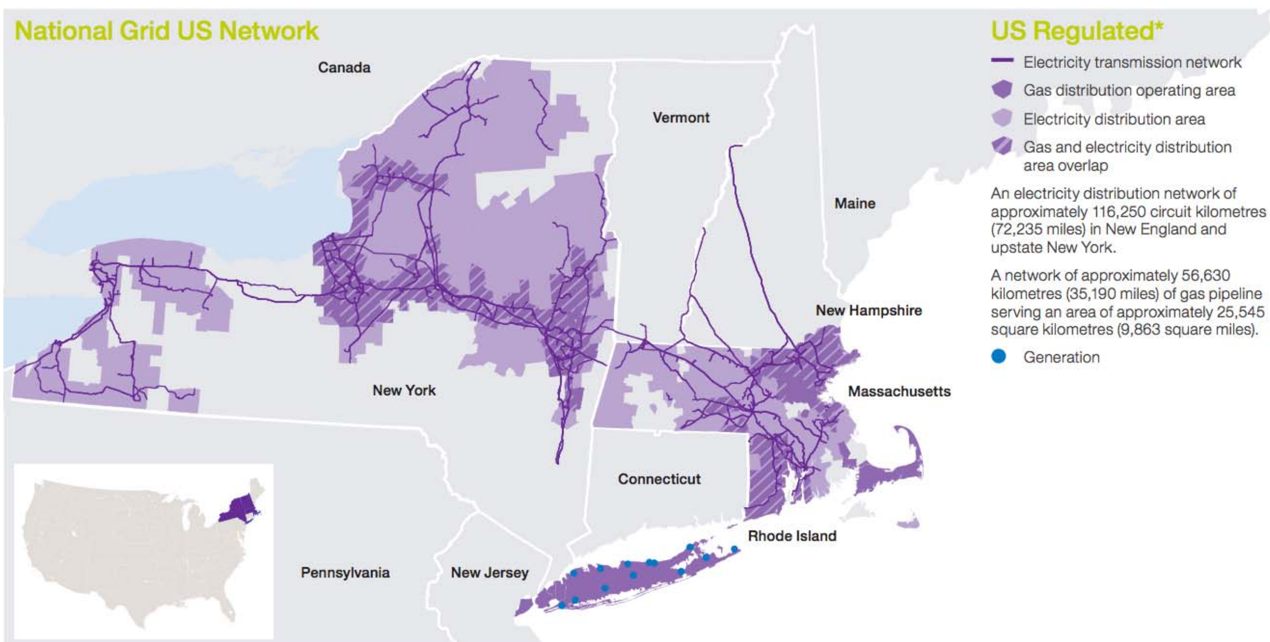
CONTENTS

Summary

National Grid's US electric system is comprised of four companies serving 3.4 million customers in Massachusetts, Rhode Island and Upstate New York. The four electric distribution companies are Massachusetts Electric Company and Nantucket Electric Company, serving 1.3 million customers in Massachusetts, Narragansett Electric Company, serving 0.5 million customers Rhode Island and Niagara Mohawk Power Company, serving 1.6 million customers in upstate New York. Figure 1[1] shows the Company's service territory in the U.S..

Figure 1



*Access to electricity and gas transmission and distribution assets on property owned by others is controlled through various agreements. Source: National Grid

Forecasting peak electric load is important to the Company's capital planning process because it enables the Company to assess the reliability of its electrical infrastructure, enables timely procurement and installation of required facilities, and it provides system planning with information to prioritize and focus their efforts. In addition to these internal reliability and capital planning internal uses, the peak forecast is also used to support regulatory requirements with the state, federal, and other agencies.

Narragansett Electric Company's (NECO) peak demand in Rhode Island in 2017 was 1,688[2], on Thursday, July 20th at hour-ending 16. The 2017 peak was 15% below the NECO all-time high of 1,985 MW reached on Wednesday, August 2, 2006.

