Kansas City Power and Light (KCP&L) Clean Charge Network

Phase 2 Analysis and Valuation of PEV Adoption

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Technical Update, July 2018

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

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ABSTRACT

Plug-in electric vehicles (PEVs) are increasingly being adopted by customers throughout the United States. It is anticipated that the prevalence of PEVs will continue to increase, as will their energy demands on the electric grid. These vehicles will be routinely charged in a residential, workplace, or commercial setting. For utilities, this potentially represents a challenge to both traditional load growth planning and load management. Furthermore, the capability of fully electric vehicles is evolving, with greater affordability and improved performance, in particular pushing electric driving range beyond 200 miles at a price of around $35,000. This evolution is also being seen on the medium- and heavy-duty sides of the market, specifically in electric buses. Many segments of transportation electrification are therefore moving toward higher levels of direct current (DC) charging power, from the current 50 to 125 kilowatts (kW) to future levels exceeding 400 kW per charging port.

In 2016, the Electric Power Research Institute (EPRI) completed a preliminary scoping analysis of the effects of transportation electrification in the Kansas City Power & Light (KCP&L) service territory. This report presents the results of the Phase 2 analysis, which focused on analyzing and valuing PEV adoption in the context of KCP&L's Clean Charge Network, which consists of over 1,000 electric vehicle charging stations, more than any city in the United States. The report briefly discusses PEV adoption scenarios nationally and in the Great Plains Energy Service (GPES) territory, which includes KCP&L and KCP&L Greater Missouri Operations Company (GMO), followed by a discussion of PEV charging technology trends and challenges, and the environmental impacts of PEV adoption. The report then provides a detailed analysis of the impact of transportation electrification on the GPES electric system and ratepayer impacts of electric vehicle adoption based on simulations of increased electric vehicle adoption stimulated by the implementation of the Clean Charge Network.

Keywords

Plug-in electric vehicles (PEVs)
PEV charging
Electric vehicle supply equipment (EVSE)
PEV load shapes
Ratepayer impact measure (RIM)

EXECUTIVE SUMMARY

In 2016, the Electric Power Research Institute (EPRI) completed a preliminary scoping analysis of the effects of transportation electrification in the Kansas City Power & Light (KCP&L) service territory. This report presents the results of the Phase 2 analysis, which focused on analyzing and valuing plug-in electric vehicle (PEV) adoption in the context of KCP&L's Clean Charge Network, which consists of over 1,000 electric vehicle charging stations. The analysis consists of five sections that describe PEV adoption scenarios both nationally and in the Great Plains Energy Services (GPES) service territory; PEV charging technology trends and challenges; the environmental impacts of PEV adoption; the impact of transportation electrification on the GPES electrical systems; and the ratepayer impacts of electric vehicle adoption. The analysis used the results of the Phase 1 project, existing research, and model simulations.

A summary of the findings from the Phase 2 study for each topic analyzed includes:

PEV Adoption Scenarios

Over the past eight years, more than 800,000 PEVs have been sold in the United States. This includes both plug-in hybrid electric vehicles (PHEVs) as well as fully electric battery electric vehicles (BEVs) with a wide range of prices and travel range. Looking ahead, the PEV market is expected to continue to expand and with it the demand for PEV charging options in a variety of locations: at home, in public, and at work locations. Based on EPRI's current projection for sales in the GPES service territories, PEV sales are expected to accelerate. Sales were projected over time using estimates for three potential levels of PEV adoption: low, medium, and high. There is a wide range in the number of PEVs projected to be in service in the GPES service territories in 2025 between the Low, Medium and High Adoption scenarios, with the Low scenario projecting approximately 6,500 PEVs, the Medium scenario projecting approximately 35,000 PEVs, and the High scenario projecting approximately 85,000 PEVs.

PEV Charging Technology Trends and Challenges

Advances in charging technologies include wireless charging, vehicle-to-grid and vehicle-to-home charging, and higher-capacity charging. Vehicle-to-grid, vehicle-to-home, and higher-capacity charging are still primarily in the development and demonstration stage, although there has been some deployment of higher-capacity charging. Electric vehicle supply equipment (EVSE) network communications are advancing, including the development of PEV charge network protocols, consumer charge network roaming, and several charge management methods. As the industry trend toward PEVs with larger batteries and increased range continues, EV driver charge patterns will shift from "top off" to "long dwell time" charging. This will result in a reduced need for public infrastructure, but create an increasing need for charging availability at long dwell time locations, home, workplace, and multi-family dwelling units. Home charging challenges include electric access at home charging locations, power capacities, and costs. Multi-family dwellings and workplace charging stations face similar challenges.

Environmental Impacts of PEV Adoption

EPRI's analysis indicated that transportation electrification would result in modest but measurable improvements in air quality in the Kansas City area. The analysis also showed that although PEVs have lower life cycle greenhouse gas emissions than most conventional vehicles throughout the country, the benefits are lower in the more coal-intensive Midwest. However, the recent analysis shows that PEV emissions in the Southwest Power Pool (SPP) North region are now equivalent to a 46-miles per gallon (MPG) conventional vehicle, an improvement of 10 MPG in 5 years. EPRI also analyzed the effect of greenhouse gas emissions for transportation electrification with KCP&L and Greater Missouri Operations Company (GMO) generation sourced electricity. The results indicate that a PEV charged from the GPES grid in 2018 will have greenhouse gas emissions higher than the most efficient hybrid vehicle available, but will be lower than most non-hybrid vehicles. The analysis also indicated that greenhouse gas emissions from electric transportation will reduce over time as the electric generation in the KCP&L and GMO service areas shifts towards lower-emitting sources.

Electric Grid Impacts of PEV Adoption

This section provides EPRI's initial assessment of the potential effects of increasing transportation electrification on the GPES electrical systems. The load shape for charging PEVs under a variety of different assumptions was estimated. If charging is available only at home, the unmanaged PEV charging load ends up being concentrated in the early evening hours as drivers return home from work. This load is highly coincident with existing GPES generation and residential customer peak load periods. This system peak coincidence is reduced significantly if charging is available at all locations, with much of the load moved to work and community locations. For managed PEV charging, the evening peak period is significantly reduced as the majority of home charging moves to after midnight. The work and community charging loads are not modified, so some load is still present during the afternoon peak, but this could be separately managed. Options for managing charging load include time-of-use (TOU) rates, real-time rates, demand response, and active charge management.

The analysis of generation and transmission level system impacts suggests that the GPES bulk power system can support a significant level of PEV adoption and that PEV charging will have the greatest impact during the late afternoon system peak load hours. The analysis shows that with managed home charging, the peak capacity needed is less than 40% of what might be needed in the case of unmanaged charging. With managed home charging, the GPES system capacity needed for 175,000 PEVs in 2035 (medium adoption scenario) is projected to be about 92 MW or 1.4% of the current GPES 6,400 MW generating capacity. Depending on how system load and PEV charging changes over time, there may be unexpected impacts during peak and non-peak periods. However, these grid impacts can be further mitigated by adopting additional charge management techniques.

In the Phase 1 study[1], EPRI's analysis of the distribution system found that the GPES commercial distribution grid has sufficient capacity available to support a large number of PEVs. In this analysis, EPRI found that the Clean Charge Network (CCN) workplace charging patterns were consistent with the EPRI "work" profile and complementary to the system and commercial customer load profiles. The CCN retail/public venue charging patterns were also found to be consistent with the EPRI "community" profile, and identifies some small potential contribution to system peak during the 4:00 - 6:00 PM hours. As with the Phase 1 study, EPRI would not expect any significant loading issues on commercial distribution feeders resulting from workplace or public charging in the near future.

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[1] The Phase I study results were provided to KCP&L but were not published.

This study provided a more in-depth analysis of the localized impact PEV adoption could have on the residential neighborhood distribution grid. Across all jurisdictions, the average installed transformer capacity per residential customer is 13 kVA. With the average residential demand at approximately 8 kVA, adding a single PEV with a 6.6 kW on-board charger could have a significant impact on the customer's service and local distribution transformer. The analysis used EPRI's Hotspotter tool to estimate how many transformers may be overloaded using the number of PEVs anticipated to be present in 2025 under the Medium and Low Adoption scenarios. The analysis predicts 110 overloads or 0.08% of residential transformers for unmanaged charging under the Medium Adoption scenario. Managed home charging significantly reduced the early evening overloads, but increased the overloads occurring after midnight, resulting in a net reduction in projected overloads of approximately 33%. Overall, these results indicate that, in the near term, the impacts of PEV adoption on the residential distribution grid will be modest and manageable.

These Hotspotter results are a starting point to understanding the localized grid impacts of residential PEV charging. More detailed data and analysis, including individual transformer loading, would be needed to understand the impact for individual transformers. Further analysis could assess the potential for other charge management techniques to reduce the quantity of potential residential transformer overloads.

This analysis finds that a significant number of PEV can be supported on the GPES system with minimal grid impacts for the foreseeable future, but suggests that further study may be warranted to better understand the charging behavior of residential customers to better predict how and to what level PEV charging can be actively managed. A better understanding of how PEV charging changes over time would improve the utility's ability to predict system impacts, particularly as PEV adoption is expected to grow over time.

Ratepayer Impacts of PEV Adoption

EPRI conducted simulations of increased electric vehicle adoption stimulated by the implementation of the Clean Charge Network. The construction of the CCN reduces range anxiety by providing drivers access to readily accessible public charging stations. While construction of the CCN will facilitate increased PEV adoption, the majority of PEV charging will occur at home and workplace locations, not at the CCN stations. This analysis shows that there is a net positive benefit to all utility customers from utility rate-based charging infrastructure. The key success factor is vehicle adoption. EPRI tested the medium vehicle adoption scenario for each GPES service area and found that over the 10-year analysis period, the CCN investment has a ratepayer impact measure of 2.35 and produces over $20 million in present value net benefits for all customers. A 75% PEV adoption sensitivity analysis determined that if 75% of the predicted PEV adoption impact is realized, the CCN investment will still achieve a ratepayer impact measure of 1.74 and produce over $11 million in present value net benefits for all customers.

LIST OF ABBREVIATIONS

AC	alternating current
AEO	Annual Energy Outlook
AMI	automated metering infrastructure
BEVs	battery electric vehicles
CCN	Clean Charge Network
DC	direct current
DOE	Department of Energy
EIA	Energy Information Administration
EVSE	electric vehicle supply equipment
FERC	Federal Energy Regulatory Commission
g/mi	grams per mile
gge	gasoline gallon equivalent
GMO	Greater Missouri Operations Company
GPES	Great Plains Energy Services
ICE	internal combustion engine
IEEE	Institute of Electrical and Electronic Engineers
ISO	Independent System Operator
kVA	kilovolt-amp
kW	kilowatt
LMP	locational marginal prices
MDU	Multi-Family Dwelling Unit
MPG	miles per gallon
NREL	National Renewable Energy Laboratory
OCA	Open Charge Alliance
OCPP	Open Charge Point Protocol
OEMs	original equipment manufacturers
OVGIP	Open Vehicle Grid Integration Platform
PEVs	plug-in electric vehicles
PG&E	Pacific Gas & Electric
PHEVs	plug-in hybrid electric vehicles
RB	rate-based

RIM	ratepayer impact measure
RTO	Regional Transmission Organization
SAE	Society of Automotive Engineers
SPP	Southwest Power Pool
TOU	time-of-use
UCLA	University of California, Los Angeles
UCS	Union of Concerned Scientists
V2G	vehicle-to-grid
V2H	vehicle-to-home
VMT	vehicle miles traveled
Wh	Watthour

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1 INTRODUCTION

Transportation is the last significant sector of the economy to be electrified. Compared to other alternative fuels, electricity is abundant and ubiquitous. In addition, transportation electrification infrastructure typically can be built economically, because it leverages the existing electrical system and can be installed incrementally as needed. Finally, transportation electrification currently provides comparatively much lower operating costs at about $1 per gasoline gallon equivalent (gge).

Throughout the United States, utility customers are experiencing the environmental and economic benefits of transportation electrification, including:

- More than 800,000 light-duty PEVs on the road in the United States (through February 2018), with significant market penetration in key metropolitan markets in California, Georgia, Oregon, Washington, Texas, and several Northeastern states.
- Current and future deployment of U.S. charging infrastructure totaling approximately $2.5 billion.
- Port electrification projects in Georgia (Savannah) and California (Long Beach, San Diego and Los Angeles).
- Electrification of warehouse forklifts.
- Electrification of airport ground support equipment.
- Electrification of medium-duty delivery vehicle fleets.
- Electrification of municipal transit bus fleets.

The utility industry is facing the transformative challenge of integrating a wave of novel end-use technologies at customer premises—including electric vehicles, renewable generation, energy storage, and energy management control systems. While these technologies may enable customers to reduce or shift their grid-supplied energy usage for economic benefit, their dependence on the electric grid for reliability and transactive value remains.

It is anticipated that the prevalence of PEVs will continue to increase as will their energy demands on the electric grid. Automotive original equipment manufacturers (OEMs) have announced the launch of dozens of new PEV models through the end of 2023. In other words, by 2023, the automotive industry has announced nearly 100 individual plug-in electric vehicles that will be for sale in dealerships across the country, a third of which will likely be SUVs or crossovers.

These vehicles will be routinely charged in a residential, workplace, or commercial setting. For utilities, this potentially represents a challenge to both traditional load growth planning and load management. Furthermore, the capability of fully electric vehicles is evolving, with greater affordability and improved performance in particular, pushing the electric driving range beyond 200 miles at a price of around $35,000. This evolution is also being seen on the medium- and heavy-duty sides of the market, specifically in electric buses. Many segments of transportation electrification are therefore moving toward higher levels of direct current (DC) charging power, from the current 50 to 125 kilowatts (kW), to future levels exceeding 400 kW per charging port.

Utilities are serving as the trusted PEV energy advisor for their customers, advising them on issues including electric vehicle options, rates, total cost of ownership, environmental impact, charging station options, and providing tools and charging support, up to and including utility-owned and operated charging infrastructure.

2
PEV ADOPTION SCENARIOS

Recent Sales Trends for PEVs

Over the past eight years, more than 821,462 PEVs have been sold in the United States. This includes both plug-in hybrid electric vehicles (PHEVs) as well as fully electric battery electric vehicles (BEVs) with a wide range of prices and travel range. Looking ahead, the PEV market is expected to continue to expand and with it the demand for PEV charging options in a variety of locations: at home, in public, and at work locations.

National Trends

The cumulative number of PEVs sold in the United States as of the end of February 2018 is shown in Figure 2-1. The breakdown of PEV models is shown in Figure 2-2.

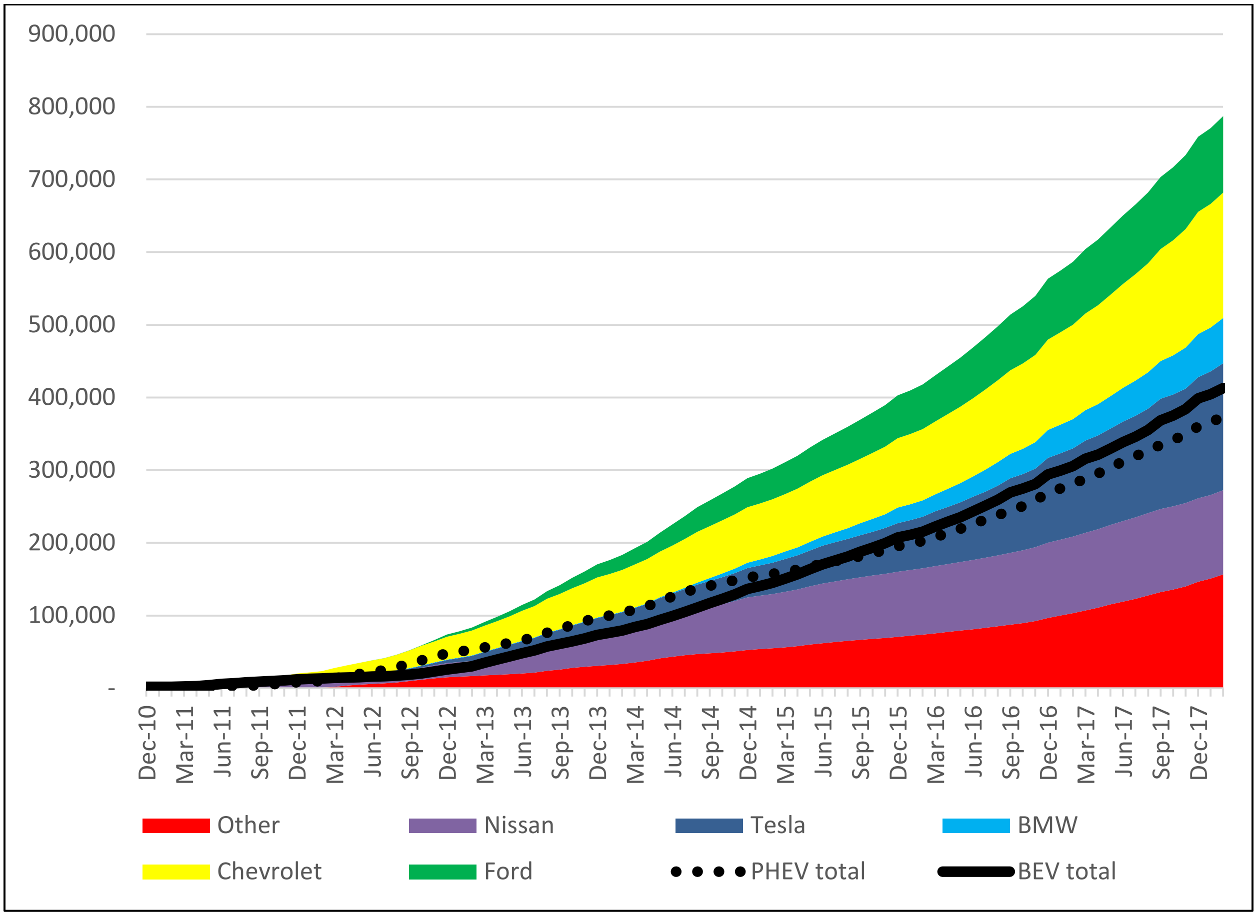

Figure 2-1
Nationwide annual cumulative PEV sales through February 2018

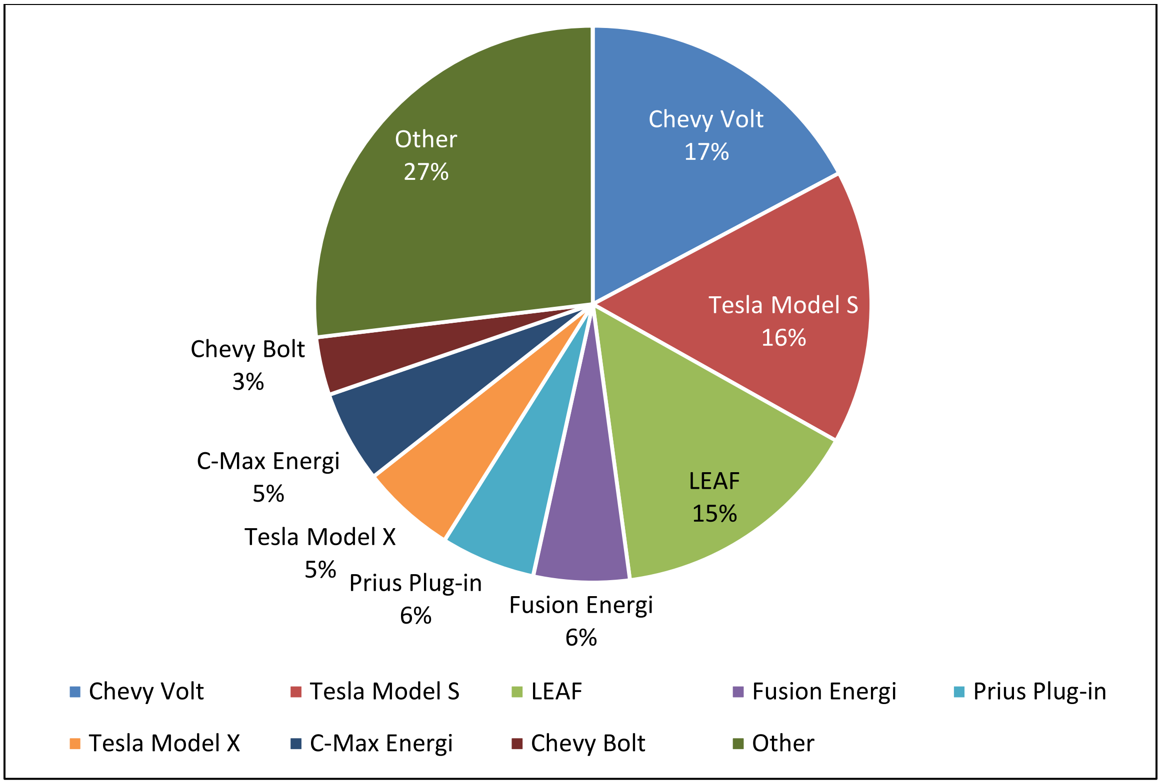

Figure 2-2
Nationwide cumulative PEV sales through February 2018 broken down by vehicle model

The largest PEV sales categories are the Chevrolet Volt, Tesla Model S, and Nissan Leaf. Looking forward, it is expected that PEV sales will move toward larger battery models with longer ranges. It is also expected that the price of these longer-range PEVs will decrease in the future.

GPES PEV Adoption Trends

Great Plains Energy Services (GPES) has two subsidiaries: KCP&L and KCP&L Greater Missouri Operations Company (GMO). Similar to national trends in the GPES service territories, the PEV with the largest cumulative sales is the Volt with 26% of the total sales, followed by the Tesla Model S with 18% of sales, the Nissan LEAF with 13% of sales, and the Ford C Max Energi and Ford Fusion Energi with a combined share of 17%. The remainder of sales represent less of the total share, likely due to limited availability of many PEVs in Kansas and Missouri (see Figure 2-3).

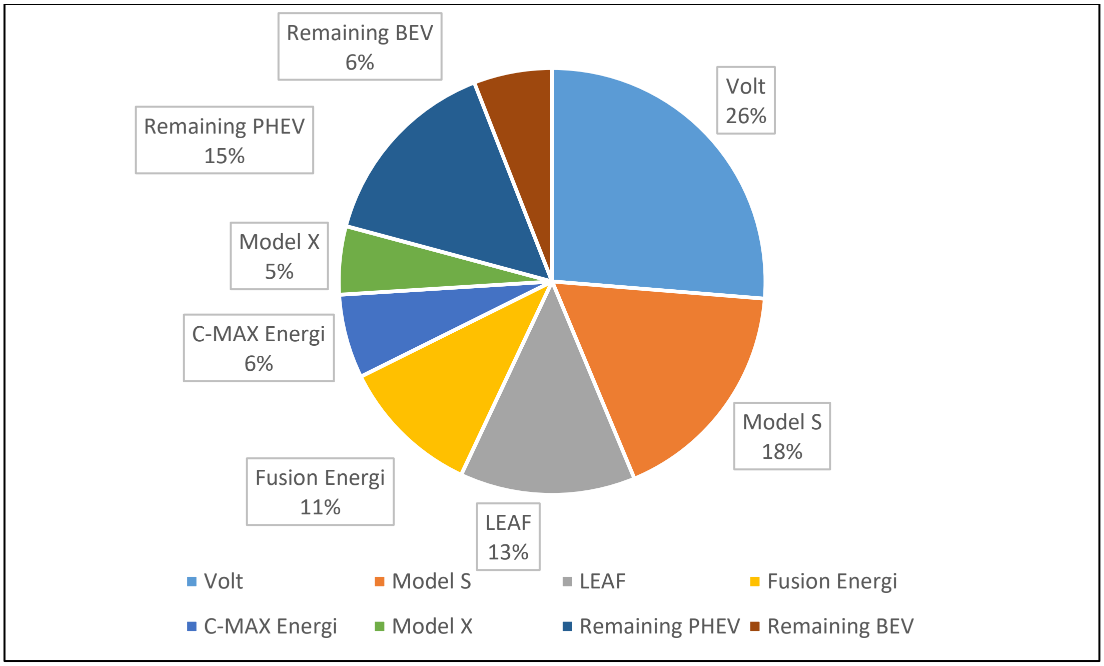

Figure 2-3
Cumulative Sales for the GPES territories broken down by vehicle type (as of February 2018)

Sales trends in the GPES territories (Figure 2-4) show cumulative sales numbers from January 2011 through February 2018 of 2,454 PEV sales.

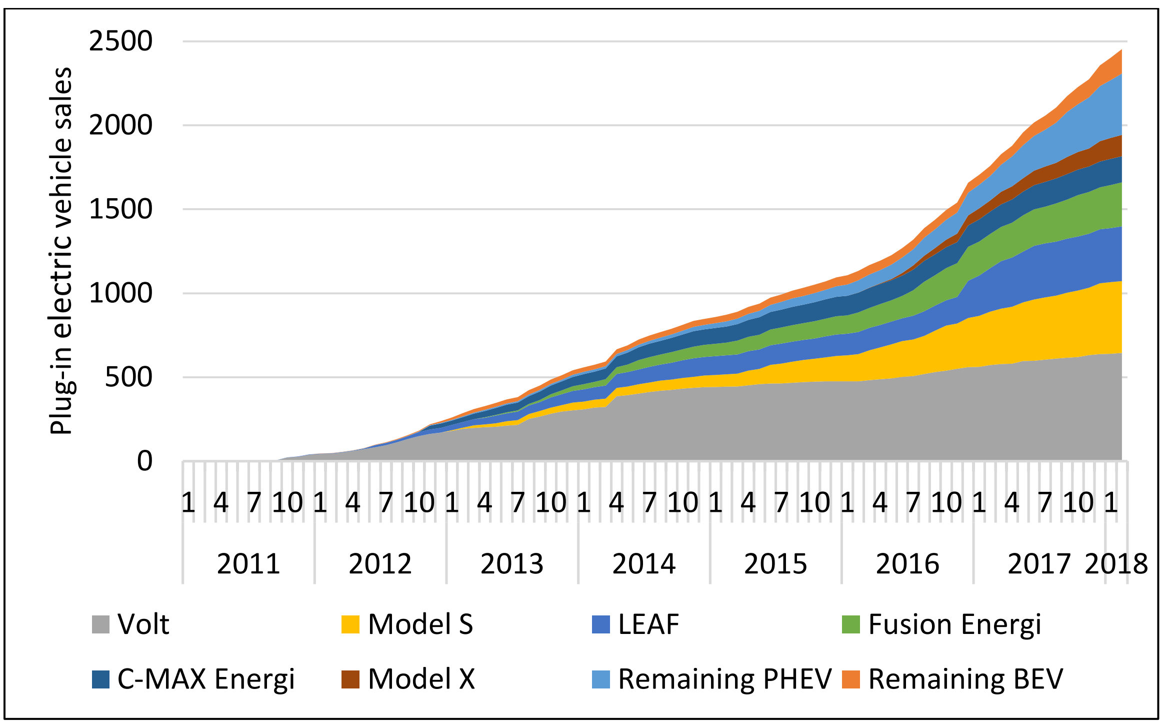

Figure 2-4
Cumulative sales over time in GPES service territories broken down by vehicle type (January 2011 - February 2018)

Figure 2-5 shows how the total PEV sales were divided up between the territories of the different GPES operating companies. The share of sales for each operating company was determined by using data provided by GPES on which ZIP codes were included in each operating company to estimate the fraction of each county within the service territory. This calculation used data on total vehicles by county and ZIP, not just PEVs, to eliminate biases from short-term concentrations of PEVs, which are still relatively rare. It should be noted that the total PEVs in Kansas and Missouri is slightly higher than the cumulative new vehicle sales, indicating that used vehicles are entering the state from other markets. This could be due to importation of PEVs that are not currently available in the area or imports from areas with state or local new PEV purchase incentives (which would depress the used PEV market).

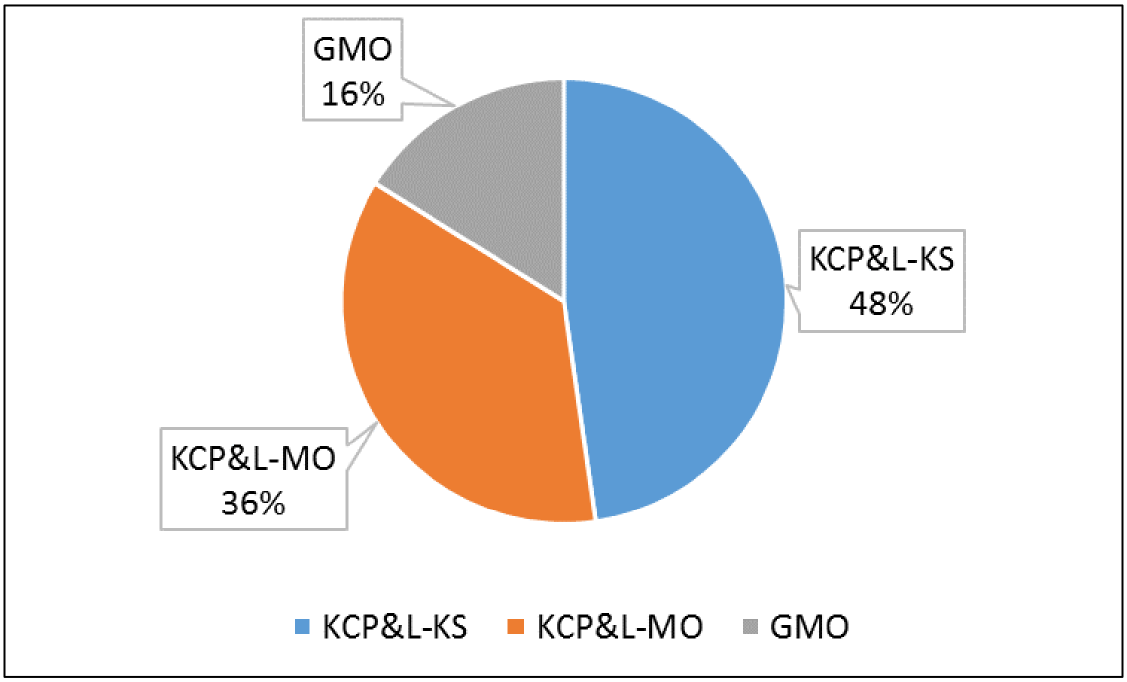

Figure 2-5
Allocation of PEV sales in GPES operating company territories

Projections of PEV Adoption

PEV sales are expected to accelerate according to EPRI's current projection for sales in the GPES service territories (a summary of EPRI's Electric Vehicle Projection tool is presented here; for more details on the projection methodology please see EPRI report 3002011613, *Plug-in Electric Vehicle Market Projections: Scenarios and Impacts*) [1]. Projections were created for each operating company.

For this study, the starting point for the projections is the actual 2014 PEV registrations in each service territory prior to the construction of KCP&L's Clean Charge Network, which consists of over 1,000 electric vehicle charging stations, more than any city in the United States. Sales were then projected over time using estimates for three potential levels of PEV adoption: low, medium, and high. These scenarios help provide guidelines for what PEV adoption numbers may look like depending on different adoption rates. A slightly different percentage of each vehicle type was used for each year of each scenario to reflect a shift to larger battery vehicles in the future. In total, the tool generates projections of new vehicle sales, vehicle population, vehicle miles traveled (VMT), amount of electrified VMT, liquid fuel consumption (gasoline and diesel), electricity consumption, and greenhouse gas emissions.

The three vehicle adoption projection scenarios are defined below. They are based on three data sources: recent PEV registration data for 2010-2014 (which EPRI has at the county level), a near-term national PEV sales estimate created by EPRI for 2015 through 2018, and other external publicly available forecasts. The full set of external forecasts is shown in Figure 2-6, and each scenario is based on a different mix of these forecasts.

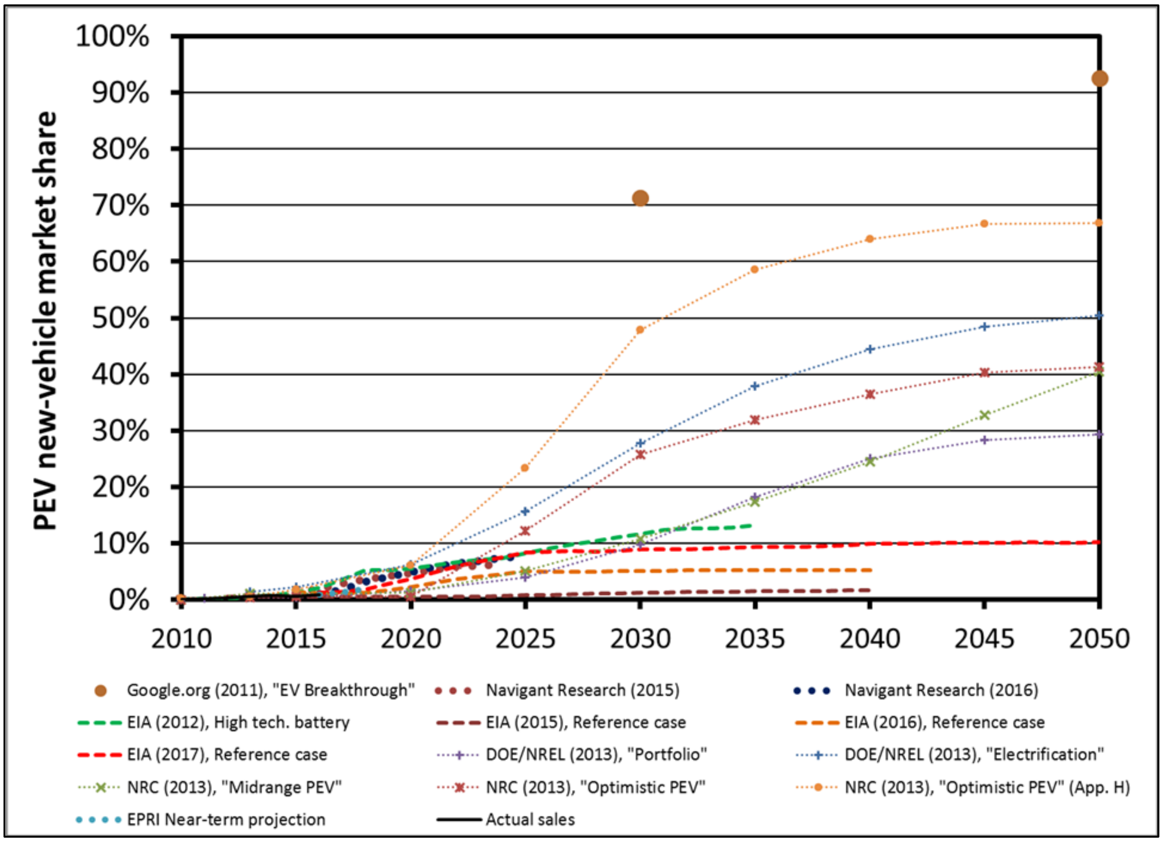

Figure 2-6
External forecasts used as sources for sales projections

The first step for creating the scenarios was creating "proxy" scenarios based on the following sources:

- ***Low Adoption Proxy:*** This scenario was based on the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2015 [2]. This version of AEO uses a vehicle choice model and assumptions that are generally unfavorable toward PEVs. In fact, the actual PEV market shares in 2013 and 2014 were about 25% higher than the AEO 2015 Reference case, and the 2015 sales are expected to be approximately 75% higher than the AEO-predicted sales. In light of this, the proxy Low Adoption scenario was set as the AEO Reference case multiplied by 1.5 (50% higher). The Low Adoption proxy represents how PEV sales may grow nationally if battery costs remain high, regulations that drive PEV sales are canceled, and incentives are reduced.

- ***Medium Adoption Proxy:*** This scenario was based on the National Research Council's (NRC's) *Transitions to Alternative Vehicles and Fuels* report [3] (the Midrange PEV Scenario) and the "Portfolio scenario" from the infrastructure Expansion report published by National Renewable Energy Laboratory (NREL) on behalf of the U.S. Department of Energy (DOE) [4]. These two estimates were chosen as a proxy for the Medium Adoption scenario from about 2035 onward since other more recent scenarios predict significantly higher PEV sales in 2025. The Medium Adoption scenario *long-term* proxy was determined as a simple year-by-year numerical average of the NREL and NRC estimates.
- ***High Adoption Proxy:*** This scenario is an average of two scenarios that are highly favorable to PEV adoption. It utilizes the "Optimistic PEV" case in Appendix H of the NRC 2013 report [3] and the "Electrification" case of the DOE/NREL (2013) report [4].

Once the proxy scenarios were developed, each of them was realigned to originate from the actual PEV sales rate in 2014 and the Medium Adoption scenario was aligned with the near-term projection through 2018. Navigant Research [5] projects PEV sales in 2018 that are much higher than the EPRI near-term forecast or the AEO 2017 Reference case; for that reason, the early portion of the Navigant estimate was deemed to be optimistic and used to guide the High Adoption scenario in 2018 and 2019. The growth rate of the Navigant scenario slows over 2020 to 2025 and its estimate of PEV market share is close to the AEO 2017 Reference case in 2025. The Medium Adoption scenario was set slightly lower than these two external scenarios in 2025. The Medium Adoption scenario then continues to increase to meet the long-term proxy in 2035. This realignment leads to the national Low, Medium, and High Adoption scenarios, which are illustrated by Figure 2-7.

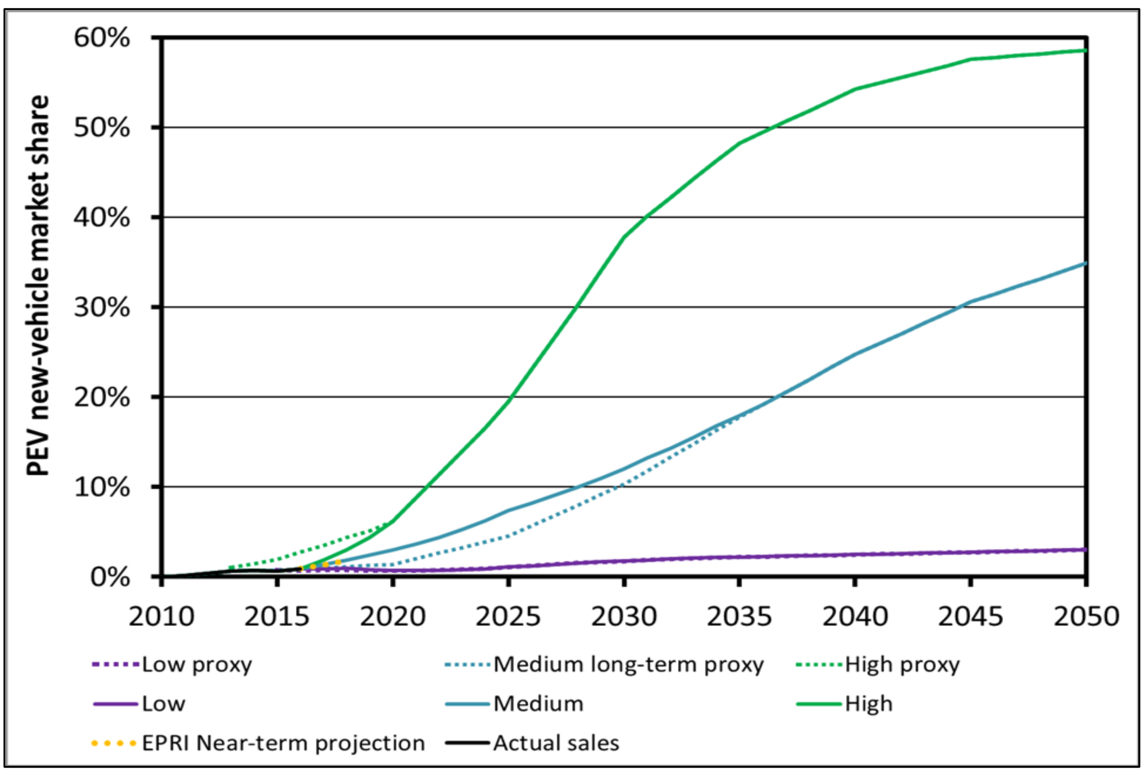

Figure 2-7
National adoption scenarios projections

Figure 2-8 shows how EPRI's national scenario compares with two different versions of the AEO, which is often used as a common reference scenario. In 2015, the AEO projected relatively high battery costs and did not fully account for the effects of California's Zero Emissions Vehicle Mandate, so projected sales were relatively low. This is used as a basis for EPRI's Low Adoption scenario, implicitly assuming that current policies supporting PEVs are reversed. In 2017, the EIA adjusted the input assumptions concerning PEVs, resulting in a much higher share. This results in AEO2017 closely tracking to EPRI's Medium Adoption scenario until about 2025, despite AEO2017 not being used as an input to the scenario. However, the AEO only includes current policies and takes a relatively conservative view of battery costs and customer demand for PEVs, so adoption levels out in 2025.

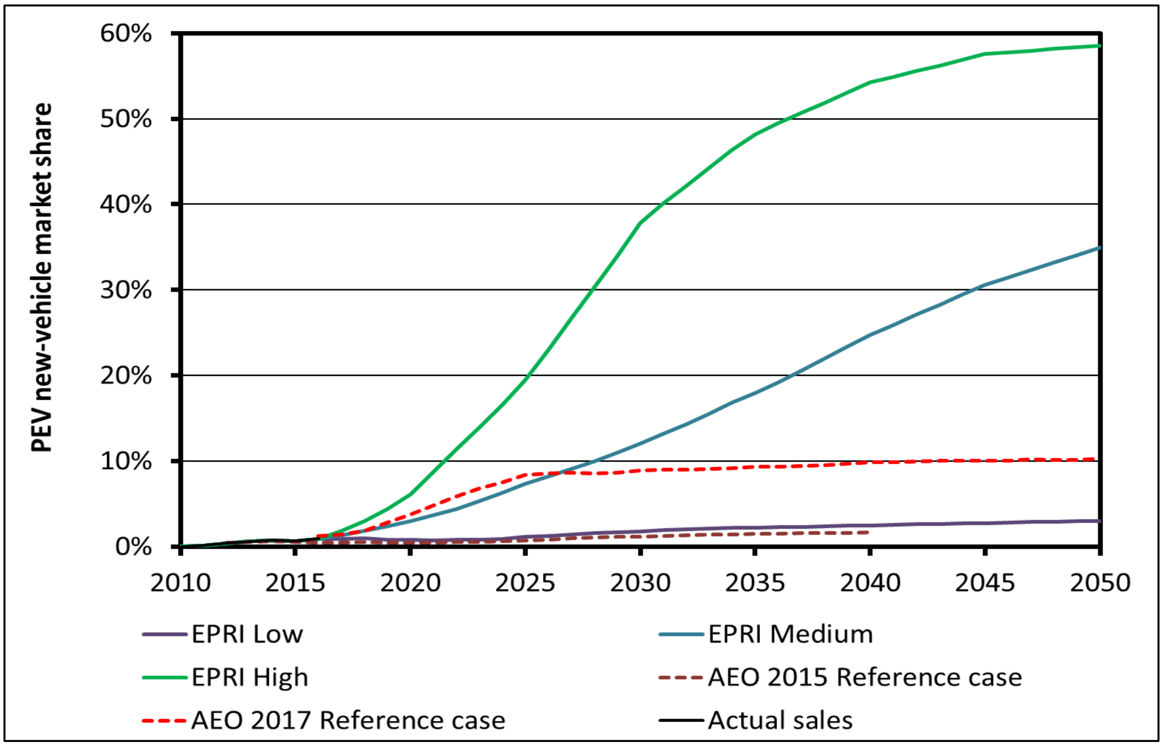

Figure 2-8
National projections compared to AEO2015 and AEO2017

These national projections are scaled to the regional level based on the following factors:

- Actual sales through the end of 2014.
- Whether there are specialized local factors like unusually high incentives.

This methodology was used to project annual sales in each of GPES's operating companies. Figure 2-9 shows the projected annual PEV sales in the GPES service territories through 2025. The three PEV adoption scenarios are shown (Low, Medium and High). There is a wide range between the Low and High adoption scenarios, with the Low scenario showing approximately 1,000 PEVs sold in the GPES service territories in 2025 and the High scenario reaching approximately 22,000 PEVs sold in 2025.

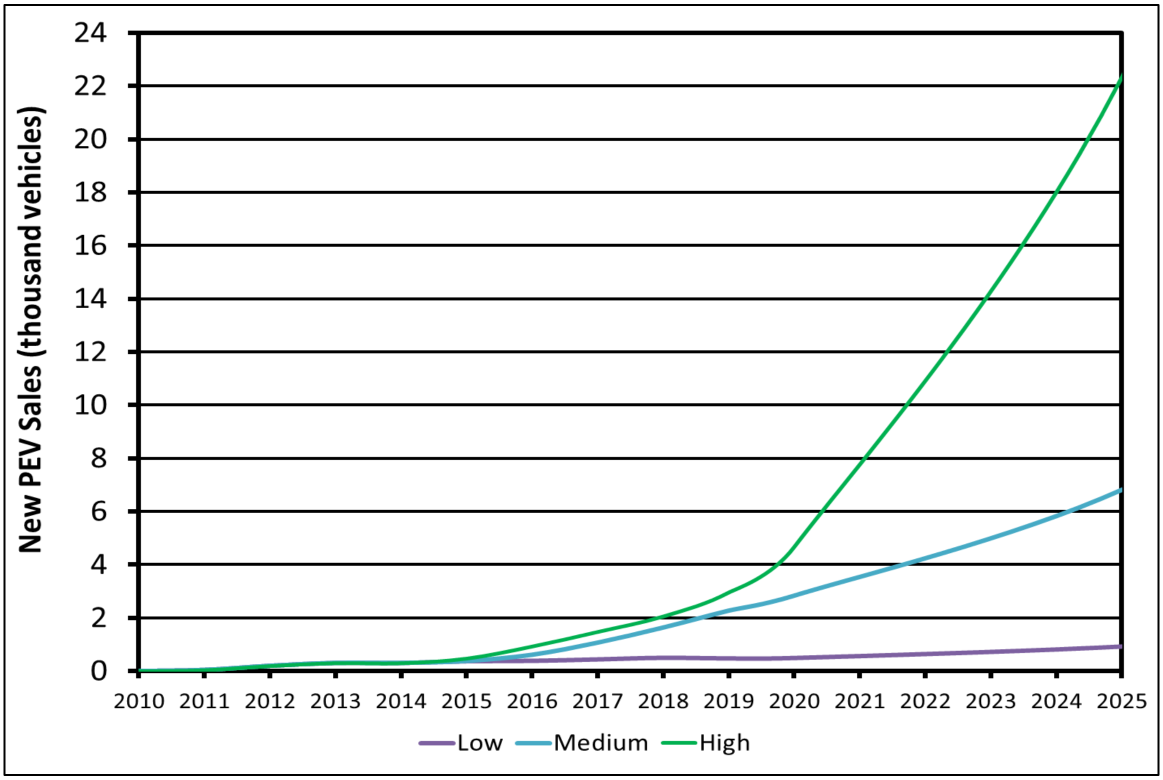

Figure 2-9
GPES annual PEV sales projections

Figure 2-10 shows the projected cumulative number of PEVs in the GPES service territories through 2025. Again, the three PEV adoption scenarios are shown. Cumulative adoption also varies significantly, with approximately 6,500 PEVs in the GPES service territories in 2025 under the Low scenario; 35,000 PEVs under the Medium scenario; and approximately 85,000 PEVs in service under the High scenario in 2025.

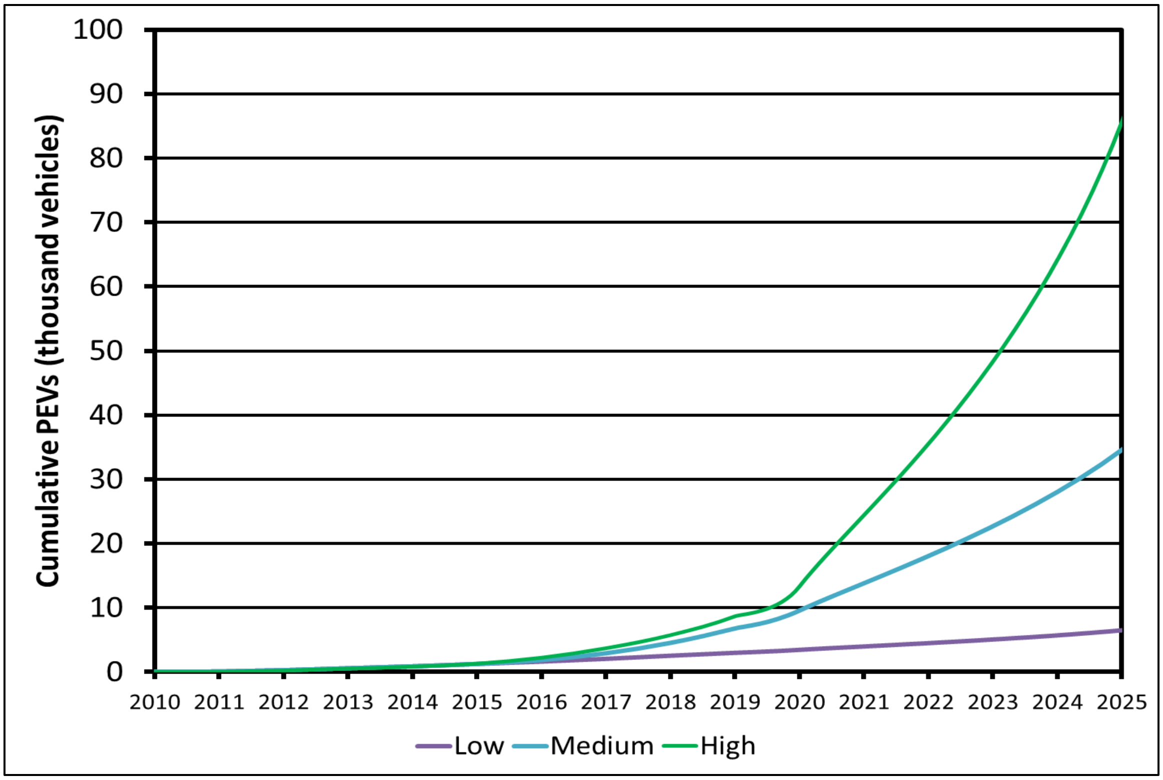

Figure 2-10
GPES cumulative PEV adoption projections

Table 2-1 provides the projected cumulative number of PEVs in the GPES service territories through 2050 for each PEV each adoption scenario. Similar tables for each service territory are contained in Appendices A, B, and C.