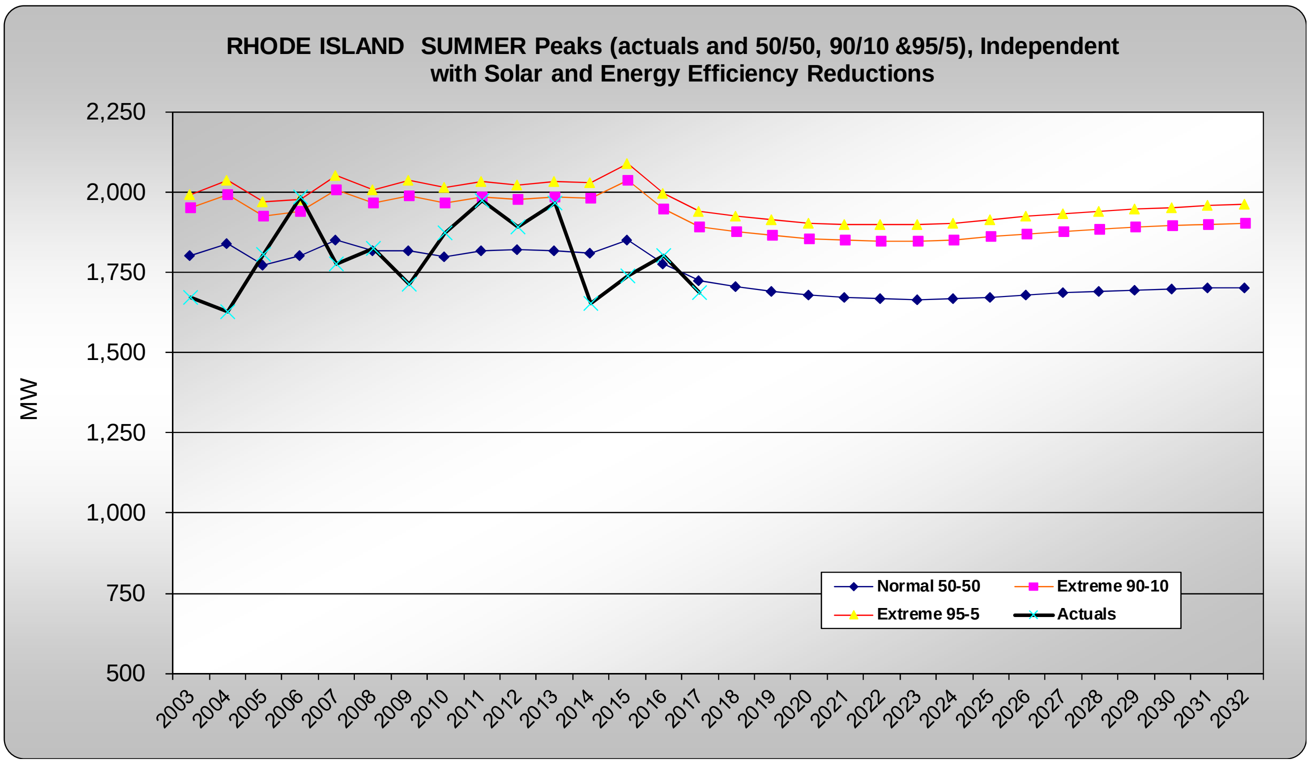
[1] National Grid also serves gas customers in these same states which are also shown on this map.
[2] Meter Data Service's system level PRELIMINARY peak and subject to change

This summer's peak weather was considered *cooler* than normal (average). This year's peak is estimated to be 35 MW below the peak the company would have experienced under normal weather conditions. Thus, on a weather adjusted "normal" basis this year's peak was estimated to be 1,723 MW, a decrease of -3.1% vs. last year's weather-adjusted 'normal' peak.

The forecast indicates that the overall service territory will experience negative growth of -0.1% annually over the next fifteen years, primarily due to the impacts of energy efficiency and solar PV offsetting any underlying economic growth.

Figure 1 shows this forecast graphically.

Figure 1



Forecast Methodology

National Grid in Rhode Island forecasts its peak MW demands for its service territory in the state.

The overall approach to the peak forecast is to relate (or regress) peak MWs to energy growth. For each zone, peak MWs are regressed against energy growth and company/zonal economic factors (if appropriate). This method allows the peak MW forecasts to grow along with energy growth rates for the Company, however it also allows the peak to adjust to other economic influences in each area.