Table 2-1
GPES cumulative number of PEVs by adoption scenario projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2014	845	845	845
2015	1,213	1,225	1,323
2016	1,589	1,830	2,246
2017	2,016	2,885	3,718
2018	2,501	4,502	5,761
2019	2,957	6,745	8,692
2020	3,421	9,540	13,318
2021	3,884	13,060	20,877
2022	4,412	17,355	31,749
2023	4,993	22,337	46,041
2024	5,639	28,041	63,828
2025	6,457	34,569	85,660
2026	7,369	42,001	112,630
2027	8,425	50,462	144,805
2028	9,619	60,238	182,548
2029	10,935	71,326	225,994
2030	12,340	84,027	275,721
2031	13,860	98,432	328,906
2032	15,478	114,818	384,859
2033	17,155	133,168	443,345
2034	18,873	153,513	504,249
2035	20,622	175,911	567,188
2036	22,381	200,044	630,574
2037	24,150	225,869	693,961
2038	25,911	253,359	757,097
2039	27,672	282,398	819,658
2040	29,388	312,903	881,359
2041	31,088	344,385	940,837
2042	32,733	376,857	998,102
2043	34,328	410,252	1,053,043
2044	35,884	444,502	1,105,561
2045	37,400	479,514	1,155,762
2046	38,860	514,686	1,202,826
2047	40,287	549,951	1,246,861
2048	41,682	585,208	1,288,054
2049	43,035	620,418	1,326,572
2050	44,384	655,548	1,362,668

3
PEV CHARGING TECHNOLOGY TRENDS AND CHALLENGES

PEV Charging Basics

PEVs can be charged with alternating current (AC) or direct current (DC). While all electric vehicles in the market today have AC charging interfaces, only a limited number offer DC charging interfaces. The types of charging a vehicle can accept is indicated by the connector located on the vehicle (see the following discussion on charging connectors). For AC charging, the actual power electronics that convert AC power to DC power, as is used at the vehicle battery, reside onboard the vehicle. For DC charging, these power electronics are external to the vehicle.

Charging Levels

The Society of Automotive Engineers (SAE) standard that defines charging interfaces also defines a set of charging "levels" to categorize charging. The SAE definitions follow:

- AC Level 1 – charging a vehicle with AC power at 120 Vac and up to 16 Aac using a standard electrical receptacle. This allows a charging at up to 1.92 kW.
- AC Level 2 – charging a vehicle with AC power at 208 Vac to 240 Vac and up to 80 Aac using dedicated supply equipment. This allows charging at up to 19.2 kW.
- AC Level 3 – this level has not been defined.
- DC Level 1 – charging a vehicle with DC power at 50 Vdc to 1000 Vdc and up to 80 Adc. This allows charging at up to 80 kW.
- DC Level 2 – charging a vehicle with DC power at 50 Vdc to 1000 Vdc and up to 400 Adc. This allows charging at up to 400 kW.
- DC Level 3 – this level has not been defined.

The use of these levels has been inconsistent within the industry, with DC fast charging often being incorrectly referred to as "Level 3" charging. Additional confusion has arisen with the availability of DC chargers capable of charging power levels above 100 kW, which are still DC Level 2 chargers but may be referred to as high-power, ultra-fast or extreme-fast chargers. Table 3-1 illustrates typical charging hardware that supports the various charging levels [6].

Table 3-1
PEV charging levels illustrated

	CHARGING LEVEL	CIRCUIT CAPACITY; DESCRIPTION	LOCATION	ONBOARD CHARGER CAPACITY	MILES/HOUR OF CHARGING*	COMMENTS
	AC Level 1	Dedicated 110-120V, 15- or 20-amp circuit; three-prong outlet; cordset comes with car; or charging station.	Home Work Public	1.4kW	4 – 6	Since cars are often parked at work or home for 8+ hours a day, Level 1 may be sufficient.
	AC Level 2 (Low)	Dedicated 240V, 30-amp circuit; charging station.	Home Work Public	3.3kW	8 – 12	Sufficient to charge many electric vehicles with no time limitations.
	AC Level 2 (High)	Dedicated 240V, 40-amp – 100-amp circuit; charging station.	Public Work Home	6.6kW – 19.2kW	16 – 24 for lower power; >60 for higher power	Lower power sufficient to charge most electric vehicles with no time limitations; 40-amp circuit most common for home charging. Higher power sufficient for battery electric vehicles with time limitations; infrequently used for home charging.
	DC Fast	Dedicated 480V – 600V, up to 300-amp circuit; charging station.	Public	30 – 100kW**	150 – 200***	Charges most battery electric vehicles to 80% in 20 minutes.

* Numbers are approximate. Charging time varies based on the car's battery size.
** Most fast-charging stations currently are rated at 50 kW; Tesla Superchargers can be higher; 150 kW is planned and up to 350 kW is in research.
*** Tesla Superchargers are slightly faster.

Charging Capacity

The charging capacity of charging stations and PEVs varies across models and brands. Charging stations and the PEV on-board charging electronics are designed so that the lowest capacity element of the system is not overloaded during charging. Some examples:

- Using an AC Level 2 charger with a maximum capacity of 3.3 kW with a vehicle that has a maximum capacity of 6.6 kW – charging will be limited to a maximum of 3.3 kW.
- Using an AC Level 2 charger with a maximum capacity of 6.6 kW with a vehicle that has a maximum capacity of 3.6 kW – charging will be limited to a maximum of 3.6 kW.
- Using a DC fast charger with a maximum capacity of 150 kW with a vehicle that has a maximum capacity of 50 kW – charging will be limited to a maximum of 50 kW.
- Using a DC fast charger with a maximum capacity of 50 kW with a vehicle that has a maximum capacity of 150 kW – charging will be limited to a maximum of 50 kW.

Note that the actual charging rate during a charge session is always determined by the battery management system that is located onboard the PEV, for both AC and DC charging. Variations in battery temperature and battery state of charge may limit the charging power to a value lower than the allowable maximum.

Charging Connectors

There are four types of connectors (illustrated in Table 3-2) used for light duty electric vehicle charging in North America [6]:

- The SAE J1772 AC connector (used for both AC Level 1 and Level 2 charging).
- The SAE combo connector, sometimes referred to as the combined connector system (CCS) (used for AC level 1, AC level 2 and DC charging).
- The CHAdeMO connector (used for DC charging only).
- The proprietary Tesla connector (used for AC and DC charging).

Table 3-2
Electric vehicle connectors Used in North America

	CONNECTOR DESCRIPTION	CHARGING LEVEL	POWER
	120V cordset with SAE J1772 standard connector comes with all electric vehicles except Tesla. The J1772 connector plugs into the car; the other end plugs into a three-prong outlet.	Level 1	1.4kW
	SAE J1772 standard connector used with charging station.	Level 1 Level 2	3.3kW – 19.2kW
	SAE Combo connector used with American and European cars that are fast-charging capable.	DC Fast Charge	30kW – 100kW
	CHAdeMO connector used with Asian cars that are fast-charging capable.	DC Fast Charge	30kW – 50kW
	Tesla connector used only with Tesla Model S and Model X.	Level 2	10kW – 20kW
		Supercharger	Up to 145kW

Advances in Charging Technology

Wireless Charging

The SAE has been working for several years on a Recommended Practice for wireless charging of light duty vehicles—SAE J2954. The initial output from this work was released in May 2016 in the form of a Technical Information Report that allowed the industry to begin hardware development and field testing of wireless charging systems. The U.S. Department of Energy labs have played an active role in testing and validation of the standards with SAE, particularly Idaho National Lab [7]. In November 2017, SAE released the J2954 Recommended Practice document. Based on press from automakers and wireless hardware manufacturers, it is anticipated that wireless charging systems will begin to appear as an option on production electric vehicles in the late-2018/early-2019 timeframe. For instance, Mercedes-Benz S550e is planning to offer wireless charging in 2018 [8].

No prediction is offered for the rate at which wireless charging might become available on vehicles or in the public charging space. Several observations that inform how deployments might progress follow:

- There is a cost to adding wireless charging to a vehicle. The system requires that a receiving coil be located on the underside of the vehicle and that some form of driver guidance system be provided to allow alignment of the vehicle with the stationary charging pad.
- Automakers will likely offer wireless charging as a cost adder option as is currently typically done with DC fast charging ports. This allows a consumer uninterested in wireless charging to avoid the added cost.
- It is not clear if automakers would offer wireless charging as a package, including the stationary power electronics and transmitting pad along with vehicle wireless charging capability or would simply allow purchasers to choose that the vehicle be wireless charging capable without any off-board hardware.
- Automakers have only loosely defined charging pad location on the vehicle, which may impact how the vehicle would have to park (say back-in or nose-in) to use a wireless charger.
- Automakers are unlikely to offer a vehicle with only a wireless charging interface, as that vehicle would be incompatible with all existing public charging infrastructure.
- Most automaker announcements have come from luxury brand vehicles.
- There are currently no production electric vehicles that are factory equipped with wireless charging capability. Plug-in vehicles on the road today cannot take advantage of a wireless charging system without adding retrofit hardware.
- Wireless charging at a consumer's home site would likely involve use of a surface mounted charging pad, offering a very simple, low cost means of installation.
- Public wireless charging installations, particularly in outdoor spaces where snow removal or other activities prevent a surface mounted stationary charging pad, would require that the charging pad be embedded below the pavement surface. This will likely make wireless charging installations costlier than wired solutions.
- The stationary portion of a wireless charger contains active power electronics and must have a stationary pad for energy transfer. This makes it likely that wireless chargers will have a higher price point than AC electric vehicle supply equipment of equivalent power capacity.

- The customer reaction to safety concerns related to wireless charging is unknown.
- The current standard for wireless charging only addresses power flow from the electric gird to the vehicle. In order to support reverse power flow for vehicle-to-grid operation, an updated wireless charging standard and additional power electronics onboard the vehicle would be required.
- Wireless charging may prove particularly attractive to self-driving (autonomous) vehicle operation, as an electric vehicle could self-charge without the need for human operator intervention.

Vehicle-to-Grid

A potential application of electric vehicles that continues to be explored is "vehicle-to-grid". Vehicle-to-grid, often referred to as V2G, is an application where the battery storage onboard the PEV has the capability to provide energy back to the electric grid. For a device capable of returning energy to the electric grid, there are a number of potential services the device can provide the grid. The value of these services is strongly dependent on the speed of response, energy capacity, and power capacity of the vehicle; and grid conditions at the specific geographic location where the vehicle is connected to the grid. Implementation of V2G requires that the grid condition(s) being supported by V2G be known and communicated to the vehicle in real time so that the vehicle's systems can provide controlled power flow back to the grid as needed.

There are two primary methods to transfer power from the vehicle:

- In AC form using the standard AC charging port.
- In DC form using a DC fast charge port.

In the case of AC, power electronics onboard the vehicle would have to be capable of bi-directional operation, that is, the power electronics could both charge and discharge the vehicle. To date, no automakers have chosen to install bi-directional AC charging hardware on their vehicles, so there are currently no production electric vehicles being sold in the U.S. that can support AC power transfer back to the grid through their standard charge port.

In the case of DC power transfer, power electronics located off-board the vehicle would be needed to couple energy from the vehicle back to the grid, that is, they would also need to be bi-directional. While such hardware has been developed and deployed for various pilots, there are no commercial products that have been widely deployed for consumer use. In addition, automakers have not incorporated the capability to support bi-directional DC chargers in their vehicles for consumer use.

Several pilots have been and are being conducted in the vehicle-to-grid area. Three example pilots include:

- V2G pilot at Los Angeles Air Force Base. A final report is available from Southern California Edison [9]. A detailed description of the equipment and testing is available [10].
- A California Energy Commission-funded effort by UC San Diego and Nuvve [11].
- Vehicle-to-grid school bus demo – Clinton Global Initiative [12].

These and previous pilots have demonstrated the technical feasibility of V2G. There remain technical, systematic, and regulatory hurdles to widespread use of V2G:

- Developing standards, regulatory requirements, and processes for the utility interconnect.
- What impact does non-mobility related grid services have on batteries relative to providing mobility? How will this impact vehicle warranties?
- What are the value-creating use cases that leverage reverse power flow?
- How and what type of control strategy would be used to maximize the grid-connected value of V2G capable vehicles?
- What are the cybersecurity requirements and implications of V2G?
- What is the vehicle cost impact of adding V2G capability? Would a consumer be willing to pay the extra cost?
- What is the value proposition?
  - To the vehicle maker?
  - To the consumer?
  - To the utility?
- Could integration with other distributed resources enhance the value?
- How do you deal with a value proposition that may be very strongly a function of time of day, geographic location, and how/where the vehicle is connected to the grid?
- There is no well-developed market for V2G services on a national basis. How does such a market develop?
- There is a need for a national market for vehicle-to-grid services since automakers don't produce "regional" vehicles.
- The value of grid services is dependent on the availability of devices to provide the service. This means that the value of V2G services for an individual vehicle will decrease over time as the population of vehicles capable of V2G increases.
- Vehicles capable of V2G will have to compete on a cost basis with stationary storage systems and other distributed energy resources.
- A vehicle can only support the grid when it is plugged in. Widespread use of V2G then requires that a sufficient population of vehicles be plugged in at the time V2G is needed by the grid. Thus, charging infrastructure must be plentiful enough to support this connectivity.
- Existing AC charge stations are not safety listed for reverse energy flow.
- A communications system must exist to telemeter grid conditions to vehicles to enable their grid support.
- Wireless charging standards do not support V2G at this time.

Vehicle-to-Home

Like V2G, "vehicle-to-home" or V2H is another potential application for PEV. Here the PEV is used as an off-grid backup energy supply for a home, business, or other local electric load. In this application, the vehicle only provides electricity in isolation from the grid as is currently done with backup generators. Nissan and Mitsubishi have both conducted public demonstrations of V2H systems in Japan, the United States, and Europe, but to date, no automaker has released such hardware for public sale and consumer use. While simpler than V2G from a systems and logistics perspective, which requires additional external inputs (for instance a pricing signal) and additional controls, it appears that automakers have not yet seen a sufficient value proposition to make such systems available. One concern that is common with V2G and V2H is understanding the impact on the vehicle's mobility while providing auxiliary services.

As noted in the discussion on V2G, V2H would have to show itself to be cost competitive with other backup generation sources, such as generators or stationary storage systems.

Higher-Capacity Charging

No industry discussions have occurred related to increasing the AC charging capacity of vehicles, but there are active discussions to increase DC fast charging capabilities to greater than 350 kW to provide a charge duration for larger batteries similar to the time needed for liquid re-fueling of internal combustion vehicles. A detailed discussion of high-power DC fast charging at power levels above 150 kW can be found in a 2017 DOE report [13]. A handful of PEV charging facilities have been deployed that include provision or future 350 kW-level charging.

EVSE Network Communications

PEV Charge Network Protocols

There are currently two groups working on standard protocols for management of electric vehicle charging equipment networks:

- The Open Charge Alliance (OCA) provided an update on their progress at the EPRI Infrastructure Working Council meeting on October 25, 2017 [14]. Version 2.0 of the Open Charge Point Protocol (OCPP) was published in April 2018. OCA now plans to move the protocol into an IEC standard (63110). OCA has indicated that version 2.0 of the protocol will not be backward compatible with previous versions of OCPP.
- The Institute of Electrical and Electronic Engineers (IEEE) also has a standards body working on a charge station management protocol under IEEE P2690 [15]. The P2690 chair provided an update on the working group's activity at the EPRI IWC meeting on June 7, 2017 [16]. The presentation indicated that the working group had been formed, provided a roster and provided information on how to join the effort. It is anticipated that the working group will be developing the protocol throughout 2018.

It is not clear how the industry will deal with the two competing standards when they are completed. Many installations in place today use either proprietary protocols or an earlier version of the OCPP (V1.5 or V1.6) protocol.

Consumer Charge Network Roaming

There have been at least two attempts to establish a clearinghouse that would allow for consumer roaming across charging networks. A group was formed in the 2011 timeframe called Collabortev. This group failed with the bankruptcy of Ecotality, which operated the Blink network. A new group called the ROEV Association [17] was formed in late 2015 and announced at the Los Angeles Auto Show on November 19, 2015. The group has had no public profile and it is unclear if they have made any progress toward enabling an industry-accepted clearinghouse for charging network operators. The news and events section of the ROEV website only includes the press announcement related to formation of the group.

Charge Management Methods

Managed charging can be as simple as charging the vehicle on a set time schedule or by responding to external control signals from a local energy management system or the utility or a combination of time schedule and remote control.

While not a direct control method, time-of-use (TOU) rates can be used to influence consumer charging behavior and could be viewed as a charge management method.

Remote control capabilities can enable a consumer to automatically charge their vehicle when electric rates are lowest and reduce or stop charging when the grid needs to curtail load. It should be noted that many of the benefits of V2G, discussed previously, can be realized through managed charging using only varying time/energy flow to the vehicle. Utilities may benefit from being able to shift EV charging load impacts on their system in time or capacity.

Utility benefits of managed charging include:

- Provides the potential to time shift peak EV demand to avoid adding to the system peak.
- Provides a means of lowering stress or overloads on a localized portion of the electric grid.
- Increased grid utilization and lowers the average cost of energy for all electric consumers.

Challenges of managed charging include:

- For the consumer, these automated operations must be seamless, easy to implement and have minimal or no impact on the primary function of a consumer's vehicle – transportation.
- For the utility, implementing remote control capabilities requires investment in the communications infrastructure and development of control systems and strategies.
- Exposes the vehicle and the grid to cybersecurity threats when remote control and communication is involved.
- The cost of implementing a controlled charging scheme likely must be less than the economic benefit of managed charging. These values and costs can be difficult to assess.
- Generally requires a method for consumers to "opt-out" of a controlled charging event. This may lessen the value of the controlled charging capability.
- Care must be taken to avoid conflicting charging control signals when multiple system elements are intelligent. For example, a vehicle's on-board timer may be set to delay charging to midnight while the charge station that the vehicle is plugged into is set to not allow charging after midnight.

BMW and Pacific Gas & Electric (PG&E) completed a successful pilot of managed charging related to grid services in 2017, parts of which have been extended through 2018 [18]. This project showed the viability of both remote controlled smart charging and influencing consumer behavior with time-of-use rates.

EV On-Board Charge Management

Automakers often include onboard vehicle controls to assist consumers in managing their charging. In addition to phone apps and internet web portals that allow consumers to see their vehicle statistics and start and stop charging remotely, most EVs offer charging controls in the form of a delayed charging timer (where the consumer sets a start time for charging) and charge by departure time (where the consumer tells the vehicle when to be done charging). For a consumer that has a time-of-use electric rate that offers a lower cost of charging at night, delayed charging can be used to ensure that a vehicle waits to start charging at the lower nighttime rate. Charge by departure time can be used as a simple means to limit having a large number of vehicles start charging at a fixed time (such as the time when a lower time-of-use rate takes effect) based on the diversity of vehicle range, battery state of charge and departure time requirements. The Chevrolet Volt offers the ability to set charging price limits where the vehicle can respond to a time-of-use schedule that is remotely communicated to the vehicle. Note that only direct to vehicle control allows smart charging to take the vehicle battery's state of charge into account.

Control through Home or L2 Charge Station

Many charge station manufacturers offer local and remote charging control functions similar to the onboard vehicle system capabilities. These include start of charge timers, phone and web apps that allow for remote start/stop of charging and the ability to accept external control signals to manage charging. These controls can include delay timers, ability to respond to a utility control signal, such as a demand response event, and the ability to adjust the rate of charging from a remote-control signal. One limitation of home L2 charge station control is that the vehicle battery state of charge is not known by the charge station.

OEM and Third-Party Telematics Providers

Most PEVs are equipped with an OEM telematics system – remote communications capability implemented by the vehicle manufacturer via the cellular telephone network. This connectivity offers the potential for direct to vehicle control for managed charging (and is one aspect of EPRI's Open Vehicle-to-Grid Integration Platform project). The cost of the communications system is borne by the consumer, but may be bundled with other services such as remote vehicle-start and roadside service assistance, spreading the system cost across more services. One challenge is that a utility would have to communicate with multiple telematics systems in order to reach multiple brands of vehicles. Since telematics systems connect directly to the vehicle, they have full access to vehicle information such as battery state of charge and driver departure time habits.

Alternatively, third-party telematics providers provide solutions that connect to the vehicle and provide vehicle information via a separate cellular telephone network connection. The cost of the communications system is typically borne by the utility or PEV charge management service providers. This provides a single telematics integration point and eliminates the reliance on the customer maintaining the OEM telematics subscription service.

Management Through a Communications Platform

EPRI has an active project exploring the use of a single server platform that would integrate telematics systems, direct to vehicle communications systems, and direct to charge station communications systems in a seamless fashion from the utility's perspective. Called the Open Vehicle Grid Integration Platform (OVGIP), this is a cloud-based computer service that would allow utility grid state information to be passed to a large number of vehicles through a single communications path from the utility to the platform. The OVGIP would in turn use multiple paths to reach the connected vehicles via a charge station, through telematics or using a hybrid of these signal paths. The OVGIP moves much of the complexity of previously described control paths to a single platform that, in turn, has interfaces to multiple vendor and OEM communications systems where standard or proprietary protocols may be used for communications. In 2018, the goal is to demonstrate 11 different Smart Charging use cases through a single platform. The project focus will then shift to developing and demonstrating two key ways to manage charging: 1) light communications providing minimal information but broadly applicable and with the greatest potential for maximum impact, and 2) a full-blown aggregated DR program highlighting full capabilities of the platform. It is anticipated that customers will be able to sign-up for one of these options later in 2018.

Trends in PEV Charger Location

Range Anxiety

A common theme found in consumer surveys is the need for visible public charging infrastructure to bolster consumer confidence in owning a plug-in electric vehicle. Several recent studies, summarized here, have concluded that the presence of charging infrastructure is critical to advancing plug-in electric vehicle adoption.

The Union of Concerned Scientists and Consumer's Union joined together to conduct a consumer survey in California and the Northeastern U.S. in 2016 [19]. Table 3-3 shows the top five responses to the question "Which of the following are your BIGGEST concerns toward owning a plug-in electric vehicle [20]." For both the eastern U.S. and California, public charging station availability ranked as the first or second greatest concern of consumers.

Table 3-3
Union of Concerned Scientists/Consumers Union survey results

Rank	Reason	Respondents
Northeastern United States		
1	There are too few, if any, public charging stations where I travel	14.45%
2	I don't know enough about PEVs to have concerns	13.68%
3	PEVs are too expensive	12.31%
4	PEVs can't travel far enough on a full charge	11.49%
5	Repair and/or maintenance costs for a PEV could be higher than a gasoline care	9.65%
California		
1	PEVs can't travel far enough on a full charge	17.47%
2	There are too few, if any, public charging stations where I travel	14.91%
3	PEVs are too expensive	12.94%
4	Repair and/or maintenance costs for a PEV could be higher than a gasoline care	10.37%
5	I am unable to charge a PEV at my home or workplace	9.57%

A 2014 University of Vermont/Sandia National Lab survey [21] of U.S. consumers lists six top concerns, as shown in Table 3-4. Having charging available at work or near business ranked as the sixth most important factor in vehicle adoption by consumers.

Table 3-4
University of Vermont/Sandia Lab consumer survey results, factors that increase comfort or concerns when considering a future PHEV purchase

Rank	Reason	Respondents
1	Realizing a PHEV could have significant savings on monthly fuel costs, especially if gasoline prices continue to rise	86.0%
2	Having recharge facilities at home for easy overnight charging	83.1%
3	Getting a tax rebate of $7,500 for purchasing a PHEV	82.3%
4	Having a 10-yr/150,000-mi PHEV battery warranty	80.2%
5	Realizing a PHEV can run on gasoline after the battery is drained, so that range is not limited (compared to a BEV)	77.8%
6	Having charging facilities available at work or near businesses I frequent	71.7%

A literature survey conducted by Argonne National Lab [22] found that "charging availability" was one of the four most prominent policy measures having a positive influence in plug-in electric vehicle market adoption, following purchase rebates, tax credits, and tied with high occupancy vehicle exemptions. The literature survey concluded that "Vehicle charging infrastructure is an important prerequisite for PEV adoption." The Argonne literature review provides an excellent summary of a number of policy study reports and surveys.

M.J. Bradley & Associates issued an independent report [23] in early 2017 looking at potential roles for utilities in the Northeast and Mid-Atlantic states and concluded that "increased availability of charging stations will make electric vehicle ownership more attractive to a broader population and accelerate uptake of the technology."

Vehicle Range Increases

Many of the early plug-in electric vehicles available to consumers prior to 2017 had all-electric ranges under 100 miles. This limitation was primarily due to battery size and weight. As automakers seek to reach a broader range of consumers, battery sizes are being increased to increase vehicle range. Examples are the Chevy Bolt PEV and the Tesla Model 3 that offer greater than 200 miles of range while offering a price point more in line with conventional vehicles. As a point of comparison, the average transactional price of a new car in November 2017 was approximately $35,300 [24]. It is anticipated that this trend will continue with future vehicle introductions.

Charging Infrastructure—the Shift from "Top Off" to "Long Dwell Time" Charging

The National Renewable Energy Lab has published a national analysis of infrastructure requirements for plug-in electric vehicles [25]. The study determined that based on a broad set of factors, for a population of 15 million vehicles in 2030 a non-residential AC charge port to vehicle ratio of 40 ports per 1,000 vehicles (national average) may be adequate to support this level of PEV adoption. This assumed that 88% of vehicle charging occurred at a plug-in electric vehicle's home location. The study noted that there was a strong sensitivity in the required number of chargers to the assumed percentage of home charging, where reducing the home charging assumption to 82% would increase the predicted need for public charging by nearly a factor of two (or closer to 80 ports per 1,000 vehicles).