Each of these models is developed based on a “reconstructed” model of past load. That is, claimed energy efficiency and known solar PV are first added back to the historical data set before the models are run. Future projections are made based on the “reconstructed” data set, then future cumulative estimates of savings for the distributed energy resources (DERs) for energy efficiency and solar-PV are taken out to arrive at the final forecast.

Post-model reductions were made to the initial forecast models for energy efficiency (EE) and solar (DG) and increased for historical demand response (DR) impacts.

The results of this forecast are used as input into various system planning studies. The forecast is presented for all three weather scenarios. The transmission planning group uses the extreme-90/10 weather scenario for its planning purposes. For distribution planning, the degree of diversity is reduced and the variability of load is greater, so a 95/5 forecast is used.

Distributed Energy Resources (DERs)

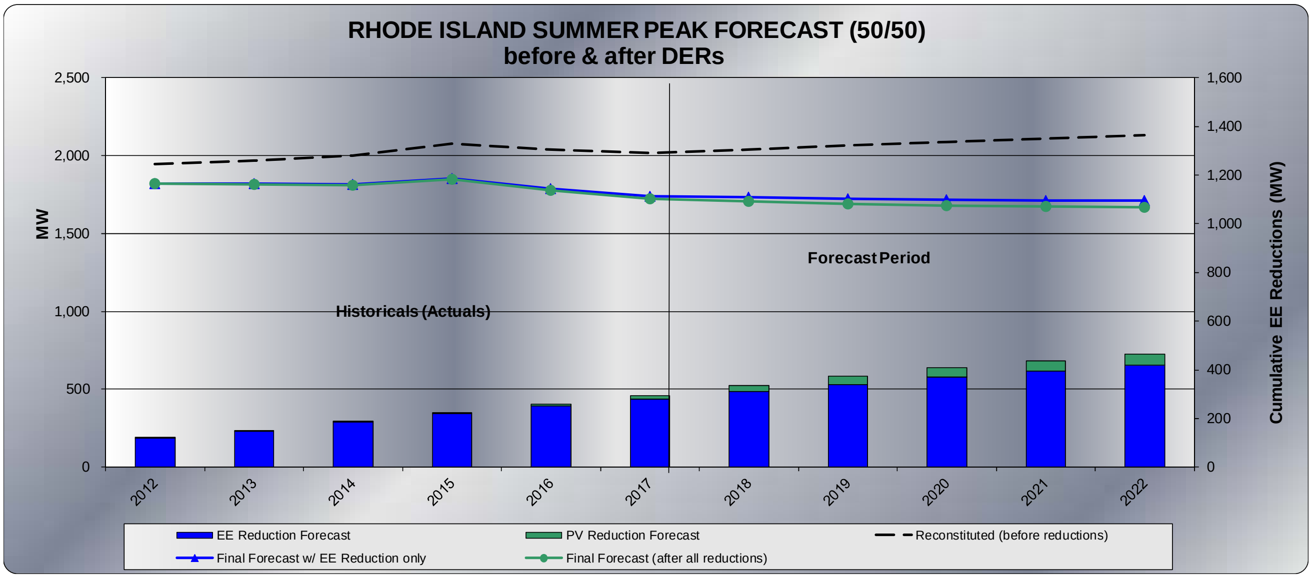
In New England there are a number of policies, programs and technologies that are impacting customer loads. These include, but are not limited to energy efficiency, distributed generation (specifically solar distributed generation) and demand response. These collectively are termed distributed energy resources because they impact the loads at the customer level, as opposed to traditional, centralized power supplies.

Energy Efficiency (EE)

National Grid has been running energy efficiency programs in its Rhode Island jurisdiction for a number of years and will continue to do so for the foreseeable future. In the short-term (one to three years) energy efficiency targets are based on approved company programs. Over the longer term the Company uses the ISO-NE projections (actually the company’s prorata share of EE by load within each ISO zone) for these longer term projections. The ISO-NE EE projections account for state policies, company programs and other market factors.