Another factor that strongly influences predicted charging behavior is the vehicle electric range. Increasing range is expected to lessen the need for public charging. The NREL study reflects this in two ways: a larger population of PHEVs (which generally have a smaller all-electric range) or PEVs with shorter range both drive a need for more public charging infrastructure. Most PHEVs have a range of 50 miles or less and must plug in more often to maximize the number of electric miles driven. As PEVs increase in range capability, the opposite effect is expected – they will be more likely to charge at locations where they are parked for longer periods and use less public charging infrastructure. For longer all-electric ranges, the NREL study identified the need for Intercity fast DC charge locations every 60 to 70 miles along the interstates and intra-city fast DC stations spaced so no car was more than 3 miles from a charge port.

As the industry trend is toward PHEVs and EVs with more range, a reduced need for public infrastructure, but an increasing need for charging availability at long dwell locations is expected to continue. The key long dwell location would be at the vehicle's home parking spot, whether a single-family home, multi-family dwelling unit (MDU) parking lot, or on street parking. Workplace parking is likely to be a key long dwell location for vehicles used for commuting.

Home Charging Challenges

Electric Access at Home Charging Location

While a charge station in the garage of a single-family home might be the ideal format for PEV charging, many Americans do not have access to either fixed parking or AC outlets. A study by Carnegie Mellon [26] estimated that only 56% of vehicles have access to a dedicated parking space, with 47% of these being at an owned residence. They also found that only 38% of households have an outlet available within 20 feet of a parking space.

A second factor noted in the Carnegie Mellon study that represents a long-term impact (although likely many years and potentially decades out) is that to achieve a PEV penetration of greater than 39% of all light duty vehicles, home charging would need to support charging of more than one vehicle. The study noted that this would likely entail the need for electrical upgrades for many homes.

Limitation of Home Level 1 Charging

For those that have access to a dedicated outlet, AC Level 1 charging may be a viable option. A key limitation of Level 1 charging is the power capacity. Table 3-5 shows EPA energy use values [27], [28] per 100 miles of driving for several production vehicles. Note that an estimated value of 46.8 kWh/100 miles (2.1 miles/kWh) is provided for pickup trucks, as there are currently no production pickup trucks in the consumer vehicle market. This table can be compared to Table 3-6, which shows the required time to charge based on miles driven for three classes of vehicles, including pickup trucks. For a compact sedan, even a 60 mile per day range could be supported by a Level 1 charger if the vehicle has at least 11.6 hours per day to charge. For an electric pickup truck, that same 11.6 hours would only support a daily range of 30 miles.

Table 3-5
EPA kilowatt-hours per 100 miles, values for common 2017 PEV models

Model	EPA kWh/100 mi	Miles/kWh
2018 Tesla Model X P100D	39.0	2.6
2018 Tesla Model S P100D	35.0	2.9
2018 Chevy Volt	31.0	3.2
2018 Nissan Leaf	30.0	3.3
2018 BMW i3 (94 A-hr)	29.0	3.4
2018 Chevy Bolt EV	28.0	3.6
2018 Tesla Model 3 LR	26	3.8

Table 3-6
Estimated time to charge using an AC Level 1 charger for varying three vehicle classes based on daily distance driven

	Assumed Distance per Energy (mi/kWh)	Assumed Daily Driving (miles)	Daily Energy Needs (kWh)	Time to Charge using 12 A at 120 V) (hr)
Compact sedan	4	10	2.8	1.9
		20	5.6	3.9
		30	8.3	5.8
		40	11.1	7.7
		50	13.9	9.6
		60	16.7	11.6
Full-size sedan	3	10	3.7	2.6
		20	7.4	5.1
		30	11.1	7.7
		40	14.8	10.3
		50	18.5	12.9
		60	22.2	15.4
Pickup truck	2	10	5.6	3.9
		20	11.1	7.7
		30	16.7	11.6
		40	22.2	15.4
		50	27.8	19.3
		60	33.3	23.1

For low electric range vehicles, such as a PHEV with a 30-mile all-electric range or for a battery electric vehicle driver that has a low number of daily miles driven, Level 1 charging provides a viable charging option. Use of Level 1 charging becomes much less effective for larger vehicles and for drivers that routinely operate their vehicle over longer ranges. Note that as vehicle range capabilities grow, plug-in electric vehicles will become more viable for drivers with long daily driving range habits. It should be noted that it is a requirement of AC Level 1 chargers that the outlet used for their operation be dedicated to that function due to their using the full current capacity of the circuit. Even for homes with garages or outlets in proximity to parking, it may be difficult to find an outlet that is available for dedicated use (meaning no other loads share the outlet's circuit).

Level 2 Home Charging

When Level 1 charging is not sufficient to support a driver's needs, or where a new dedicated outlet would need to be installed to support a Level 1 charger, installation of a Level 2 AC charging interface is an option. For drivers that have access to a fixed parking location that has appropriate access to sufficient AC power, this type of home charging can meet all the vehicle energy needs for local trips. Table 3-7 shows the charge times for use of a 7.2-kW capacity AC Level 2 charger for the same driving conditions used in Table 3-6. Note that the longest charge time is 4.6 hours for a pickup truck with a daily driving range of 60 miles.

Table 3-7
Estimated time to charge using a 30-A AC Level 2 charger for varying vehicle distance driven

	Assumed Energy/Distance	Assumed Daily Driving	Daily Energy Needs in kWh	Time Needed to Charge (30A@240V) (7.2kW)
Vehicle Type	**miles/kWh**	**miles**	**kWh**	**hours**
Compact Sedan	4	10	2.8	0.4
	4	20	5.6	0.8
	4	30	8.3	1.2
	4	40	11.1	1.5
	4	50	13.9	1.9
	4	60	16.7	2.3
Full Size Sedan	3	10	3.7	0.5
	3	20	7.4	1
	3	30	11.1	1.5
	3	40	14.8	2.1
	3	50	18.5	2.6
	3	60	22.2	3.1
Pickup Truck	2	10	5.6	0.8
	2	20	11.1	1.5
	2	30	16.7	2.3
	2	40	22.2	3.1
	2	50	27.8	3.9
	2	60	33.3	4.6

Cost Challenges of L2 Home Charging

A key challenge that can limit installation of Level 2 AC chargers at residences is the cost of installation. Availability of sufficient electric system capacity and proximity of the parking location to power access can make cost of installation vary over a wide range. Recent data from Avista's Electric Vehicle Supply Equipment Pilot Program [29] indicates that residential installation-only costs can vary over a greater than six to one price range, with an average cost for installing charging hardware of $973. Of 63 residential sites in their pilot, two sites had installation costs of over $2,500 and one site had a cost that exceeded $3,000. Again, these variations can be due to the need for electrical system upgrades, long distance runs from electric service to the parking area, wiring installation costs for trenching, and paving/concrete restoration after an installation.

Multi-Family Dwelling Unit Charging Challenges

Another area of challenge for home charging is for consumers that live in multi-unit dwellings. A study conducted by the University of California, Los Angeles (UCLA) Luskin School of Public Affairs [30] indicated that:

- Equipment installation costs vary widely, with an average cost of $5,400 and low and high costs of $1,800 to $17,800 respectively per charge port.
- Property owners have little motivation to invest in charging infrastructure.
- Renters are unlikely to install a permanent piece of equipment at a rental property.

The broad installation cost variation found in the study reflects that for many MDUs, parking is not conveniently located near available power sources, requiring extensive boring or trenching to install charging equipment. For MDUs with large surface parking areas, this may prove particularly challenging when compared to MDUs with more compact parking structures such as garages. Additionally, one would expect over time that an MDU would potentially need to install multiple charging stations, which could drive the need for costly electrical infrastructure upgrades.

A Nova study [31] indicated that installation of charging in apartment facilities is challenging due to complex ownership and management structures and that economic justifications are often made at multiple levels with different priorities being considered.

The combination of potential high cost and complex logistics acts to limit the volume of apartment-based charging facilities.

Workplace Charging

For consumers with a lack of dedicated parking and no access to an AC outlet, a home site that would require a high-cost charge station installation, or living in an MDU, workplace and public charging infrastructure is an enabler of PEV ownership. Workplaces often have many of the same challenges seen at MDUs – parking areas that are remote from power, the need to install multiple chargers, and the high cost of hardware installation. In the Avista pilot previously cited [30], the cost of workplace charging installations was five times the cost per port of a residential installation, even when using dual-port charger installations. A key factor for controlling installation cost is to locate charging hardware as close to electrical resources as possible.

Incentives for employers to provide charging facilities include worker retention, use in recruiting, and presenting a green ethos to their community.

4
ENVIRONMENTAL IMPACTS OF PEV ADOPTION

Battery electric vehicles (BEVs) have almost no direct emissions and PHEVs have much-reduced direct emissions if they are driven substantially on electricity. However, the generation of electricity to recharge PEV batteries results in indirect emissions that will decrease the environmental benefits of transportation electrification. This section discusses the net environmental effects of transportation electrification, including the effects on greenhouse gas emissions and the effects on air quality within the United States and the GPES service territories.

Air Quality Effects of Transportation Electrification

In *Environmental Assessment of a Full Electric Transportation Portfolio* (EPRI report 3002006880) [32], EPRI analyzed the effects of a large-scale shift toward electric transportation on a number of different air quality indicators. In this analysis, a "large scale" shift was represented as 17% of light-duty and medium-duty miles being electrified, which is consistent with the "High Adoption" projection described previously (in this projection 15% of miles would be electrified by 2030). The analysis additionally includes significant electrification of non-road devices like forklifts and lawn and garden equipment. As shown in Figure 4-1 for ozone levels and Figure 4-2 for $PM_{2.5}$ levels, the results indicate that transportation electrification would result in modest but measurable improvements in air quality in the Kansas City area.

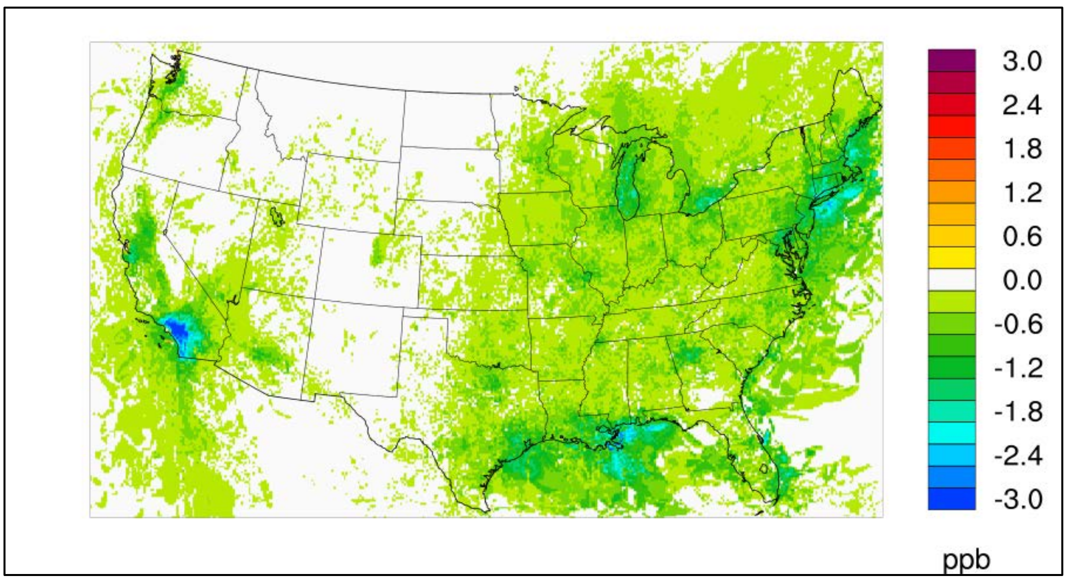

Figure 4-1
Change in projected 2030 ozone levels due to transportation electrification (in terms of annual fourth highest 8-hour-ozone levels for each cell)

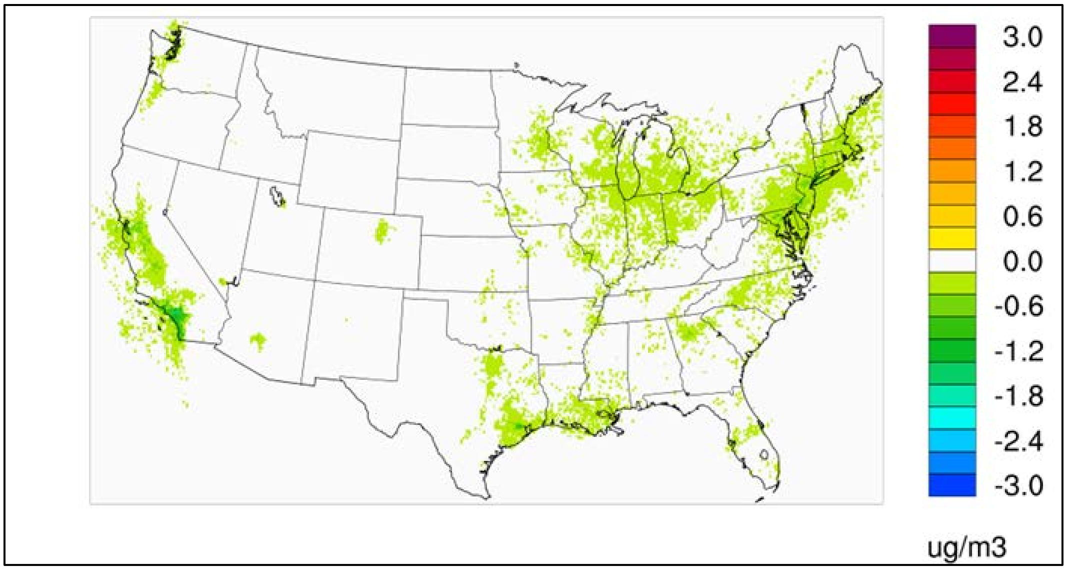

Figure 4-2
Change in projected 2030 PM2.5 levels due to transportation electrification in terms of annual eight highest 24-hour average concentrations (µg m^{-3}) of $PM_{2.5}$

Net Greenhouse Gas Emissions for Transportation Electrification by Region

When considering the effects of transportation electrification, it is important to compare the benefits of reducing gasoline or diesel consumption with increased electricity generation. Figure 4-3 shows a nationwide comparison performed by the Union of Concerned Scientists (UCS) in 2015 [33]. This analysis shows the fuel economy that a gasoline vehicle would have to achieve to have the same life cycle greenhouse gas emissions as a current PEV. PEVs have lower life cycle greenhouse gas emissions than most conventional vehicles throughout the country, but benefits are lower in the more coal-intensive Midwest. In the Southwest Power Pool (SPP) North (SPNO) region that includes KCP&L and the Greater Missouri Operations Company (GMO), the UCS 2015 analysis based on 2009 generation emissions data found that PEV emissions are equivalent to the emissions of a gasoline powered internal combustion engine (ICE) vehicle with a fuel economy of 36 MPG.

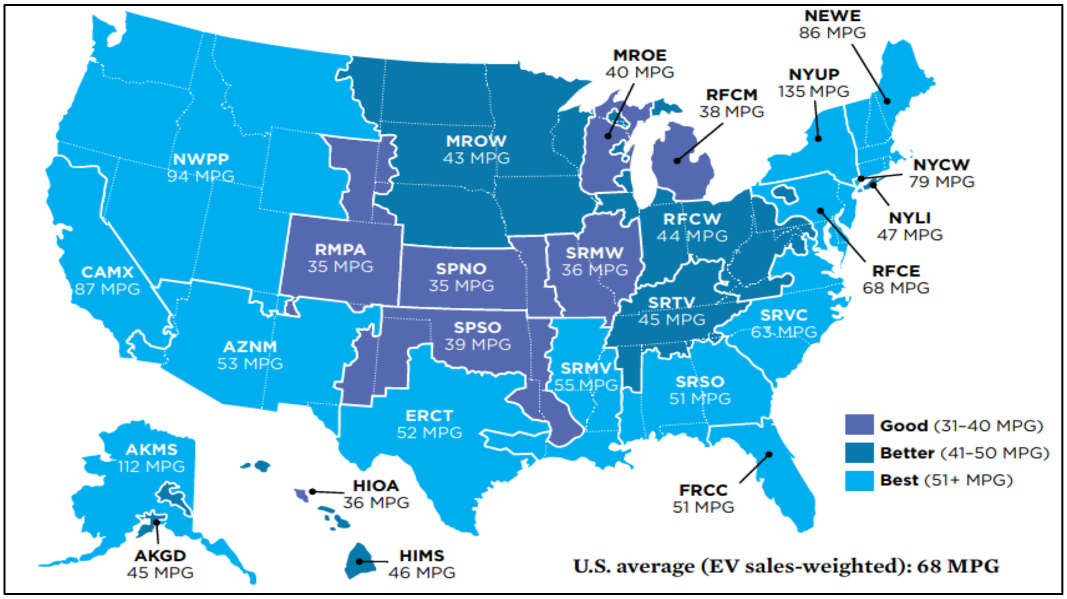

Figure 4-3
Equivalent fuel economy for a PEV in regions across the United States

In 2017, UCS updated this analysis using 2014 generation emissions data. Figure 4-4 shows that PEV emissions in the SPP North region are now equivalent to a 46-miles per gallon (MPG) conventional ICE vehicle [34]. This is lower than some gasoline powered vehicles, but is significantly above the 2017 model year vehicle average of 25.2 MPG [35]. The 46 MPG equivalent rating is an improvement of 10 MPG from just five years ago and reflects the addition of significant environmental controls and increased renewable generation in the SPP generation fleet. In addition, since 2014, GPES's generation fleet has continued to reduce emissions as coal plants are retired and more renewable generation resources are added.

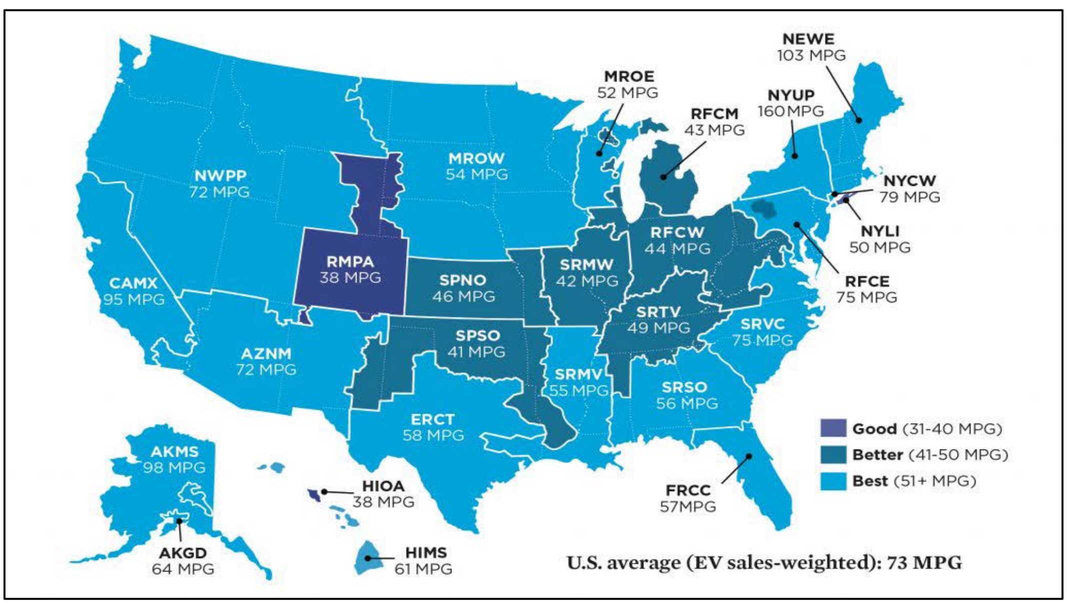

Figure 4-4
Equivalent fuel economy for a PEV in regions across the United States

Electricity Generation in the GPES Service Territories

Nationally, coal generation has historically been the primary source of electric generation and is the primary source of electric-sector greenhouse gas emissions and a significant source of other pollutants. When evaluating the environmental impacts of transportation electrification, it is important to understand the composition of the local generation resource mix.

KCP&L and GMO obtain electricity from a variety of sources, with a significant portion (23%) of their generating capacity in 2016 coming from non-fossil fuel sources. As indicated in Figure 4-5, KCP&L and GMO have made significant progress in reducing air emissions and building a more diverse, sustainable generation fleet by adopting renewable wind and solar power, investing in environmental upgrades at coal-fired power plants, and retiring older, less-efficient generation units.

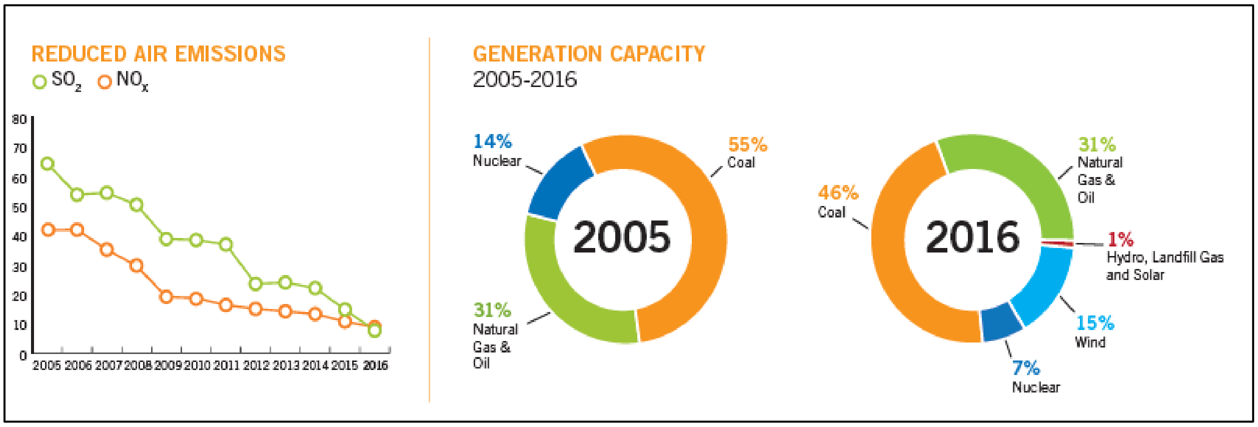

Figure 4-5
Great Plains Energy reduced air emissions and generation fleet composition (2005-2016)

KCP&L and GMO are both members of the SPP. The SPP is a Regional Transmission Organization (RTO) mandated by the Federal Energy Regulatory Commission (FERC) to ensure a reliable supply of power, adequate transmission infrastructure and competitive wholesale electricity prices. In 2014, the SPP launched its Integrated Marketplace. Like other RTO or Independent System Operator (ISO) markets, the SPP Integrated Marketplace determines which generating units among market participants should run, within the operating constraints of a unit, at any given time for maximum cost-effectiveness. Prior to the establishment of the Integrated Marketplace, KCP&L was its own balancing authority, serving its native load with its own generation and purchased power. Table 4-1 provides an estimate of the generation fuel mix that will be used to meet the 2018 projected load requirements for KCP&L, GMO and combined utility operations [36]. In 2018, coal production will comprise 44% of GPES generation capacity, but it is projected to be the source for nearly 65% of the energy produced.

Table 4-1
Great Plains Energy estimated generation mix for 2018

Generation Fuel	KCP&L Capacity (MW)	GMO Capacity (MW)	Total GPES Capacity (MW)	Share of Combined Capacity	KCP&L Energy (GWh)	GMO Energy (GWh)	Total GPES Energy (GWh)	Share of Combined Energy
Coal	2,569	905	3,474	44%	13,746	4,601	18,347	65%
Nuclear	549		549	7%	4,056		4,056	14%
Oil	401	60	461	6%	0	0	0	0%
Natural gas	782	1,109	1,891	24%	129	62	191	0.7%
Wind	1,031	359	1,390	18%	4,036	1,367	5,403	19%
Hydro/Landfill	60	1.6	61.6	1%	383	12	395	1.4%
Solar	0.2	3	3.2	0%	0	5	5	0%
Total	5,392	2,438	7,830	100%	22,350	6,047	28,397	100%

Net Greenhouse Gas Emissions for Transportation Electrification with KCP&L and GMO Generation Mix

This discussion presents EPRI's analysis of the effect of greenhouse gas emissions for transportation electrification with KCP&L and GMO generation sourced electricity. Greenhouse gas emissions to support transportation electrification are derived from two sources: local electric generation fleet emissions and upstream fuel-source emissions.

The local electric generation fleet emissions for each utility were obtained from the KCP&L and GMO 2017 Integrated Resource Plans and were based on the 2018 fleet compositions and estimated generation mix as summarized in Table 4-1. The upstream fuel-source emissions were calculated using the NW-Central region report described in EPRI's report *Reports on Recent Generation Trends for Electric Transportation* [37]. The NW-Central region includes both Kansas and Missouri, and this dataset allows the generation fractions to be converted into fuel input to calculate upstream emissions.

Figure 4-6 shows a greenhouse gas comparison between gasoline-only vehicles (conventional and hybrid) and electric vehicles for sample grids that are 100% coal, 100% natural gas, and KCP&L and GMO sourced generation. For each grid mix, the emissions are derived from the generation efficiencies in the NW-Central region and the average upstream emissions for the nation. The following vehicles were used for the comparison:

- PEV—Chevrolet Bolt EV with 119 MPGe (128 city / 110 highway) [38].
- Conventional—Chevrolet Sonic automatic with 30 MPG (27 city / 36 highway); the Sonic shares a common platform with the Bolt EV) [39].
- Hybrid—Toyota Prius Eco with 56 MPG (58 city/ 53 highway); the Prius Eco is the most efficient gasoline-only production vehicle available in the U.S.) [40].

These results indicate that a PEV charged from the KCP&L grid in 2018 will have greenhouse gas emissions of 230 grams per mile (g/mi), 17% higher than the most efficient gasoline vehicle available and 37% lower than a comparable non-hybrid vehicle. These emissions rates are 39% higher than natural gas, but 28% lower than coal.

These results indicate that a PEV charged from the GMO grid in 2018 will have greenhouse gas emissions of 300 g/mi, 53% higher than the most efficient gasoline vehicle available and 18% lower than a comparable non-hybrid vehicle. These emissions rates are 81% higher than natural gas, but 7% lower than coal.

The greenhouse gas emissions from electric transportation will reduce over time as the electric generation in the KCP&L and GMO service areas shifts towards lower-emitting sources.

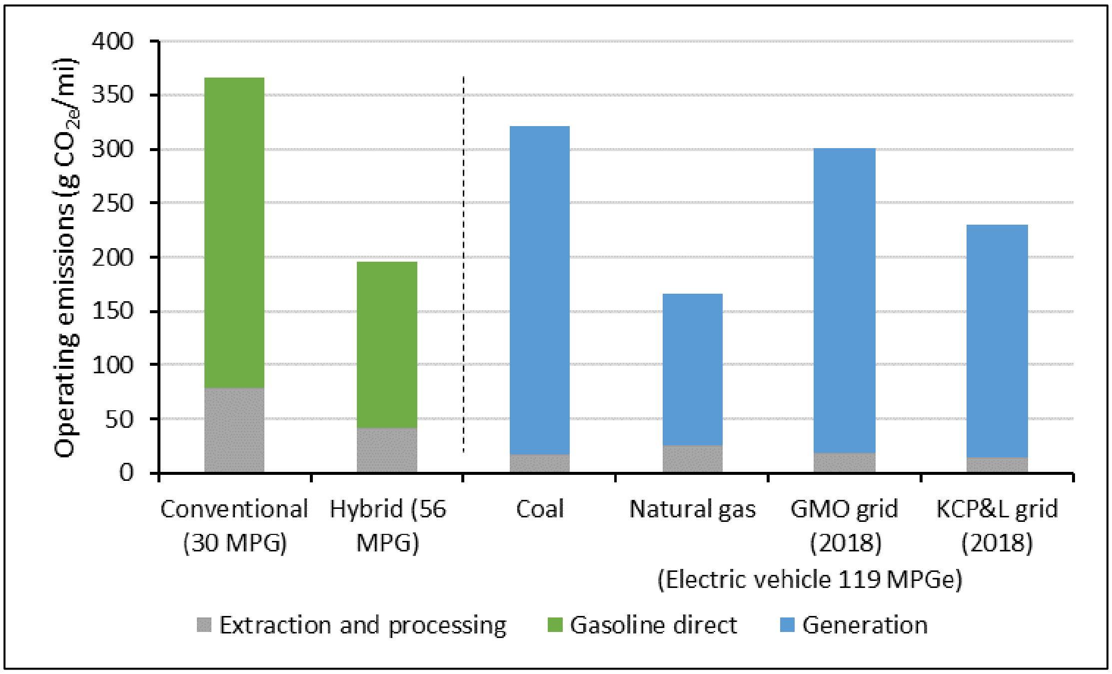

Figure 4-6
Emissions comparison gasoline-only vehicle options and PEV using KPC&L- and GMO-sourced electricity

5 GRID IMPACTS OF PEV ADOPTION

This section provides EPRI's initial assessment of the potential effects of increasing transportation electrification grid impacts in the GPES electrical systems.

PEV Charging Load Shapes

To assess the potential impact of transportation electrification on the GPES electrical systems, it was first necessary to estimate the load shape for charging PEVs under a variety of different assumptions. GPES has not collected charging data from homes and there is not enough other data to calculate residential load shapes directly, so the load shapes were modeled based on previous EPRI work as described in EPRI report's, *Guidelines for Infrastructure Planning: An Explanation of the EPRI Red Line/Blue Line Model* [41]. EPRI examined the PEV charging data provided by the Clean Charge Network for "workplace" and "retail/destination" host site locations and found them to be consistent with the "work" and "community" charging load shapes presented here.

Unmanaged PEV Charging Load Shapes

The EPRI model described in the guidelines report [41] uses data from the 2009 National Household Travel Survey [42] to estimate the use of individual vehicles. The data in the survey was processed to break out the data for each vehicle into a "vehicle day" that described the use of the vehicle throughout the day. These vehicle days were then simulated to estimate the energy use and charging behavior of PEVs using a variety of assumptions about infrastructure availability. The "unmanaged" load shape was modeled using two scenarios, the "home only" charging scenario to see what would happen if no away-from-home charging was available and the "charging available everywhere" scenario so that the effects of charging in workplaces and community locations could be seen. The results described here use the data from the "PHEV40" vehicle scenario with a 6.6 kW charger. PHEV40 represents a Plug-in Hybrid Electric Vehicle with an all-electric range of 40 miles. This scenario provided a good representation of both BEVs with longer range and shorter-range PHEVs charged at low power (the load shapes are similar in relative terms, but in absolute terms the PHEV40 uses more energy and charges at higher power than lower-range PHEVs).

The resulting load shapes are seen in Figure 5-1 for the scenario with charging available everywhere and in Figure 5-2 for charging available at home only. If charging is available only at home, the unmanaged load ends up being concentrated in the evening hours from 5:00 – 7:00 PM as drivers return home from work. This load is highly coincident with existing GPES generation and residential customer load peaks. This system peak coincidence is reduced significantly if charging is available at all locations, with much of the load moved to work and community locations. In this scenario, the load is relatively flat throughout the day, although an evening peak remains and the load is still "peaky" at the work and home locations, which may affect the distribution system.

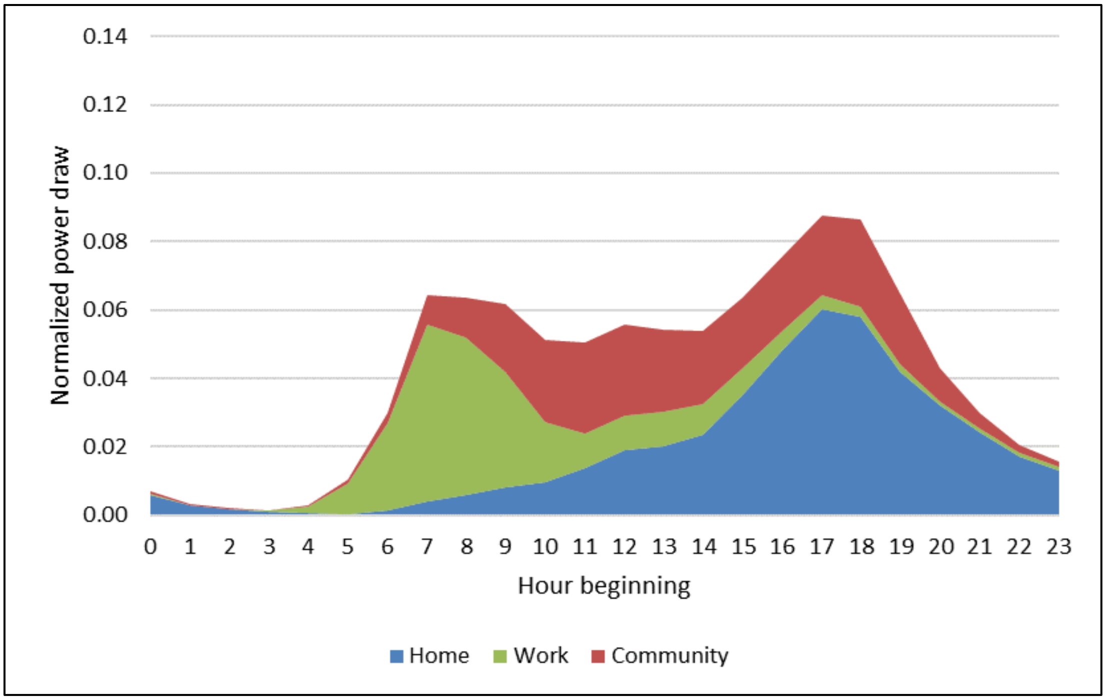

Figure 5-1
Average charging load shape for weekday charging with charging available at all locations

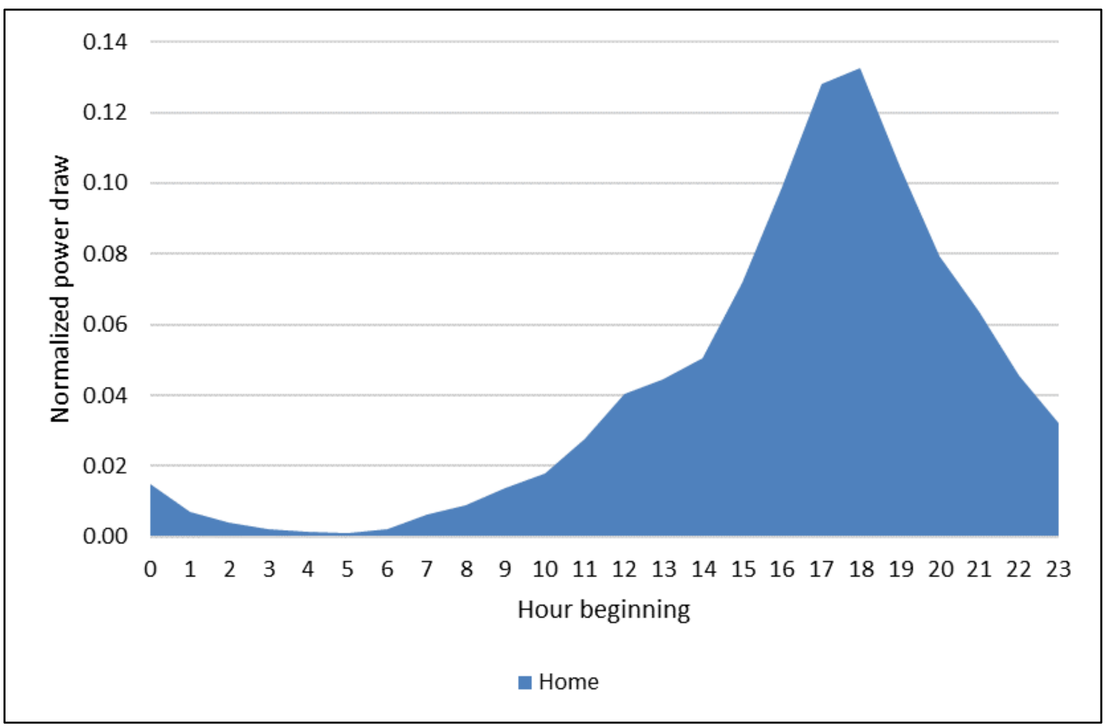

Figure 5-2
Average charging load shape for weekday charging with charging available at home only

Managed PEV Charging Load Shapes

There are various potential management strategies that would result in a wide range of potential load shapes discussed at the end of this section, but in order to model the effects of managing load it was necessary to create one specific load shape. A load shape based on the results described in *Final Evaluation for San Diego Gas & Electric's ("SDG&E") Plug-in Electric Vehicle TOU Pricing and Technology Study* [43] was created as a representative managed load shape. This study describes a real-world rate experiment in which customers were assigned TOU rates that attempted to move load into the nighttime hours, with significantly lower rates starting after midnight. The program was quite successful, with about 90% of PEV charging load shifted to off-peak hours, even without automatic management (so customers had to program vehicles or chargers themselves). The load shape from the SDG&E EPEV-L TOU rate in this experiment was used to modify the home charging load in the scenarios describe above, resulting in the load shapes shown in Figure 5-3 and Figure 5-4.

The managed load shape shown in Figure 5-3 significantly reduces the evening load peak, instead moving this charging load to after midnight. The work and community loads are not modified by this rate, so some load is still present during the afternoon peak, but this could be separately managed. The overall charging peak for this scenario is higher, but occurs between midnight and 2:00 AM, when it is unlikely to affect the generation load peak. Distribution peaks remain the same for work and community locations, and are about twice as high at home.

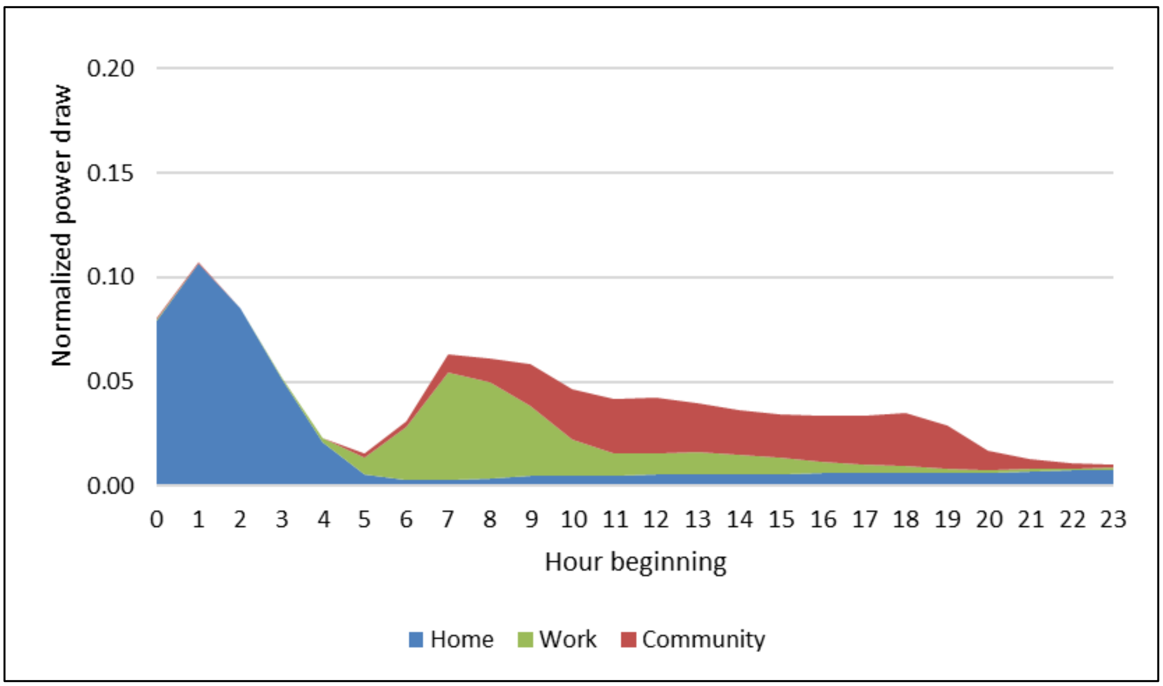

Figure 5-3
Average charging load shape for managed weekday charging available at all locations

The managed home-only load shape shown in Figure 5-4 reduces the overall load throughout the day but causes power usage to be significantly higher at night. This charging load is during the traditional load "trough," but it is high enough and steep enough that it may cause concerns, particularly on humid summer nights when air conditioning load remains high even after midnight. Additionally, the distribution peak at the home location will be two to four times higher than in other scenarios.

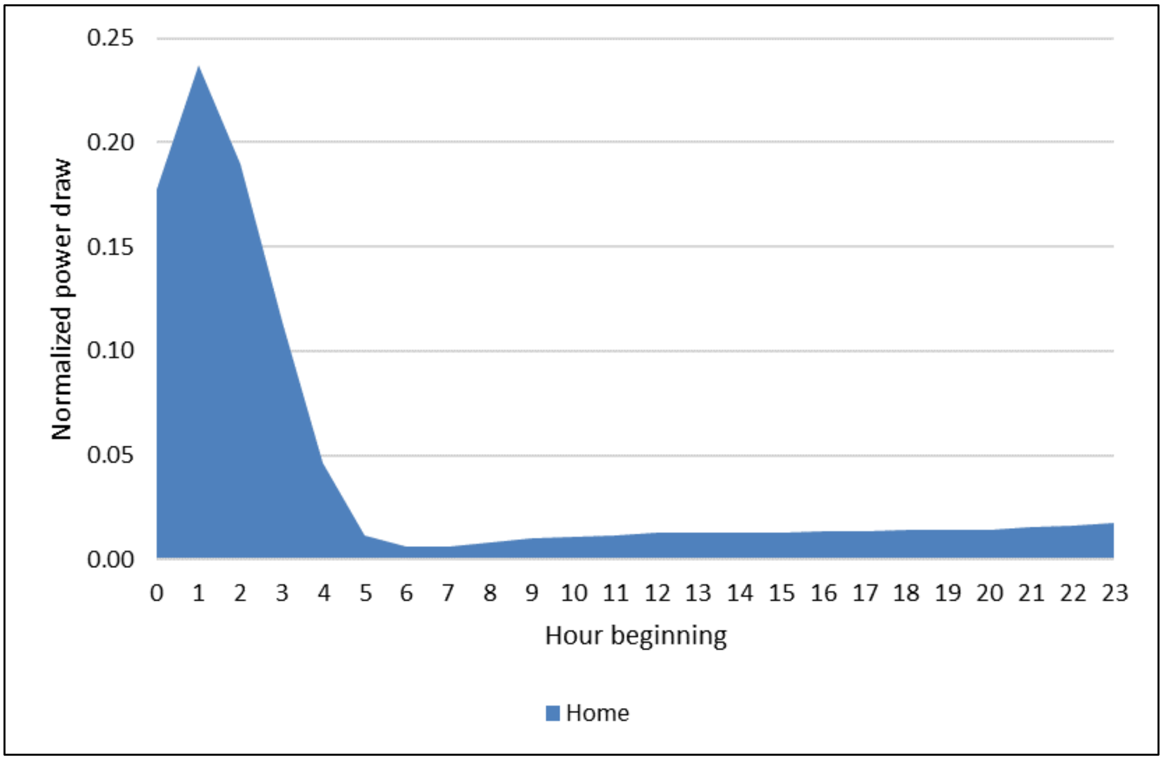

Figure 5-4
Average charging load shape for managed weekday charging available at home only

Charge Management Strategies

There are a number of options for managing PEV charging load due to the sophistication of vehicles and chargers and the unique characteristics of PEV charging. Almost all PEVs have a driver interface that allows drivers to adjust the "charging window" during which the vehicle will charge. Many also have mobile internet applications that can be used to command the vehicle to begin or pause charging. In addition, the electric vehicle supply equipment (EVSE), commonly known as the EV charger, that connects PEVs to the grid can also have an internet connection and user applications that allow the driver to control and manage the EVSE charge levels. PEV chargers are fully solid-state, so they can vary power levels continuously (up to the limit of the charger and electrical circuit breaker). The characteristics of vehicle use also make charge management possible with low customer impact since most vehicles are parked for the majority of the day and can charge in a fraction of that time. This means that even if charging is delayed by a few hours, the vehicle can still be fully charged when the driver begins the next trip.

All these characteristics mean that there are a number of options for managing charging load:

- **Time-of-use rates**: TOU rates vary the cost of electricity throughout the day to encourage electricity users to avoid peak times. This requires the customer to program their car or home charger, but these rates have proven to be quite effective in achieving peak load reduction for PEV charging.
- **Real-time rates**: Since both the PEV and EVSE can potentially communicate with upstream networks, it is possible to communicate real-time rates to these devices directly or to allow customers to remotely manage charging in response to real-time rates. Real-time rates can be varied to provide a strong signal to avoid charging at specific times. This option requires the PEV or EVSE to have an internet connection and a more sophisticated application with the ability to periodically "look up" the current price schedule.
- **Demand response**: Demand response is similar to real-time rates, but instead of providing a high price that discourages electricity use, a signal is provided to directly discontinue or significantly reduce the charge level. Demand response programs have been used to manage air conditioners, industrial loads, and a variety of other loads to reduce electricity use during specific hours and days of the year when load is particularly high. This option also requires the PEV or EVSE to be connected to a network, but only requires an application that can receive the demand response message and adjust the charge level accordingly.
- **Active Charge Management:** Active charge management is a more sophisticated form of charge management that can be leveraged by utilities and other parties to manage grid impacts and provide grid services. Active charge management can improve grid economics by minimizing charging ramp rates, reducing the need to upgrade local distribution assets, and by achieving higher utilization rates of existing generation and distribution assets.

To study and assess the relative impact of PEV charge management in this study, PEV charging under a TOU rate was assumed and the load shape previously described was used for managed home charging load profiles. Real-time rates, demand response, or active charge management programs could be used with either the managed load shape or the unmanaged load shape described above to further reduce PEV charging load during hours with particularly high load.

Generation and Transmission System Level Impacts

The key concern at the system level is the impact of PEV charging on system peak, also referred to as coincident peak impacts. Understanding the charging impacts during system peak times informs system planning to ensure that adequate generation and transmission capacity are available to supply all customer needs. The results presented here suggest that the GPES generation and transmission system can support a significant level of PEV adoption and that PEV charging will have the greatest impact during the late afternoon system peak load hours. However, depending on how system load and PEV charging changes over time, there may be unexpected impacts during non-peak periods.

Aggregate System Level PEV Charging Requirements

The PEV charging load shapes were aggregated to determine bulk power system impacts of PEV charging. The combination of existing system load and aggregate PEV charging was then compared to GPES generation capacity to estimate overloading impacts throughout the year for increasing PEV adoption. As summarized in Section 4, the 2017 GPES accredited generation capacity is approximately 6,400 MW (KCP&L: 4,260 MW, GMO: 2,130 MW).

The Medium PEV Adoption scenario from Section 2 was used as the basis for the PEV adoption projections. The projected PEV vehicle counts shown in Table 5-1 were used to estimate the aggregate system level load added by PEV charging.

Table 5-1
Cumulative number of PEVs for Medium Adoption scenario by jurisdiction, for 2014 to 2035

	2014	2015	2016	2017	2018	2019	2020	2025	2030	2035
GMO	157	230	356	592	970	1,495	2,155	8,811	22,945	49,906
KCP&L-KS	359	496	714	1,078	1,626	2,389	3,321	11,802	28,506	59,899
KCP&L-MO	326	491	754	1,213	1,902	2,860	4,058	13,943	32,562	66,102
GPES Total	842	1,217	1,824	2,883	4,498	6,744	9,534	34,556	84,013	175,907

GPES provided the 2016 hourly load for each system (8760 system load) and the aggregate PEV charging was added to this load to determine load shape impacts and the frequency of system overload throughout the year. An aggregate 8760 PEV charging profile was created using the 24-hour weekday and weekend day profiles. It was assumed that vehicles have charging available everywhere—home, work, and community charging.

To create the aggregate 8760 charge profile, it was assumed that the PEV counts in Table 5-1 all drove an average of 34.6 miles per day and required 12.2 kWh of charging daily. Differences in weekend and weekday charging are driven by where (home, community, and work) and when charging occurs during the day (based on home arrival time). Differences in the assumed charging profile with the ability to managed charging were also incorporated to see the differences in system impact for unmanaged vs. managed charging.

Applying the weekday unmanaged charging profile to the 2025 PEV Medium Adoption scenario results in the aggregate PEV load shape shown in Figure 5-5. This is a diversified charging profile representing average vehicle charging for each vehicle in the population. Transmission and distribution losses have been added to take the load to the generator bus bar for comparison with existing system loading. System energy losses for residential (home) charging are assumed to be 12% and for commercial (work and community) charging are assumed to be 7.5%. The majority of evening charging takes place at home. The peak of about 41 MWh of hourly consumption at the system level (with losses) for a 34,556 PEVs is expected to occur between 4:00 and 5:00 PM on weekdays.

If charging were managed, PEV charging in the early evening hours, coincident with the company system could be reduced. The aggregate managed charge profile based on a TOU rate is shown in Figure 5-6. Delaying home charging increases the number of vehicles beginning to charge during a given hour and the resulting expected daily peak. With shifting of evening charging at home, the increased PEV charging consumption peak of 51 MWh now occurs between midnight and 1:00 AM, and is not coincident with typical peak periods. With managed charging, the charging load consumed during the system peak hour is reduced to about 15 MWh, less than 40% of the added load with unmanaged charging.