Figure 2 shows the expected loads and energy efficiency program reductions to NECO peaks by year. As of 2017, it is estimated that these EE programs have reduced loads by 279 MW than if there were no programs run. By 2032, it is expected that this reduction will grow to 582 MW or 25% of what load would have been had these programs not been implemented. Over the fifteen year planning horizon these reductions lower annual growth from 1.0% to 0.1% per year.

Figure 2



Distributed Generation (Solar – PV)

There has been a rapid increase in the adoption of solar[3] throughout the state. The Company tracks historical PV and that becomes the basis of the historical values shown. The projection for the future is based on the Company's pro-rata share by load of PV in each zone that the ISO-NE shows in its annual load & capacity report[4]. The ISO-NE considers current PV and policy goals for the future. Since the Company does not have its own territory wide PV programs as it does with energy efficiency this approach ensures consistency with the statewide and area specific projections of the ISO. In the short-term (one to three years) the company reviews the quantity of applications already in the 'queue' to make sure the projections based on the share of ISO estimates are reasonable.

Figure 2 above shows the expected NECO loads and solar reductions to peaks by year. As of 2017, it is estimated that this technology may have already reduced system peak loads by 16 MW. By 2032 it is expected that these reductions may grow to 66 MW[5], or about 3% of what load would have been had this technology not been installed. Over the fifteen year planning horizon these reductions lower annual growth from 0.1% to -0.1% per year.

[3] The Company limits this discussion to the impacts of solar distributed generation because it is the single largest contributor and the fastest growing of all distributed generation technologies at this time.
[4] 2017 Capacity, Energy, Load & Transmission Report, a report by the New England Independent System Operator, Inc., "CELT", dated May 2017.
[5] These are Company system summer peak impacts; these are approximately 21% of connected PV MWs.

The prevalence of DERs and their continued expansion clearly show how loads have been significantly lowered due to their success.

Explicit reductions to system peaks have been made for these energy efficiency and solar PV programs.

Demand Response

Demand Response (or "DR") are programs that actively target reductions to peak demand during hours of high expected demand and/or reliability problems. These are in contrast to the more passive energy efficiency savings discussed above that provide savings throughout the year. The DR programs enable utilities and operating areas, such as the New England Independent System Operator (ISO-NE) to take action in response to a system reliability concern or economic (pricing) signal. During these events customers can actively participate by either cutting their load or by turning on a generator to displace load from behind the customer's meter.

The ISO-NE has been implementing these type programs for a number of years now and for the purposes of this report are referred to as "wholesale DR". These programs have been activated several times over the last decade. The Company's policy has been to add-back reductions from these call-outs to its reported system peak numbers. This is because the Company is not in control of the call-out days nor times and thus there is no guarantee that these ISO –NE call-outs would be at the times of Company peaks. Therefore, the Company recognizes their existence, but must plan in the event that they are not called.

Table 2 shows the estimated reductions* for the historical call-outs on the peak days.

Table 2

DATE	HOUR	NEMA	SEMA	WCMA	RI
11-Aug-2016	16	4.9	5.4	16.7	10.4
11-Aug-2016	17	4.9	4.9	17.1	10.0
11-Aug-2016	18	4.5	3.7	15.9	8.8
11-Aug-2016	19	3.7	3.5	15.5	8.5
19-Jul-2013	14	4.6	6.0	13.5	9.8
19-Jul-2013	15	5.2	6.0	14.0	11.7
19-Jul-2013	16	4.4	5.1	13.5	8.8
19-Jul-2013	17	4.4	4.2	12.3	9.8
19-Jul-2013	18	4.2	3.2	12.3	7.8
19-Jul-2013	19	4.0	3.7	10.1	5.9
19-Jul-2013	20	3.8	3.7	8.4	5.9
22-Jul-2011	13	9.3	12.9	16.3	24.8
22-Jul-2011	14	13.3	18.3	23.2	35.2
22-Jul-2011	15	15.1	20.7	26.3	39.9
22-Jul-2011	16	14.8	20.4	25.8	39.2
22-Jul-2011	17	14.2	19.6	24.8	37.7
22-Jul-2011	18	13.1	18.0	22.8	34.7
02-Aug-2006	13	1.0	7.0	13.5	36.1
02-Aug-2006	14	1.0	7.0	13.5	36.1
02-Aug-2006	15	1.0	7.0	13.5	36.1
02-Aug-2006	16	1.0	7.0	13.5	36.1
02-Aug-2006	17	1.0	7.0	13.5	36.1
02-Aug-2006	18	1.0	7.0	13.5	36.1
01-Aug-2006	16	0.2	1.1	2.2	5.8
01-Aug-2006	17	0.2	1.1	2.2	5.8
01-Aug-2006	18	0.2	1.1	2.2	5.8
01-Aug-2006	19	0.2	1.1	2.2	5.8
01-Aug-2006	20	0.2	1.1	2.2	5.8

*It should be noted that the absolute MW do not always translate into one-to-one reductions to the peak depending on the timing of DR call-outs and pre-DR metered loads.

Weather Assumptions

Weather data is collected from Providence, the relevant weather station for Rhode Island.

The weather variables used in the model include heating degree days for the colder winter months and temperature – humidity indexes (THIs)[6] for the warmer summer months. These weather variables are correlated to the actual days that each peak occurs in each season

[6] THI is calculated as (0.55 * dry bulb temperature) + (0.20 dew point) + 17.5. Maximum values for each of the 24 hours in a day are calculated and the maximum value is used in the WTHI formula.

over the historical period. Summer THI uses a weighted three day index (WTHI)[7] to capture the effects of prolonged heat waves that drive summer peaks.

Weather adjusted peaks are derived for "normal (50/50)" average weather, "90/10 (1 in 10)" extreme weather and "95/5 (1 in 20)" extreme weather. Extreme weather scenarios are determined using a "probabilistic" approach that employs "Z-values" and standard deviations (i.e. the more variable the weather has been on peak days over the historical period, the higher the 90/10 and 95/5 levels will be versus the average).

- Normal "50/50" weather is the average weather on the past 20 seasonal peak days.
- Extreme "90/10" weather is such that it is expected that 90% of the time it should not be exceeded. It is similarly inferred that it should occur no more than one time in a ten year period.
- Extreme "95/5" weather is such that it is expected that 95% of the time it should not be exceeded. It is similarly inferred that it should occur no more than one time in a twenty year period.

These "normals" and "extremes" are used to derive the weather-adjusted historical and forecasted values for each of the normal and extreme cases.

[7] WTHI is weighted 70% day of peak, 20% one day prior and 10% two days prior

APPENDIX A: NARRAGASETT ELECTRIC COMPANY (NECO)

RHODE ISLAND
SUMMER (Independent) Peaks — **AFTER Solar & Energy Efficiency Reductions**

YEAR	Actuals (MW)	Actuals (% Grwth)	Normal 50-50 (MW)	Normal 50-50 (% Grwth)	Extreme 90-10 (MW)	Extreme 90-10 (% Grwth)	Extreme 95-5 (MW)	Extreme 95-5 (% Grwth)	WTHI ACTUAL
2003	1,670		1,803		1,950		1,991		80.1
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2020	-	-	1,679	-0.7%	1,855	-0.5%	1,905	-0.5%	-
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2031	-	-	1,702	0.1%	1,901	0.2%	1,958	0.2%	-
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	Normal 50-50	Extreme 90-10	Extreme 95-5
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Compound Avg. 5 yr ('17 to '22)	-0.7%	-0.5%	-0.4%
Compound Avg. 10 yr ('17 to '27)	-0.2%	-0.1%	0.0%
Compound Avg. 15 yr ('17 to '321)	-0.1%	0.0%	0.1%

WTHI

NORMAL	82.2
EXTREME 90/10	85.0
EXTREME 95/5	85.8

RHODE ISLAND SUMMER Independent 50/50 Peaks (MW) (before & after DERs)