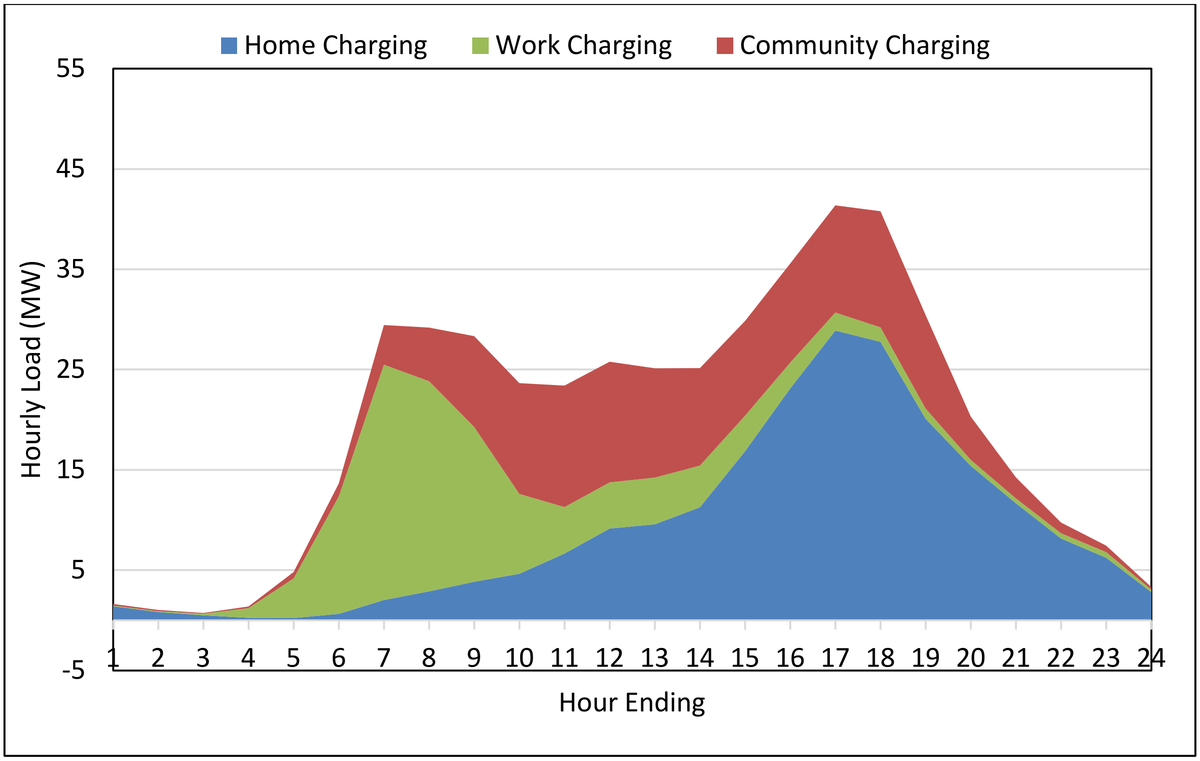

Figure 5-5
GPES aggregate unmanaged PEV weekday charging load, for 2025 medium PEV adoption

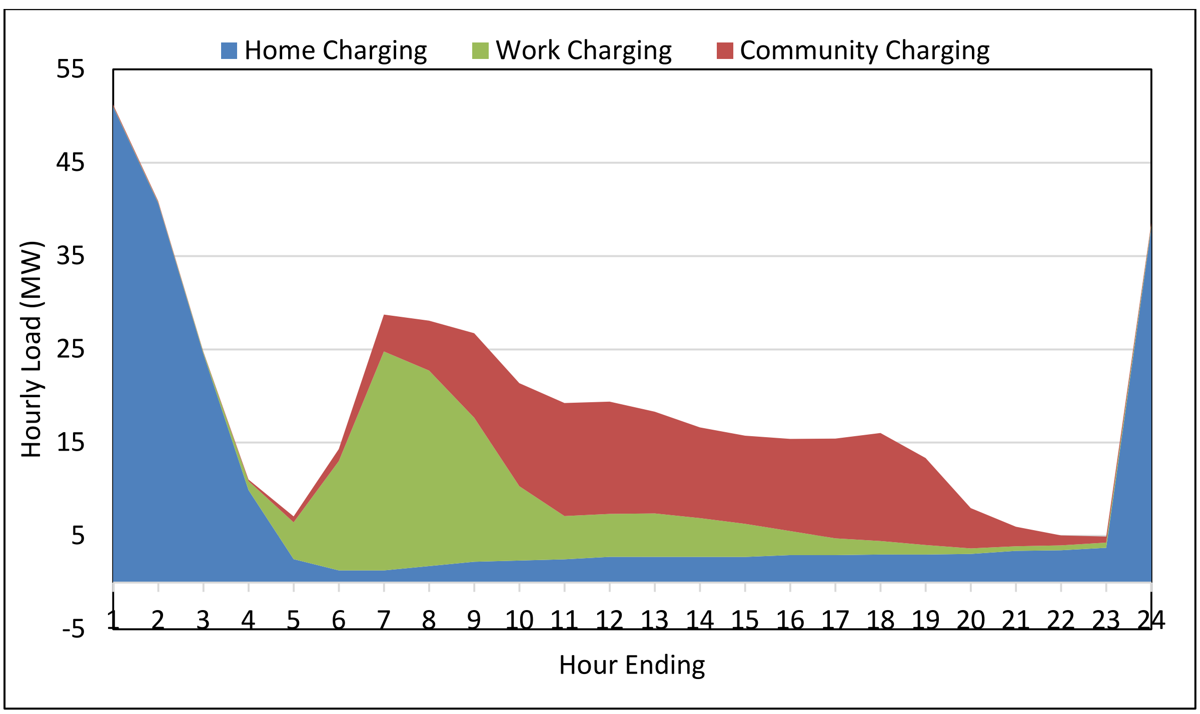

Figure 5-6
GPES aggregate managed PEV weekday charging load, for 2025 medium PEV adoption

GPES PEV Medium Adoption projections are provided for 2014 through 2035 along with estimated annual PEV charging energy and peak capacity for managed and unmanaged charging in Table 5-2. Similar tables for the GMO, KCP&L-MO, and KCP&L-KS service territories are contained in Appendices A, B, and C. With managed charging, the peak capacity needed in each year is less than 40% of what might be needed in the case of unmanaged charging. Marginal demand loss factors are used to estimate coincident peak demand at the generator; 12% is used for commercial consumption and 15% for residential charging. A generation reserve margin of 12% is also included in the peak capacity estimates.

GPES system capacity needs for 2035 levels of PEV under the Medium Adoption scenario are projected to be about 3.8% of the current GPES 6,400 MW generating capacity; with managed charging this is reduced to about 1.4% of current capacity.

Table 5-2
GPES generation and transmission system capacity impact with PEV Medium Adoption scenario

	Cumulative No. PEVs in GPES	Share of Total Vehicles	Annual PEV Consumption at the Meter	Peak Capacity* for Unmanaged Charging	Peak Capacity* for Managed Charging
2014	845	0.0%	4 GWh	1 MW	0 MW
2015	1,225	0.1%	5 GWh	2 MW	1 MW
2016	1,830	0.1%	8 GWh	3 MW	1 MW
2017	2,885	0.1%	13 GWh	4 MW	2 MW
2018	4,502	0.2%	20 GWh	6 MW	2 MW
2019	6,745	0.3%	30 GWh	9 MW	4 MW
2020	9,540	0.4%	42 GWh	13 MW	5 MW
2021	13,060	0.6%	58 GWh	18 MW	7 MW
2022	17,355	0.8%	77 GWh	24 MW	9 MW
2023	22,337	1.0%	99 GWh	31 MW	12 MW
2024	28,041	1.2%	125 GWh	39 MW	15 MW
2025	34,569	1.5%	154 GWh	48 MW	18 MW
2026	42,001	1.8%	187 GWh	59 MW	22 MW
2027	50,462	2.2%	225 GWh	70 MW	26 MW
2028	60,238	2.5%	268 GWh	84 MW	32 MW
2029	71,326	3.0%	318 GWh	99 MW	37 MW
2030	84,027	3.5%	374 GWh	117 MW	44 MW
2031	98,432	4.02%	438 GWh	137 MW	52 MW
2032	114,818	4.64%	511 GWh	160 MW	60 MW
2033	133,168	5.33%	593 GWh	186 MW	70 MW
2034	153,513	6.08%	684 GWh	214 MW	80 MW
2035	175,911	6.90%	783 GWh	245 MW	92 MW

* Coincident with system peak, hour ending 17 (4-5 PM), includes losses and 12% generation reserve margin.

2016 Peak Day Impact

The GPES 2016 peak day of August 4 is shown in Figure 5-7, with a peak of 5,804 MW occurring between 4:00 and 5:00 PM (hour ending 17). Compared to the aggregate charge profile in Figure 5-5, the unmanaged charging peak occurs right around expected system peak times.

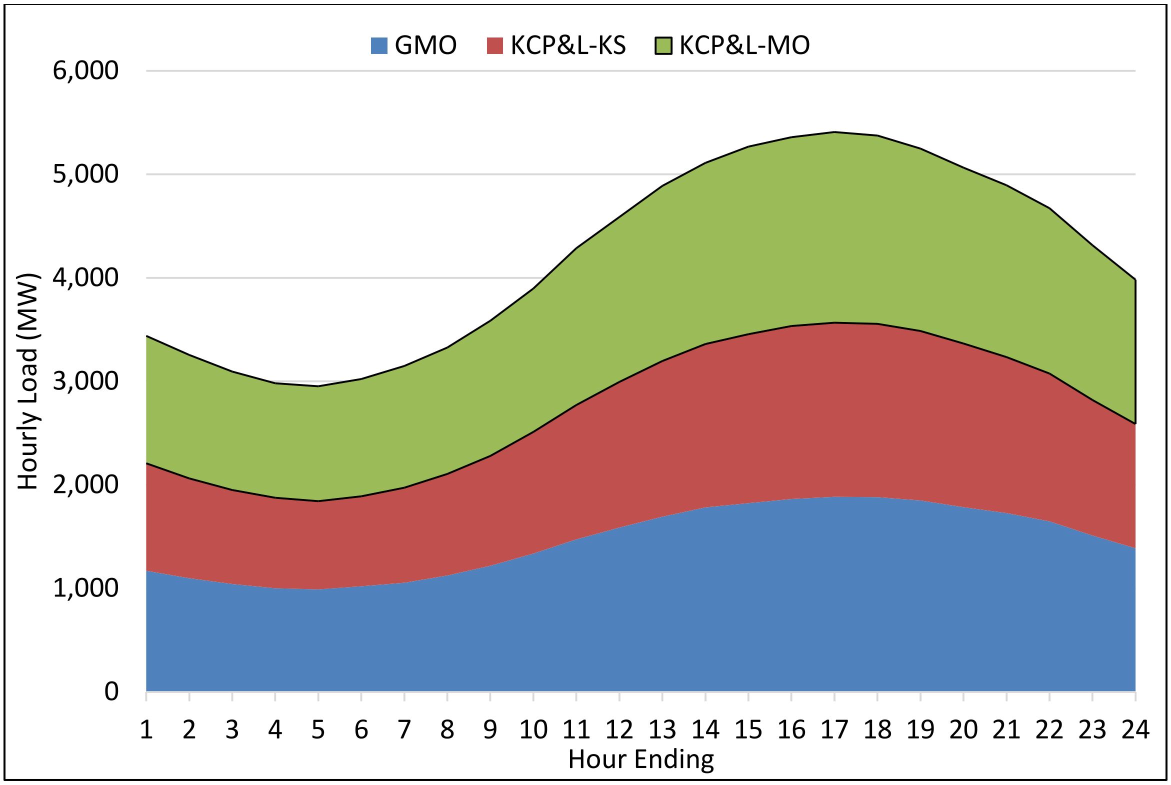

Figure 5-7
GPES 2016 peak day load profile

To assess the ability of the GPES system to accommodate a significant level of transportation electrification, the unmanaged and managed PEV charge profiles shown in Figure 5-5 and Figure 5-6 were used to construct a 2016 system peak day load profile with the number of PEVs projected in 2015 for under the medium adoption scenario. Figure 5-8 shows the 2016 peak day load profile with the addition of the 2035 unmanaged PEV charging load.

Figure 5-9 shows the 2016 peak day load profile with the addition of the 2035 managed PEV charging load. Work and community charging still adds to the system peak; however, the system peak impact is minimized with home charging shifted. When added onto the system peak day, the aggregate charging is not apparent. A zoomed version of Figure 5-8 and Figure 5-9 is provided in Figure 5-10 and Figure 5-11 respectively, where the impact of managed home charging is more apparent.

Using the approach presented here, it would take a total of 250,000 PEVs , or about 12% of total 2017 estimated vehicles in the GPES service territories, before the 2016 peak would have exceeded 6,400 MW.

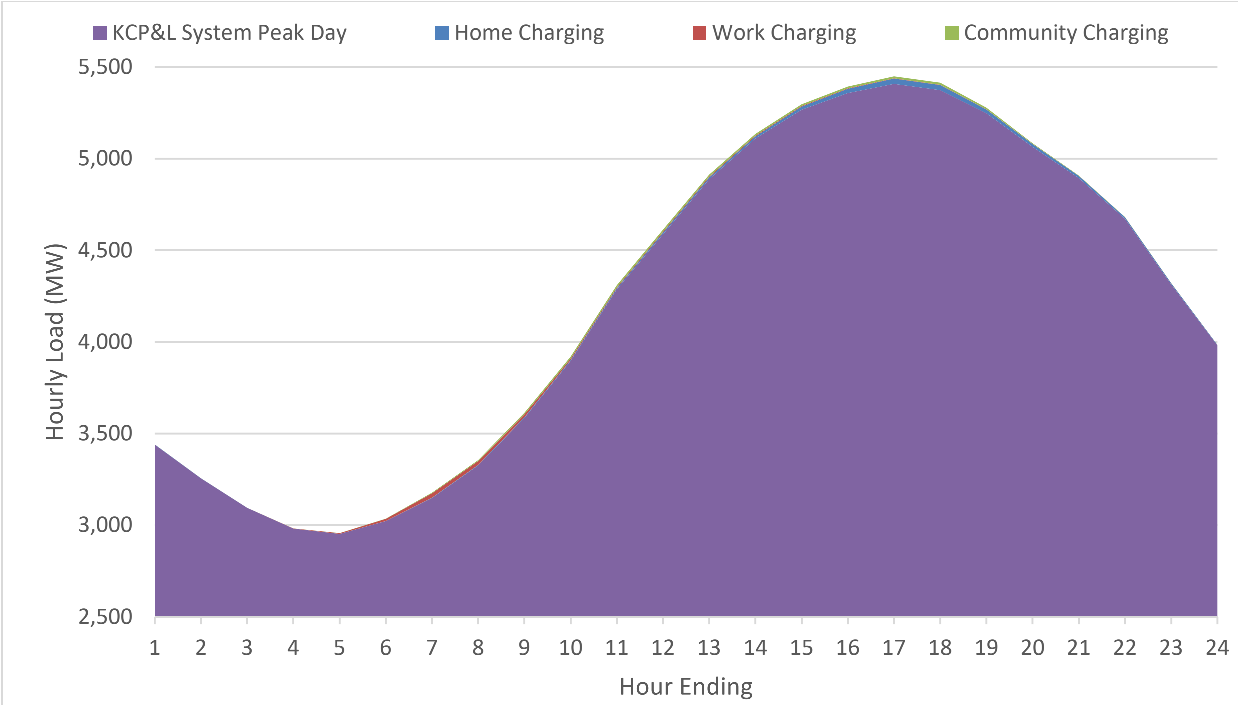

Figure 5-8
GPES 2016 peak day with aggregate unmanaged PEV charging, for 2025 medium PEV adoption scenario

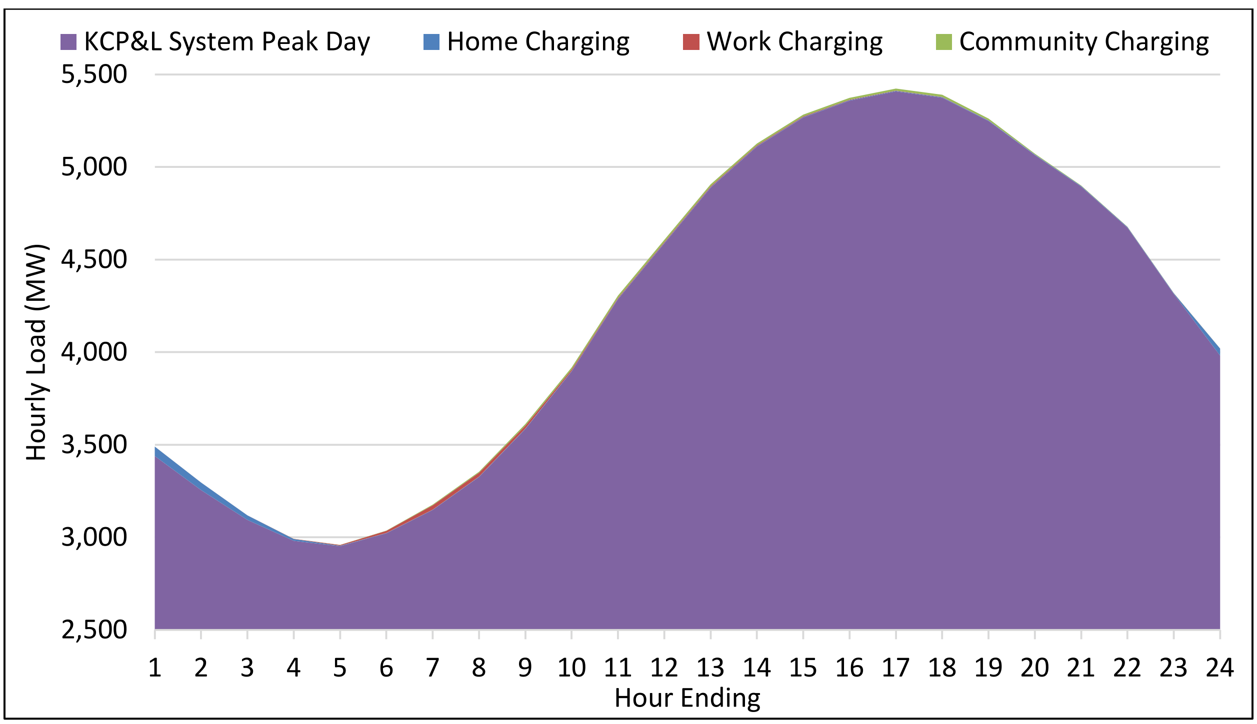

Figure 5-9
GPES 2016 peak day with aggregate managed PEV charging, for 2025 medium PEV saturation

Comparing the zoomed in version of the previous two figures, Figure 5-8 and Figure 5-9, the amount of home charging load in hour ending 17 is about 29 MW in Figure 5-10, compared to about 3 MW in Figure 5-11 when that home charging is managed. This is a 90% reduction in the amount of home charging at the peak system hour from 2016.

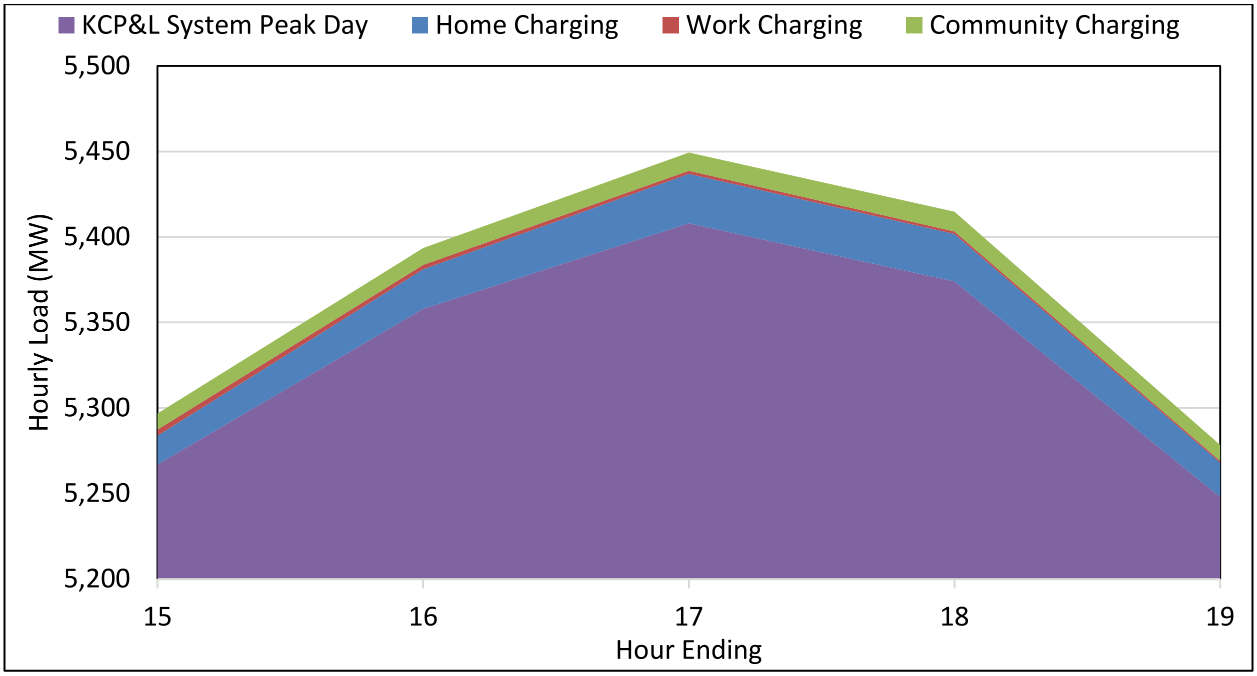

Figure 5-10
GPES 2016 peak day with aggregate unmanaged PEV charging, for 2025 medium PEV adoption scenario, focused on hours ending 15 to 19

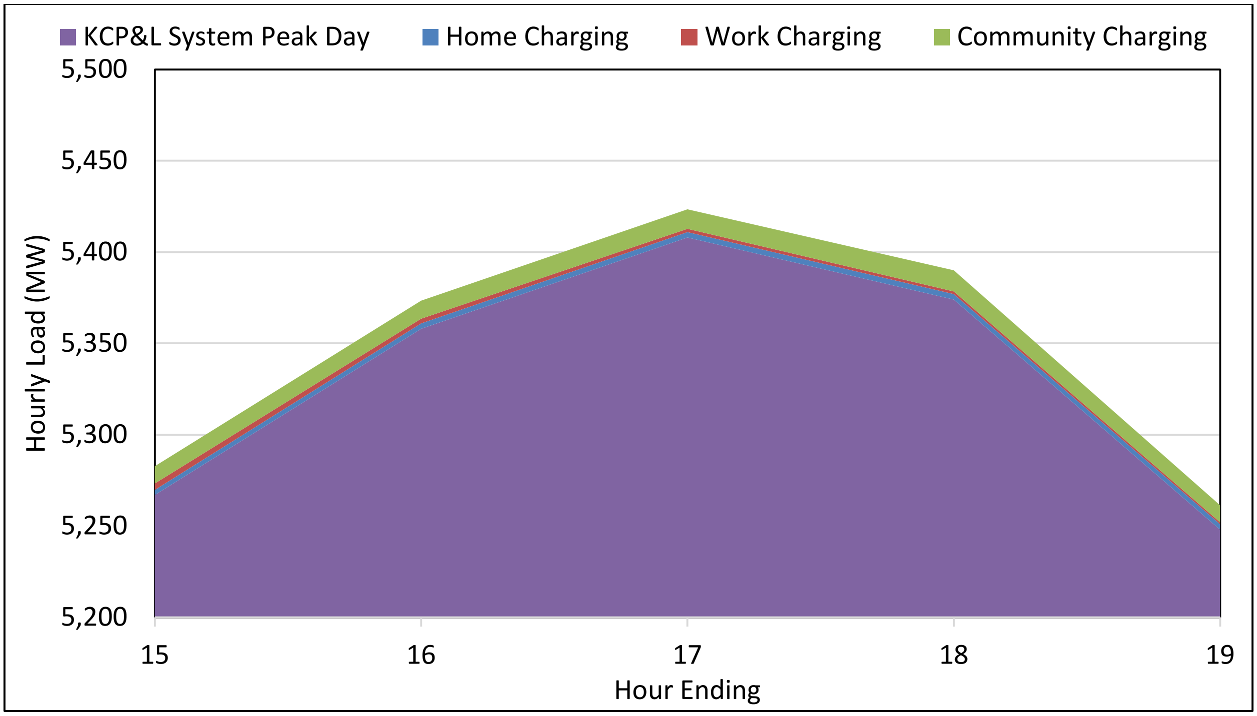

Figure 5-11
GPES 2016 peak day with aggregate managed PEV charging, for 2025 medium PEV saturation, focused on hours ending 15 to 19

Distribution System – Commercial Level Impact

In the Phase 1 study[2], EPRI performed an initial estimate of the effects of increasing transportation electrification on the GPES distribution system. This analysis aimed to address the question: How much would PEVs affect GPES's commercial distribution grid through public and workplace charging infrastructure use? The analysis involved collecting information from monthly commercial peak load curves, total yearly commercial MWh, and projected MWh due to PEV adoption. This information was combined with an estimation of hourly loads generated from the GPES currently deployed public charging stations. The analysis showed that there is more than enough capacity available to support a large number of PEVs. The following paragraphs provide a summary of the key points identified in the Phase 1 study specifically related to the impact of PEV charging on the commercial level distribution system.

The GPES companies' distribution systems incorporate approximately 32,000 transformers serving primarily commercial customers. Table 5-3 shows that the commercial transformer capacity is generally underutilized and should typically have excess capacity. However, these figures do not consider the customer's hourly load profile, the transformer load profile, and typical PEV charging times.

[2] The Phase I study results were provided to KCP&L but were not published.

Table 5-3
GPES service transformer utilization by load class

	Commercial (GS)	Residential (RS)
Total load served	11,045,956 MWh	6,819,978 MWh
Megawatt-hour potential (based on nameplate rating)	54,498,535 MWh	40,551,030 MWh
% currently used	20.27%	16.82%

Using peak monthly meter data from GPES as well as PEV load estimated from initial charging data observed at the Clean Charge Network (CCN) public charging stations, peak load times for both the commercial grid as well as public charging can be estimated. Figure 5-12 shows the normalized distribution of an average commercial daily load (blue) as well as a normalized vehicle distribution load on public chargers (orange). It shows that while the two different demand curves peak at different times, there is some coincident peak in the late afternoon. Therefore, it is important to look critically at those hours to see if there is enough capacity for the potential demand.

Since the initial study, significantly more CCN charge data has become available for analysis. Approximately 50% of the CCN charging stations have been installed at locations that primarily support driver workplace charging. Figure 5-13 illustrates the aggregated daily charging pattern of workplace charging for the last two weeks of July 2017. The figure illustrates a consistent weekday charging pattern that begins early in the morning, reaches a peak by mid-morning, and is significantly reduced by noon. This charging pattern is consistent with the workplace charging profile presented earlier and is complementary to both the system and commercial service transformer profiles.

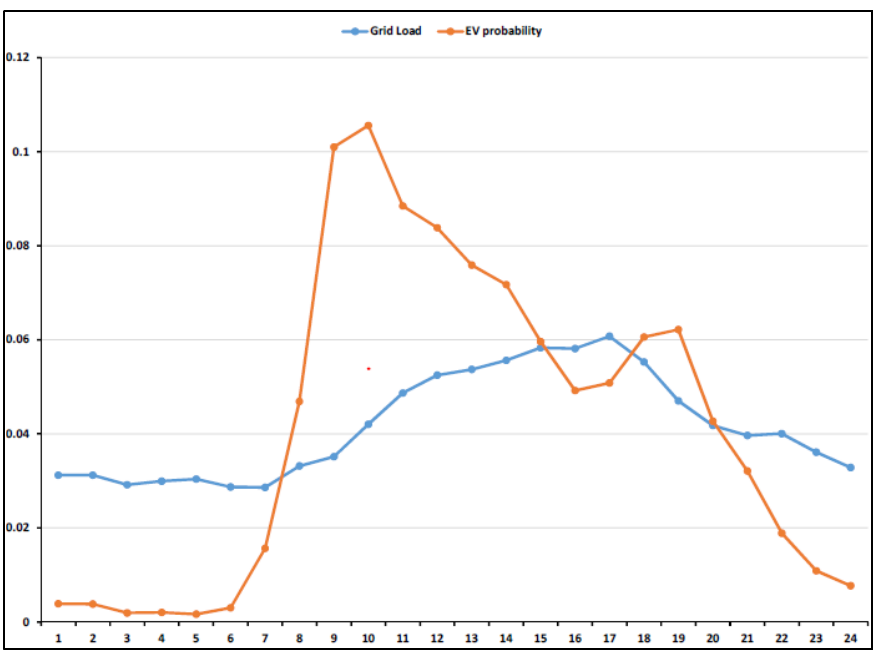

Figure 5-12
Probability of public PEV charging and normalized commercial load profile

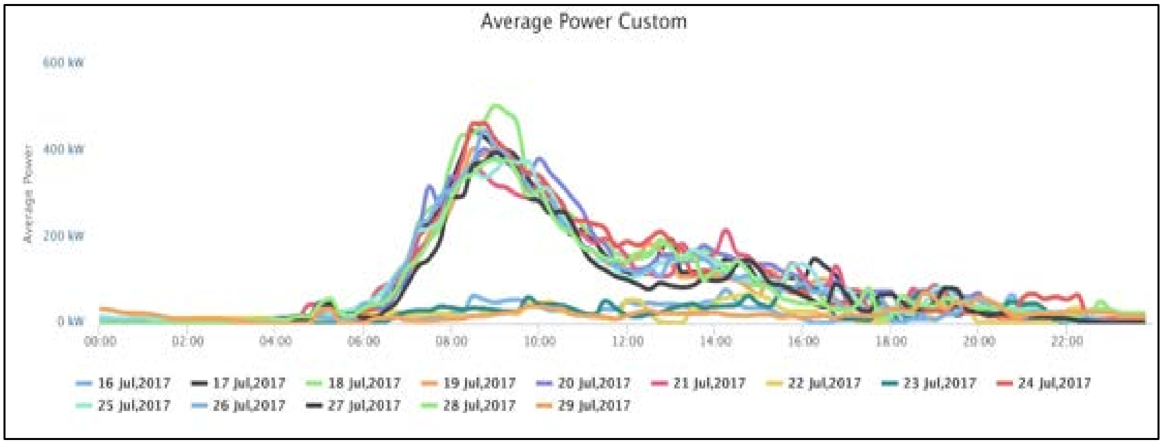

Figure 5-13
2017 CCN workplace charging profile, July 16 – 29, 2017

Approximately 40% of the CCN charging stations have been installed at retail/public venue locations that primarily support more transient or opportunistic driver charging. Figure 5-14 illustrates the aggregated daily charging pattern of retail/public venue charging for the last two weeks in July 2017. The figure illustrates a very random daily charging pattern that begins in the morning and continues through the remainder of the day. This charging pattern is consistent with the community charging profile presented earlier and identifies some small potential contribution to system peak during the 4:00 - 6:00 PM hours.

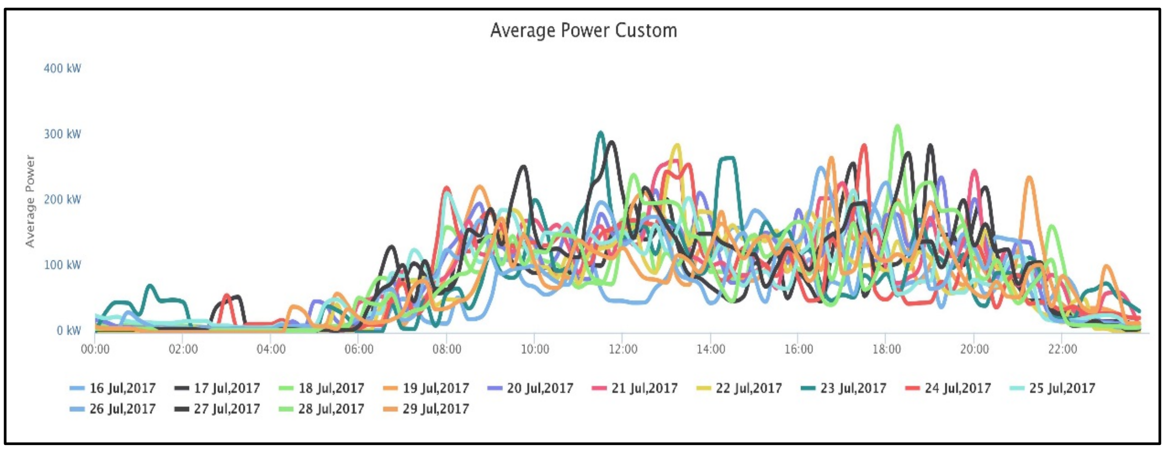

Figure 5-14
2017 CCN retail/public venue charging profile, July 16 – 29, 2017

As the Phase 1 study indicated, EPRI would not expect any significant load issues on commercial distribution feeders resulting from workplace or public charging in the near future.

Distribution System – Residential Neighborhood Level Impact

This study provides a more in-depth look at the impact PEV adoption could have on the distribution grid at the localized residential neighborhood level. This analysis performed a high-level screening of residential service transformer capacity assuming a statistically representative population of PEVs are adopted throughout the GPES service territories. EPRI's Hotspotter tool was used to estimate how many transformers may be overloaded in a Low Adoption scenario vs.

a Low Adoption scenario. The Low Adoption scenario is used to represent baseline PEV adoption, or a business-as-usual scenario for adoption, assuming no third-party or utility inducements are provided. The Medium Adoption scenario presented in Section 2 represents an above-and-beyond adoption scenario assuming that the Clean Charge Network and other programs or incentives continue to stimulate additional PEV adoption.

The Hotspotter tool provides first-level screening of distribution system impacts of PEV adoption. Because specific customer characteristics, propensity to adopt, and individual customer service drops are not considered, the results are best used to estimate how many transformers may need to be upgraded, not which specific transformers should be upgraded. Using the Hotspotter results, a utility may choose to do further, more detailed analyses to better understand expected impacts on specific portions of the distribution system.

GPES Service Territory Transformer Summary

The GPES Service territories consists of just over 200,000 service transformers. These transformers are classified as serving commercial (GS), residential (RS), or mixed load (a combination of both commercial and residential) classes. GPES provided data for 203,249 service transformers within its service territory, 128,576 of those identified as serving residential customers. Note that in the data provided, 15,787 transformers did not have a load class identified. These data are summarized in Table 5-4.

Table 5-4
GPES service transformers broken out by jurisdiction and load class

	Residential	Commercial	Mixed	Unknown	Total
GMO	68,001	14,656	10,638	5,716	99,011
KCP&L KS	34,415	8,072	8,290	5,033	55,810
KCP&L MO	26,160	9,304	7,926	5,038	48,428
GPES Total	128,576	32,032	26,854	15,787	203,249

The focus of the Phase 2 distribution impacts assessment is on residential transformers; Figure 5-15 is a histogram of the number of residences connected to each residential transformer by jurisdiction. About 93% of GPES residential service transformers serve 10 or fewer residences.

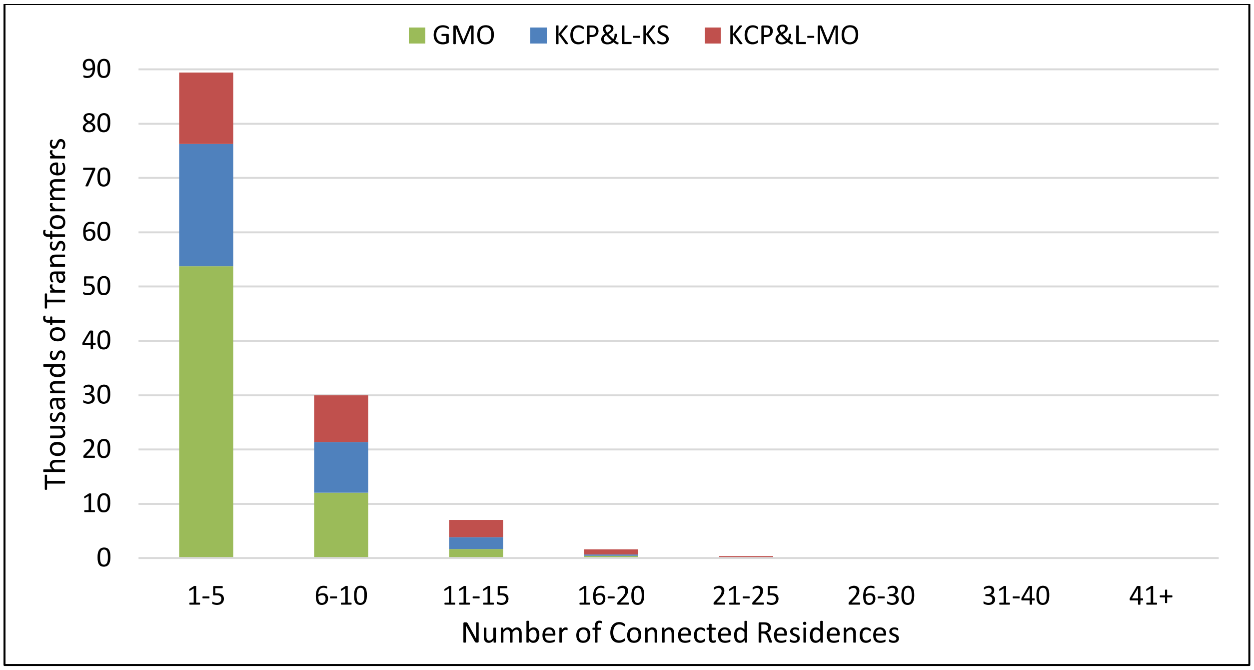

Figure 5-15
Histogram of the number of residences served by residential transformers by jurisdiction

Figure 5-16 shows the total residential kilovolt-amp (kVA) capacity for each jurisdiction broken down by overhead vs. underground transformers. If a transformer needs to be upgraded, it is much more expensive to upgrade an underground transformer than an overhead transformer. Approximately 60% of GPES residential transformers are overhead, however these overhead transformers comprise only 48% of total transformer capacity because they tend to have lower ratings.

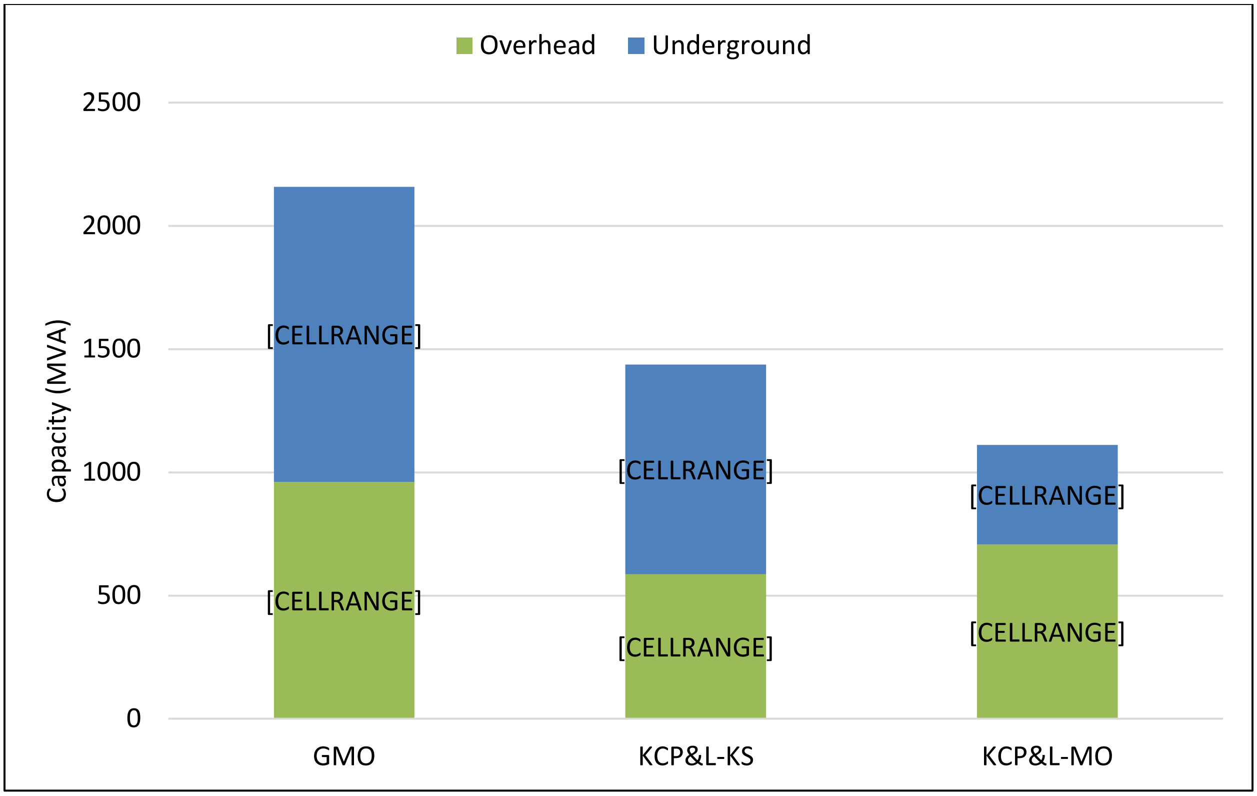

Figure 5-16
Total kilovolt-amp (kVA) capacity broken down by transformer location by jurisdiction

GPES Hotspotter Inputs

The Hotspotter tool assesses the likelihood of service transformers overloading given their kilovolt-amp rating, the number of residences they serve, and a probabilistic vehicle population. Probabilities for the number of total vehicles per home, home arrival time for a given vehicle, and miles driven during the day describe baseline vehicle usage. Estimated PEV saturation along with the probability of adopting one of six PEV types (with varying battery sizes and charge capacities) drives the PEV adoption at each home. The Hotspotter tool uses these inputs to estimate the likelihood of a transformer overloading given the added PEV charging load.

The Hotspotter analysis focused on GPES residential transformers (load class RS) with a rating greater than zero, and with annual kilowatt-hour consumption greater than zero. Appendices A-C summarizes the number of assets with data in each GPES jurisdiction. These 125,831 secondary transformers serve a total of 559,145 residences across GPES jurisdictions. Note that only 2,745 residential transformers were excluded from the Hotspotter analysis where no loading data was available.

The probability of overload is based on the transformer rating, the number of attached residences, and the current load expected on the transformer. Each home has the same probability of PEV adoption and mix, therefore the capacity per residence served by a transformer may be indicative of the likelihood of overload in a transformer rating category. For instance, with equal likelihood of PEV adoption at each home, a 25-kVA transformer serving five homes may have a higher probability of overload than a 50-kVA transformer serving five homes.

Table 5-5 shows the current average installed kilovolt-amp transformer capacity per home for various transformer ratings and jurisdiction. Note that above the 10-kVA rating the capacity per home rises to the 10-15 kVA/home range, with an average 13 kVA per residence across all jurisdictions.

Table 5-5
Average kilovolt-amp capacity per residence for select transformer ratings, by jurisdiction

Transformer Rating	Transformer Rated Capacity per Residence			
	GMO	KCP&L-KS	KCP&L-MO	GPES Overall
5 kVA	5 kVA	5 kVA	5 kVA	5 kVA
10 kVA	9 kVA	9 kVA	9 kVA	9 kVA
15 kVA	12 kVA	12 kVA	10 kVA	12 kVA
25 kVA	13 kVA	16 kVA	12 kVA	14 kVA
37 kVA	10 kVA	7 kVA	6 kVA	9 kVA
38 kVA	13 kVA	9 kVA	7 kVA	12 kVA
50 kVA	14 kVA	15 kVA	10 kVA	13 kVA
75 kVA	20 kVA	14 kVA	12 kVA	15 kVA
100 kVA	21 kVA	15 kVA	17 kVA	17 kVA
167 kVA	22 kVA	30 kVA	34 kVA	29 kVA
Overall	13 kVA	14 kVA	11 kVA	13 kVA

Analysis of the GPES automated metering infrastructure (AMI) data found residential customers have on average a 15-minute peak demand of approximately 8 kVA. Considering that most new PEVs will charge at 6.6 kVA or higher, adding a single PEV in a home could have significant impacts on individual customer peak demand.

The PEV options in Hotspotter have charge power ranging from 2.8 kW to 19.2 kW, with an average energy use of 350 watt-hours/mile; vehicle charging is assumed to be 100% efficient in all scenarios. The weighted average distance that a car drives each day is 34.6 miles/day. More detailed PEV assumptions for this work can be found in Appendix D.

Hotspotter Results

Four scenarios were run for each jurisdiction to estimate the impacts of two PEV adoption scenarios (Low vs. Medium) and managed vs. unmanaged charging. The distribution system impacts for hour beginning 17 (5:00 PM – 6:00 PM) were of primary interest, along with the impacts of managed charging in hours beginning 17 and 0 (5:00 PM and midnight). Managed charging assumes that evening charging (beginning at 5:00 PM) is shifted to start at midnight.

One scenario was run with zero PEV adoption to determine the number of probable existing transformer overloads before PEV charging is introduced. The resulting probable overloads for this base scenario were then netted out of the overloads identified for the four PEV scenarios.

The results focus on changes in service transformer overloading going from the Low to Medium adoption scenarios—the additional overloading expected in the Medium, above-and-beyond scenario. Eight sets of results are presented for each jurisdiction, for each of the following four scenarios in 2025.

1. Additional overloads for unmanaged charging in hour beginning 0, for the Medium and Low Adoption scenarios.
2. Additional overloads for unmanaged charging in hour beginning 17, for the Medium and Low Adoption scenarios.
3. Changes to overloads for the medium managed charging, compared to the Medium Adoption scenario with unmanaged charging in hour beginning 0.
4. Changes to overloads for the Medium Adoption scenario managed charging, compared to the Medium Adoption scenario with unmanaged charging in hour beginning 17.

The results are comprised of a list of transformers that have a non-zero probability of overloading with the chosen population of PEVs applied. This gives a sense for the magnitude of service transformer overloads that may result from PEV charging at home. With the charging that would have begun between 5:00 PM and midnight shifted to begin at midnight, there is the possibility for the additional overloads in the midnight hour to exceed the number of overloads reduced in one evening hour (5:00 - 6:00 PM).

The base scenario with zero PEVs has 218 probable overloads from midnight to 1:00 AM, and 1,703 probable overloads 5:00 to 6:00 PM[3]. These are overloads that are likely to occur without any PEVs on the system or are existing expected overloads. These were netted out of the overloads identified by Hotspotter to better represent the impacts of PEV charging. To put this into context, at midnight there is a lower likelihood of transformer overloading, and in the base scenario only 218 transformers or 0.2% of all residential transformers start out overloaded, which is in line with expectations.

Table 5-6 summarizes the probable occurrence of residential transformer overloads across the GPES service territories that could result from PEV adoption. The results presented evaluate the number of PEVs that would be present in 2025 under the Low and Medium PEV adoption scenarios and show the number of potential transformer overloads that could occur from unmanaged and managed charging. Unmanaged charging was tested with the 5:00 - 6:00 PM hour as the most likely charge initiation hour. Managed charging was tested with the midnight to 1:00 AM hour as the most likely charge initiation hour under a TOU rate. Transformer overloads that Hotspotter identified that would have occurred under a zero PEV adoption scenario have been netted out to show only the impact of PEV charging.

The introduction of PEVs with unmanaged charging introduced an increased occurrence of overloads for the evening and late-night hours under both adoption scenarios. However, under both adoption the number of potential overloads is significantly greater in the 5:00 - 6:00 PM hour. The 105 transformer overloads identified under the Medium, unmanaged charging Adoption scenario represent about 0.08% of the GPES residential transformers.

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[3] This is the number of likely overloads during a particular hour at a 90% confidence interval.

The results for managed home charging with TOU rates show an increase in the number of potential overloads in the 0 to 1:00 AM hour, but also show a significant reduction in the 5:00 - 6:00 PM hour. This reflects vehicle charging that would have started in the evening shifting to beginning at midnight. The 23 transformer likely overloads identified under the low adoption scenario between 5:00 and 6:00 PM represent about 0.02% of the GPES residential transformers.

In summary, as PEV adoption increases, managing residential home charging with a TOU rate decreases the number of likely transformer overloads. Specifically, for the 2025 Medium PEV Adoption scenario, likely transformer overloads are reduced by 91 during the 5:00 - 6 00 PM hour, and there are over 51 likely additional overloads at midnight. Managing charging with TOU decreases the likelihood of overloads during the 5 00 - 6:00 PM hour by 87%. In the managed case, the Hotspotter results for the two hours of 5:00 - 6:00 PM and midnight to 1:00 AM, there is a net reduction of about 40 likely overloads or 0.0003% of the residential transformers considered in this study.

Table 5-6
Summary of overall GPES Hotspotter results—number of likely transformer overloads (90% confidence level) for three scenarios with incremental impacts of medium PEV adoption in 2025

	Low PEV Adoption			Medium PEV Adoption		
	Unmanaged	Managed	Net Reduction with TOU	Unmanaged	Managed	Net Reduction with TOU
# PEVs	6,457	6,457	6,457	34,569	34,569	34,569
5:00 to 6:00 PM	23	4	19	105	14	91
0 to 1:00 AM	1	14	-13	5	56	-51
Total for these two hours	24	18	6	110	70	40

These results are a starting point to understanding the distribution impacts of residential PEV charging. More detailed analysis would be required to further analyze the localized grid impacts of PEV adoption and charge management techniques. More detailed data including customer propensity to adopt PEV, customer characteristics, and more detailed individual transformer loading would be needed to understand where PEVs are most likely to be adopted in the system, and what the impact would be for specific transformers. Further analysis could assess the potential for other charge management techniques to reduce the quantity of potential residential transformer overloads.

GMO

Appendix A, Table A-4 shows the occurrence of non-zero probability of overload for GMO assets during two hours (beginning 0 and 17), for two unmanaged scenarios (Low and Medium Adoption), and for medium PEV adoption with managed charging. Moving to managed home charging for the additional PEVs estimated in the medium scenario increases the number of likely transformers with some probability of overload in hour beginning 0 and decreases the number of overloads expected in hour beginning 17. This reflects vehicle charging that would have started in the evening shifting to begin in the midnight to 1:00 AM hour.

In summary, as PEV adoption increases, managing residential home charging with a TOU rate decreases the number of likely transformer overloads. Specifically, the 2025 medium PEV adoption transformer likely overloads are reduced by eight during the 5:00 – 6:00 PM hour, and there are six additional likely overloads at midnight. Managing charging with TOU decreases the likelihood of overloads during the 5:00 – 6:00 PM hour by 88%. In the managed case, the Hotspotter results for the two hours of 5:00 to 6:00 PM and midnight to 1:00 AM, there is a net reduction of 16 likely overloads for residential transformers considered in this study.

KCP&L-MO

Appendix B, Table B-4 shows the occurrence of non-zero probability of overload for KCP&L-MO assets during two hours (beginning 0 and 17), for two unmanaged scenarios (Low and Medium Adoption), and for Medium PEV adoption with managed charging. Moving to managed home charging for the additional PEVs estimated in the Medium scenario increases the number of transformers with some probability of overload in the hour beginning 0 and decreases the number of overloads expected in the hour beginning 17. This reflects vehicle charging that would have started in the evening shifting to begin in the midnight to 1:00 AM hour.

In summary, as PEV adoption increases, managing residential home charging with a TOU rate decreases the number of likely transformer overloads. Specifically, in the 2025 Medium PEV Adoption scenario, likely transformer overloads are reduced by six during the 5:00 – 6:00 PM hour, and there are three additional likely overloads at midnight. Managing charging with TOU decreases the likelihood of overloads during the 5:00 – 6:00 PM hour by 86%. In the managed case, the Hotspotter results for the two hours of 5:00 to 6:00 PM and midnight to 1:00 AM there is a net decrease of 15 overloads for the residential transformers considered in this study.