	------------- SYSTEM PEAK (50/50) -------------			-------- DER REDUCTIONS ------		EE % of	PV % of
Calendar Year	Reconstituted (before reductions)	Final Forecast w/ EE Reduction only	Final Forecast (after all reductions)	EE Reduction Forecast	PV Reduction Forecast	'Reconstituted' Deliveries	'Reconstituted' Deliveries
2003	1,813	1,803	**1,803**	9	0	0.5%	0.0%
2004	1,860	1,839	**1,839**	21	0	1.1%	0.0%
2005	1,802	1,772	**1,772**	30	0	1.7%	0.0%
2006	1,844	1,803	**1,803**	41	0	2.2%	0.0%
2007	1,902	1,852	**1,852**	51	0	2.7%	0.0%
2008	1,878	1,817	**1,817**	61	0	3.3%	0.0%
2009	1,893	1,816	**1,816**	77	0	4.0%	0.0%
2010	1,887	1,798	**1,798**	89	0	4.7%	0.0%
2011	1,919	1,818	**1,817**	102	0	5.3%	0.0%
2012	1,944	1,823	**1,822**	121	0	6.2%	0.0%
2013	1,968	1,820	**1,817**	148	2	7.5%	0.1%
2014	2,001	1,814	**1,811**	187	4	9.3%	0.2%
2015	2,075	1,855	**1,850**	220	5	10.6%	0.2%
2016	2,036	1,785	**1,778**	250	7	12.3%	0.4%
2017	2,018	1,739	**1,723**	279	16	13.8%	0.8%
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2020	2,087	1,718	**1,679**	369	39	17.7%	1.9%
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2029	2,293	1,756	**1,696**	537	60	23.4%	2.6%
2030	2,314	1,761	**1,699**	552	62	23.9%	2.7%
2031	2,333	1,766	**1,702**	567	64	24.3%	2.8%
2032	2,352	1,770	**1,703**	582	66	24.8%	2.8%

'07 to '17: 10-year avg	0.6%	-0.6%	**-0.7%**
'12 to '17: 5-year avg.	0.8%	-0.9%	**-1.1%**
'17 to '22: 5-year avg.	1.1%	-0.3%	**-0.7%**
'17 to '27: 10-year avg	1.1%	0.0%	**-0.2%**
'17 to '32: 15-year avg	1.0%	0.1%	**-0.1%**

Appendix B: POWER SUPPLY AREAS (PSAs)

Year One Weather-Adjustment and Multi-Year Annual Growth Percentages (Summer) **after EE and PV reductions**

			2017 Weather-Adjustments (2)			Annual Growth Rates (percents) (3)					5-yr avg	5-yr avg	5-yr avg
State	PSA	Zone (1)	for 50/50	for 90/10	for 95/5	2018	2019	2020	2021	2022	'18 to '22	'23 to '27	'28 to '32
RI	Blackstone Valley	RI	102.1%	112.1%	114.9%	-1.0	-0.9	-0.7	-0.4	-0.2	-0.7	0.2	0.2
RI	Newport	RI	102.1%	112.1%	114.9%	-1.2	-1.1	-0.9	-0.6	-0.4	-0.8	0.1	0.1
RI	Providence	RI	102.1%	112.1%	114.9%	-1.1	-1.0	-0.8	-0.6	-0.3	-0.8	0.1	0.2
RI	Western Narraganset	RI	102.1%	112.1%	114.9%	-0.4	-0.4	-0.2	0.0	0.2	-0.2	0.5	0.4

(1) Zones refer to ISO-NE designations

(2) These first year weather-adjustment values can be applied to actual MW readings for current summer peaks to determine what the weather-adjusted value is for any of the three weather scenarios.

(3) These annual growth percents can be applied to the current summer peaks to determine what the growth for each area is.

Appendix C: Historical Peak Days and Hours

year	ri	dt_ri	hr_ri
2003	1,670.3	8/22/2003	15
2004	1,628.0	8/30/2004	15
2005	1,804.5	8/5/2005	15
2006	1,985.2	8/2/2006	15
2007	1,777.3	8/3/2007	15
2008	1,823.6	6/10/2008	15
2009	1,713.2	8/18/2009	15
2010	1,872.0	7/6/2010	15
2011	1,974.1	7/22/2011	16
2012	1,892.2	7/18/2012	15
2013	1,965.4	7/19/2013	15
2014	1,652.9	9/2/2014	16
2015	1,737.6	7/20/2015	15
2016	1,802.9	8/12/2016	16
2017	1,688.2	7/20/2017	16

Year	Peak before DERs (MW)	Peak after DERs (MW)	EE DER (MW)	PV DER (MW)	Energy bef. DERs (GWh)	Energy aft. DERs (GWh)	Weather - weighted temp-humidity	Economics - Households Indexed 100=2017
2004	1,649.3	1,628.0	21.3	-	8,500.7	8,413.5	78.5	95.4
2005	1,834.8	1,804.5	30.3	-	8,426.6	8,276.5	83.1	95.2
2006	2,026.2	1,985.2	41.0	-	8,476.0	8,253.3	85.9	95.2
2007	1,828.1	1,777.3	50.8	-	8,642.3	8,347.9	80.9	95.4
2008	1,884.8	1,823.6	61.2	-	8,666.8	8,306.3	82.9	95.8
2009	1,789.8	1,713.2	76.6	-	8,602.9	8,166.4	80.3	95.9
2010	1,960.9	1,872.0	88.9	-	8,617.1	8,094.3	84.5	96.0
2011	2,076.0	1,974.1	101.6	0.2	8,734.5	8,116.3	84.8	96.6
2012	2,013.5	1,892.2	120.9	0.4	8,937.1	8,202.2	83.5	97.6
2013	2,115.8	1,965.4	147.9	2.5	9,055.6	8,164.5	84.7	98.5
2014	1,843.1	1,652.9	186.6	3.6	9,221.3	8,089.3	80.4	99.2
2015	1,962.2	1,737.6	219.9	4.8	9,305.3	7,907.4	80.4	99.6
2016	2,060.7	1,802.9	250.4	7.4	9,464.1	7,822.1	82.6	99.7
2017	1,983.2	1,688.2	278.9	16.1	9,747.1	7,846.7	81.7	100.3
2018			309.6	24.8	9,950.1	7,779.1		100.9
2019			340.1	32.2	10,183.2	7,746.0		101.5
2020			369.2	38.9	10,417.1	7,723.8		102.2
2021			395.2	42.0	10,605.6	7,678.4		102.8
2022			419.2	44.4	10,840.2	7,704.8		103.4
2023			441.2	46.7	11,068.1	7,744.2		104.0
2024			460.2	49.0	11,304.8	7,809.6		104.7
2025			477.2	51.2	11,524.2	7,875.9		105.4
2026			492.2	53.4	11,722.9	7,937.4		106.0
2027			507.2	55.6	11,963.1	8,047.7		106.7
2028			522.2	57.7	12,227.9	8,182.3		107.3
2029			537.2	59.9	12,417.5	8,242.5		107.9
2030			552.2	62.1	12,625.3	8,320.6		108.5
2031			567.2	64.2	12,824.0	8,389.4		109.0
2032			582.2	66.4	12,995.7	8,430.7		109.5

RHODE ISLAND SUMMER Independent 50/50 Peaks (MW) (before & after DERs)

	------------- SYSTEM PEAK (50/50) -------------			---- DER REDUCTIONS --		EE % of	PV % of
Calendar Year	Reconstituted (before reductions)	Final Forecast w/ EE Reduction only	Final Forecast (after all reductions)	EE Reduction Forecast	PV Reduction Forecast	Reconstituted Deliveries	'Reconstituted' Deliveries
2003	1,813	1,803	**1,803**	9	0	0.5%	0.0%
2004	1,860	1,839	**1,839**	21	0	1.1%	0.0%
2005	1,802	1,772	**1,772**	30	0	1.7%	0.0%
2006	1,844	1,803	**1,803**	41	0	2.2%	0.0%
2007	1,902	1,852	**1,852**	51	0	2.7%	0.0%
2008	1,878	1,817	**1,817**	61	0	3.3%	0.0%
2009	1,893	1,816	**1,816**	77	0	4.0%	0.0%
2010	1,887	1,798	**1,798**	89	0	4.7%	0.0%
2011	1,919	1,818	**1,817**	102	0	5.3%	0.0%
2012	1,944	1,823	**1,822**	121	0	6.2%	0.0%
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