KCP&L-KS

Appendix C, Table C-4 shows the occurrence of non-zero probability of overload for KCP&L-KS assets during two hours (beginning 0 and 17), for two unmanaged scenarios (Low and Medium Adoption), and for Medium PEV adoption with managed charging. Moving to managed home charging for the additional PEVs estimated in the Medium scenario increases the number of likely transformers with some probability of overload in hour beginning 0 and decreases the number of overloads expected in hour beginning 17. This reflects vehicle charging that would have started in the evening shifting to begin in the midnight to 1:00 AM hour.

In summary, as PEV adoption increases, managing residential home charging with a TOU rate decreases the number of likely transformer overloads. Specifically, in the 2025 Medium PEV adoption scenario, likely transformer overloads are reduced by six during the 5:00 – 6:00 PM hour, and there are three additional likely overloads at midnight. Managing charging with TOU decreases the likelihood of overloads during the 5:00 – 6:00 PM hour by 85%. In the managed case, the Hotspotter results for the two hours of 5:00 to 6:00 PM and midnight to 1:00 AM there is a net decrease of nine overloads for the residential transformers considered in this study.

Grid Impact Summary

GPES system capacity needs for 2025 levels of PEV under the Medium Adoption scenario are projected to be about 3.7% of the current GPES 6,400 MW generating capacity; with managed charging this is reduced to about 1.4% of current capacity. Using the approach presented here, it would take over 250,000 PEVs, or about 12% of total 2017 estimated number of vehicles in the GPES service territories before the 2016 peak would have exceeded 6400 MW.

This study provides a more in-depth look at the impact PEV adoption could have on the distribution grid at the localized residential neighborhood level. Based on this analysis, EPRI would not expect any significant loading issues on commercial distribution feeders resulting from workplace or public charging in the near future. EPRI's Hotspotter tool projected that approximately 0.08% of distribution transformers may become overloaded based on the 2025 PEV medium adoption scenario. Overall, these results indicate that, in the near term, the impacts of PEV adoption on the residential distribution grid will be modest and manageable.

The results presented here comparing the GPES 2016 system load data plus PEV charging load to GPES generation capacity indicate that a PEV population of about 250,000 could be supported before the 2016 peak would have exceeded 6,400 MW. This represents about 12% of the vehicles in the GPES service territories converting to PEV, and these levels of PEV adoption may be reached in the next 20 to 30 years, or sooner depending on market uptake.

This suggests that further study may be warranted to better understand the charge behavior of GPES residential customers to better predict how residential charging needs can be actively managed and to what level. A better understanding of how vehicle and EVSE population changes over time would improve system impacts predictions, particularly as PEV adoption is expected to grow over time.

6
RATEPAYER IMPACTS OF EV ADOPTION

This section describes the results of simulations of increased electric vehicle adoption stimulated by the implementation of the Clean Charge Network. The construction of the CCN reduces driver range anxiety by providing drivers access to readily accessible public charging stations. While construction of the CCN will facilitate increased PEV adoption, the majority of PEV charging will occur at home and workplace locations, not at the CCN stations. This analysis shows that there is a net positive benefit to all utility customers from utility rate-based charging infrastructure. The key success factor is vehicle adoption. EPRI tested the Medium Adoption scenario for each GPES service area and found that the CCN investment has a benefit cost ratio of over 2.35 and produced over $36 million in present value net benefits for all customers.

Methodology for Evaluating Ratepayer Effects

This section updates the ratepayer impact analysis in the preliminary scoping analysis conducted in 2016 for KCP&L-KS. This report provides a more detailed analysis of the net benefits to ratepayers in each GPES service territory. This analysis applied the updated PEV adoption scenarios and detailed charging profiles presented earlier in this report and assessed the impact of the CCN investment through the ratepayer impact measure, or RIM test. The RIM test is a comparison of the revenue the consumption produces to the incremental costs of the utility equipment, including electricity supply, capital, installation and maintenance costs. Ratios greater than 1.0 are beneficial to ratepayers and perhaps shareholders, while ratios less than 1.0 produce a subsidy that must either be assumed by ratepayers or shareholders. This test is also sometimes referred to as the all ratepayers test because it assesses the impacts on all ratepayers, both participants and non-participants [44].

The RIM test is calculated based on the following items shown below (the equation is also provided). Note that the equation depicts the RIM in terms of net present value, as opposed to a benefit-cost ratio.

- Utility Bills – a measure of ratepayer benefit from electricity use, summed over the life of the installed equipment.
- Rate-based (RB) Charger Cost – the portion of vehicle charger costs covered in the rate base.
- Incremental Supply Costs – long-run marginal costs of demand and energy needed to supply the EV charging plus losses and reserve margins.

$$Net\ RIM\ Benefit = Utility\ Bills - RB\ Charging\ Costs - Incremental\ Supply\ Costs$$

In the previous sections, there are two charging options described, one for home charging only and one for “charging available everywhere.” The ratepayer impact analysis focused on “charging available everywhere” to capture the effects of charging in workplaces and community locations, along with the effects of home charging. These charging profiles reflect a diversified single-vehicle load shape for each of the three scenarios –charging at home, at work, and in the community at large wherever charging infrastructure is available. Table 6-1 shows the assumed distribution of energy consumption for each of these three scenarios. This charging profile is the same whether the home charging is managed (charging under TOU rate) or unmanaged (charging under standard rate) – the energy used to charge remains the same, only the timing of the charge differs. Workplace and Community, or CCN, charging are unmanaged charging.

Table 6-1
Distribution of charging in three scenarios, as a percentage of total charging consumption

	Home	Workplace	Community	Total
Weekday	44.8%	25.4%	29.8%	100.0%
Weekend	46.4%	17.2%	36.4%	100.0%

The estimates are averages across all expected PEV charging consumers. Some customers may charge exclusively at work while others may charge at community facilities, but these values reflect the average across all potential consumer charging applications.

The results described here use the data from the "PHEV40" vehicle scenario with a 6.6 kW charger, since this scenario provided a good representation of both BEVs with longer-range and shorter-range PHEVs charged at low power (the load shapes are similar in relative terms, but in absolute terms the PHEV40 uses more energy and charges at higher power than lower-range PHEVs).

An expected, average daily mile used for the PEV is assumed. This value is 34.6 miles driven per day (12,600 mi/year) [43]. The efficiency of the PEV is assumed at .352 kWh/mile (2.84 mile/kWh). This is equivalent to a "window sticker" fuel economy of 96 MPGe. Some smaller BEVs currently achieve up to 130 MPGe, but larger vehicles use more electricity. For example, the Tesla Model X achieves 89 MPGe. This value reflects an assumption that the vehicle classes in the PEV market become more similar to the general market over time.

These two assumptions produce a charging need of 12.2 kWh per day. This level of charging is distributed over the three scenarios of home, workplace and community and results in the pattern shown in Figure 6-1. The normalized values are applied to the 12.2 kWh per day to provide a consumption by time of day. It is assumed that the load profiles are the same in each GPES service territory.

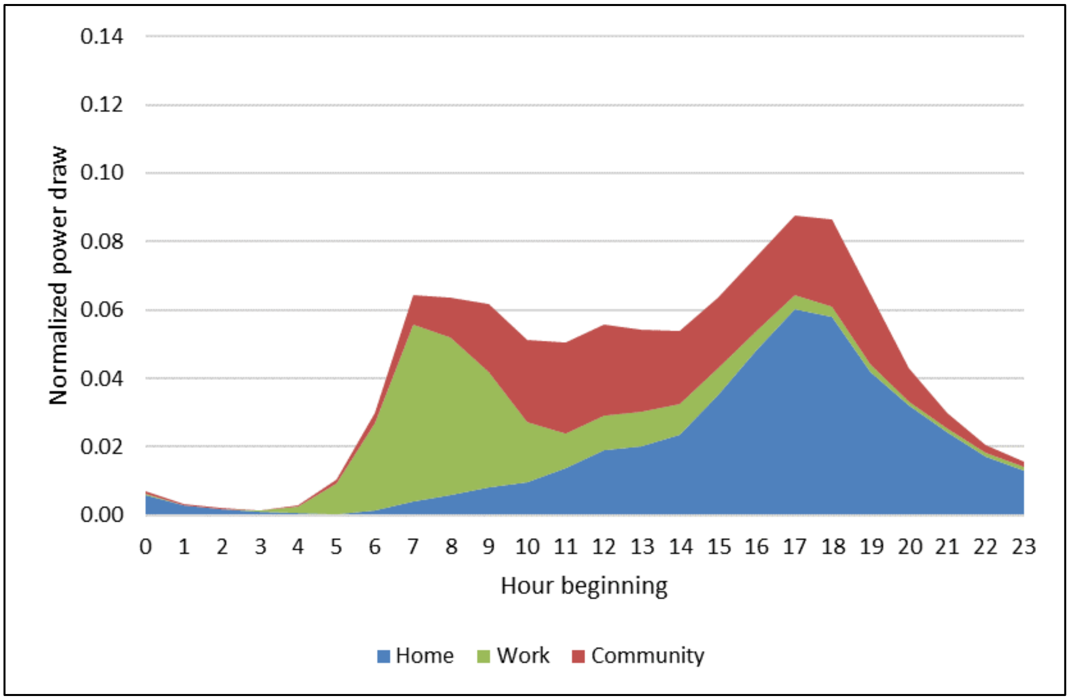

Figure 6-1
Weekday charging load profiles for three scenarios

PEV Revenues with Unmanaged Home Charging

The unmanaged power demands show a peak around 5:00 to 6:00 PM. This period is the highest demand and therefore the highest cost for most utilities, as consumers are returning home from work, plugging in their PEV, turning down their air conditioners, and beginning to cook dinner. Shifting charging patterns away from those high cost, high demand periods saves money for the utility, which ultimately saves money for all customers. Based on the unmanaged charging patterns used in this analysis, 29% of the daily charging requirements occur between the hours of 4:00 to 8:00 PM. The remainder occurs either during the rest of the day at home (15.8%) or at community sites (21.8%). Generally, workplace charging ends before 4:00 PM each day.

The incremental loads also produce additional revenues. For home charging, the default residential rate is used to price out the additional usage consumed by these PEVs. The end-block rate was used to estimate this amount. In each scenario, the additional demand and energy usage from workplace charging was priced based on the Medium General Service tariff at the <360 hours-use rate. Similarly, the usage for community charging is priced at the current Missouri CCN rates of 20 cents/kWh at Level 2 stations and 25 cents/kWh at Fast DC stations.

Table 6-2 provides an estimate of the additional 2016 revenues produced by a single PEV in each GPES jurisdiction. The unmanaged home charging scenario assumes that customers plug in and charge as soon as they arrive home, which creates a significant additional load coincident with the system and residential peak periods.

Table 6-2
2016 Revenue per PEV for each GPES jurisdiction for unmanaged charging scenario

GMO	**Summer**	**Winter**	**Annual**
Home (unmanaged)	$85.87	$112.38	$198.25
Workplace	$29.52	$54.18	$83.70
Community	$98.31	$194.86	$293.17
Total revenue per PEV	$213.70	$361.41	$575.11
KCP&L-MO	**Summer**	**Winter**	**Annual**
Home (unmanaged)	$91.49	$123.47	$214.96
Workplace	$36.49	$56.17	$92.66
Community	$98.31	$194.86	$293.17
Total revenue per PEV	$226.29	$374.50	$600.78
KCP&L-KS	**Summer**	**Winter**	**Annual**
Home (unmanaged)	$95.20	$155.10	$250.30
Workplace	$35.45	$58.94	$94.38
Community	$98.31	$194.86	$293.17
Total revenue per PEV	$228.96	$408.89	$637.85
GPES Avg.*	**Summer**	**Winter**	**Annual**
Home (unmanaged)	$92.39	$137.15	$229.54
Workplace	$34.84	$57.20	$92.03
Community	$98.31	$194.86	$293.17
Total revenue per PEV	$225.54	$389.21	$614.74

*GPES weighted averages are based on the 2016 registered PEVs by jurisdiction. GMO-304, KCP&L-MO-642, KCP&L-KS-909, and GPES Total PEVs-1855

The average annual GPES increase in revenue per PEV for charging under the unmanaged Home charging scenario would be the sum of home, workplace and public charging, or approximately $615. This reflects a cost to drive of about 4.88 cents/mile. The equivalent gasoline costs would be 8.33 cents/mile assuming 30 MPG and $2.50 /gallon of gasoline.

PEV Revenues with TOU Managed Home Charging

The TOU managed home charging profile assumes that drivers assert control over the start of the charging period to avoid on-peak periods even though no TOU is in place or there is some intervention such as a timer of smart circuit designed to control the loads. Therefore, the TOU managed home load profile consumes the same daily energy as the unmanaged load profile but with a different pattern of use, Currently, all existing GPES residential TOU rates are frozen and unavailable to new customers, but GPES recently completed a comprehensive rate study and is proposing new TOU pilot rates in its upcoming rate cases. To model the revenue impact of a TOU managed home charging scenario, the TOU rates developed in the rate study were used since they were designed to be revenue neutral with current rates. As these TOU rates are designed to shift load away from peak times to avoid capacity charges, there will be a sizable savings on the cost side discussed later. The workplace and community charging impacts will remain the same

Table 6-3 provides an estimate of the additional 2016 revenues produced by a single PEV in each GPES jurisdiction. The TOU managed home charging scenario also assumes that 80% of home charging would be controlled in conjunction with TOU rates to reduce system impacts (for instance delaying charging to after midnight).

Table 6-3
2016 Revenue per PEV for each GPES jurisdiction for TOU managed charging scenario

GMO	**Summer**	**Winter**	**Annual**
Home (80% TOU)	$56.76	$82.57	$139.33
Workplace	$29.52	$54.18	$83.70
Community	$98.31	$195.52	$294.33
Total revenue per PEV	**$184.96**	**$332.17**	**$517.13**
KCP&L-MO	**Summer**	**Winter**	**Annual**
Home (80% TOU)	$69.13	$106.57	$175.71
Workplace	$36.44	$56.09	$92.53
Community	$98.81	$195.52	$294.33
Total revenue per PEV	**$204.38**	**$358.18**	**$562.56**
KCP&L-KS	**Summer**	**Winter**	**Annual**
Home (80% TOU)	$72.42	$126.50	$198.92
Workplace	$35.40	$58.85	$94.25
Community	$98.81	$195.52	$294.33
Total revenue per PEV	**$206.62**	**$380.87**	**$587.50**

The average annual increase in revenue per PEV for charging under the TOU managed home charging scenario would be the sum of home, workplace and public charging, or approximately $600. This reflects a cost to drive of about 4.76 cents/mile. The equivalent gasoline costs would be 8.33 cents/mile assuming 30 MPG and a price of $2.50 per gallon of gasoline.

GPES Incremental Costs to Support PEV Charging

The RIM test compared the increased revenue from the additional load consumed by the PEV to the costs it imposes on the system. The costs of providing power and energy to ratepayers depends upon the distribution of power demands across the days and across the week. High power demands in the late afternoon are coincident with the power demands of other consumers. These peak periods are the costliest in terms of generation fuel cost and the need for generation capacity to ensure power is available. These are considered energy and demand costs.

Energy Costs

Energy costs reflect the fuel costs, generation efficiency and mix, and losses incurred transporting the energy to its load. GPES participates in the Southwest Power Pool (SPP) which provides an integrated marketplace for energy prices that captures the current supply and demand conditions of loads and resources. Energy supply costs are driven by the fuel costs in the case of nuclear, coal and natural gas-fired units and supply and demand condition along with transportation costs for wind and hydro. For this analysis, 2016 SPP day-ahead hourly locational marginal prices (LMP) for the KCP&L and GMO nodes were used to represent the cost of energy supplied for PEV charging.

Generation Capacity Costs

For each of the unmanaged and managed charging scenarios, there are differing levels of PEV charging occurring during the system peak period, which typically occurs between 4:00 and 6:00 PM. Some wholesale markets like MISO, PJM, or NYISO operate a capacity market that provides short-run market pricing for capacity. SPP does not operate a capacity market, but short-term capacity agreements are made between market participants. Longer-term values of capacity reflect the least cost of capacity – typically a combustion turbine amortized over the twenty-year useful life of the unit. Markets are such that over the long term, short-run marginal capacity costs converge with long-run marginal capacity costs. In markets where excess capacity exists, the short-run marginal capacity may be significantly less than the long-run marginal costs. In this analysis, a 2016 long-run value of $102/kW-year for capacity was used, which will establish a higher cost and therefore a more conservative RIM test.

Transmission and Distribution Capacity Costs

This report previously presented the analysis of potential PEV adoption impacts on the transmission and distribution grid. The analysis shows that the GPES transmission system has more than enough capacity available to support a large number of PEVs in its service territory. Further analysis of workplace charging patterns is complementary to both the system and commercial distribution feeder load profiles and would have minimal impact on the distribution system feeding commercial/business districts. The Hotspotter results indicated that residential transformer overloading during typical system peak hours (hot summer afternoons) may be significant. Shifting charging start times from the evening to after midnight reduces the stress from PEV charging, but may still require the installation of a significant amount of residential transformer capacity. In this analysis, $20/kW-year for distribution capacity was used to address these potential future costs.

RIM Test for EV Charging without CCN Investments

Table 6-4 provides a comparison of those RIM ratios across the three scenarios and a fourth for the Home (TOU managed) charging profiles. Table 6-4 provides the revenues and costs to GPES ratepayers from the incremental adoption of electric vehicles. The table reflects the incremental value to the GPES electric systems, in 2016 dollars, from the addition of one additional PEV. It is weighted across the three types of charging situations – home, work and community.

For an unmanaged home charging profile, the average net benefit of a single PEV to GPES ratepayers is $331.42/year with a RIM test ratio of 2.17. If the home loads are managed in such a way to avoid system peak conditions the net benefit to GPES ratepayers is $381.04/year with a RIM test ratio of 3.05. This difference reflects the capacity savings produced by shifting charging load away from the system peak to lower costs periods in the late evening or early morning and the reduced revenue from charging under a lower TOU retail rate.

Incremental Revenues from Increased PEV adoption

Table 6-5 applies the 2016 net revenue for the 80% TOU managed home charging scenario to the three PEV adoption projections developed in Section 2 of this report. The low projection is considered the adoption level with no additional encouragement by government or GPES actions. The medium projection reflects the expected vehicle sales with intervention by GPES to provide public charging facilities that will help allay potential buys wariness about the range of this form of transportation. The high projection is an optimistic forecast based on high customer acceptance of electric vehicles.

There are several significant points to be made about this table. First, the net revenues are presented in 2016 dollars. The inflation and discount rates have not been included in order to observe the real monetary impacts of the growth in PEV adoption. The use of real escalation rates eliminates the benefits that may accrue when inflation rates and discount rates differ. Secondly, the benefits reflect the current rate and projected TOU rate structures. Should GPES rate structures and class cost allocations change over time, the net benefits may change accordingly.

Similar tables for each GPES service territory are contained in Appendices A, B and C.

Table 6-4
2016 GPES PEV cost-effectiveness without CCN

GMO	Marginal Revenues	Marginal Costs	Net Revenue ($/year)	Ratepayer Test (RIM)
Home (unmanaged)	$198.25	$168.86	$29.39	1.1740
Workplace	$83.70	$32.68	$51.02	2.5611
Public	$293.17	$80.04	$213.13	3.6628
Home (TOU)	$124.60	$47.32	$77.28	2.6330
Unmanaged Total	**$575.11**	**$281.58**	$293.53	**2.0424**
80% TOU Scenario	**$516.20**	**$184.35**	$331.85	**2.8001**
KCP&L-MO	**Marginal Revenues**	**Marginal Costs**	**Net Revenue ($/year)**	**Ratepayer Test (RIM)**
Home (unmanaged)	$214.96	$169.18	$45.78	1.2706
Workplace	$92.66	$33.13	$59.54	2.7972
Public	$293.17	$80.83	$212.33	3.6267
Home (TOU)	$166.21	$47.45	$118.76	3.5027
Unmanaged Total	**$600.78**	**$283.14**	$317.65	**2.1219**
80% TOU Scenario	**$561.79**	**$185.76**	$376.03	**3.0243**
KCP&L-KS	**Marginal Revenues**	**Marginal Costs**	**Net Revenue ($/year)**	**Ratepayer Test (RIM)**
Home (unmanaged)	$250.30	$169.77	$80.53	1.4744
Workplace	$94.38	$33.27	$61.11	2.8370
Public	$293.17	$81.00	$212.16	3.6192
Home (TOU)	$187.21	$47.66	$139.56	3.9283
Unmanaged) Total	**$637.85**	**$284.04**	$353.81	**2.2457**
80% TOU Scenario	**$587.38**	**$186.35**	$401.03	**3.1520**
GPES Weighted Avg.	**Marginal Revenues**	**Marginal Costs**	**Net Revenue ($/year)**	**Ratepayer Test (RIM)**
Home (unmanaged)	$229.54	$169.42	$60.12	1.35
Workplace	$92.03	$33.12	$58.91	2.78
Public	$293.17	$80.78	$212.38	3.63
Home (TOU)	$169.68	$47.53	$122.15	3.57
Unmanaged Total	**$614.74**	**$283.33**	$331.42	**2.17**
80% TOU Scenario	**$566.86**	**$185.82**	$381.04	**3.05**

Table 6-5
GPES net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016 $)
2014	845	845	845	$321,979	$321,979	$321,979	805	$306,737
2015	1,213	1,225	1,323	$462,202	$466,774	$504,116	1,139	$434,005
2016	1,589	1,830	2,246	$605,473	$697,303	$855,816	1,853	$706,067
2017	2,016	2,885	3,718	$768,177	$1,099,300	$1,416,707	2,790	$992,990
2018	2,501	4,502	5,761	$952,981	$1,715,442	$2,195,171		
2019	2,957	6,745	8,692	$1,126,735	$2,570,115	$3,312,000		
2020	3,421	9,540	13,318	$1,303,538	$3,635,122	$5,074,691		
2021	3,884	13,060	20,877	$1,479,959	$4,976,382	$7,954,972		
2022	4,412	17,355	31,749	$1,681,148	$6,612,949	$12,097,639		
2023	4,993	22,337	46,041	$1,902,533	$8,511,290	$17,543,463		
2024	5,639	28,041	63,828	$2,148,685	$10,684,743	$24,321,021		
2025	6,457	34,569	85,660	$2,460,375	$13,172,172	$32,639,886		
2026	7,369	42,001	112,630	$2,807,884	$16,004,061	$42,916,535		
2027	8,425	50,462	144,805	$3,210,262	$19,228,040	$55,176,497		
2028	9,619	60,238	182,548	$3,665,224	$22,953,088	$69,558,090		
2029	10,935	71,326	225,994	$4,166,672	$27,178,059	$86,112,754		
2030	12,340	84,027	275,721	$4,702,034	$32,017,648	$105,060,730		
2031	13,860	98,432	328,906	$5,281,214	$37,506,529	$125,326,342		
2032	15,478	114,818	384,859	$5,897,737	$43,750,251	$146,646,673		
2033	17,155	133,168	443,345	$6,536,741	$50,742,335	$168,932,179		
2034	18,873	153,513	504,249	$7,191,368	$58,494,594	$192,139,039		
2035	20,622	175,911	567,188	$7,857,807	$67,029,127	$216,121,316		
2036	22,381	200,044	630,574	$8,528,056	$76,224,766	$240,273,917		
2037	24,150	225,869	693,961	$9,202,116	$86,065,124	$264,426,899		
2038	25,911	253,359	757,097	$9,873,127	$96,539,913	$288,484,241		
2039	27,672	282,398	819,658	$10,544,139	$107,604,934	$312,322,484		
2040	29,388	312,903	881,359	$11,198,004	$119,228,559	$335,833,033		
2041	31,088	344,385	940,837	$11,845,772	$131,224,460	$358,496,530		
2042	32,733	376,857	998,102	$12,472,582	$143,597,591	$380,316,786		
2043	34,328	410,252	1,053,043	$13,080,341	$156,322,422	$401,251,505		
2044	35,884	444,502	1,105,561	$13,673,239	$169,373,042	$421,262,963		
2045	37,400	479,514	1,155,762	$14,250,896	$182,714,015	$440,391,552		
2046	38,860	514,686	1,202,826	$14,807,214	$196,115,953	$458,324,819		
2047	40,287	549,951	1,246,861	$15,350,958	$209,553,329	$475,103,915		
2048	41,682	585,208	1,288,054	$15,882,509	$222,987,656	$490,800,096		
2049	43,035	620,418	1,326,572	$16,398,056	$236,404,075	$505,476,995		
2050	44,384	655,548	1,362,668	$16,912,079	$249,790,010	$519,231,015		

Ratepayer Impact of the Clean Charge Network

The next analysis describes the impact on ratepayers of rate-based utility investment in the Clean Charge Network and the resulting increased electric vehicle adoption stimulated by the CCN. Table 6-6 contains the estimated allocation of CCN charging stations by jurisdiction and the respective capital investment and carrying charges.

Table 6-6
Clean Charge Network Charging Infrastructure Investment

	# Stations	Est. Capital Investment	PV Capital Carrying Cost	Levelized Annual Capital Carrying Cost
GMO	275	3,712,500	$4,242,144	$596,439
KCP&L-MO	440	$5,940,000	$6,787,430	$954,303
KCP&L-KS	280	$3,780,000	$4,319,274	$607,283
GPES Total	995	13,432,500	$15,348,848	$2,158,025

Incremental Net Benefits of Increased PEV Adoption from CCN

The following tables show the net annual benefits for the incremental PEV adoption using the 80% TOU managed home charging profile along with the work and community benefits. Table 6-7 depicts the three PEV adoption scenarios, Low, Medium, and High. Low reflects the expected PEV adoption with no additional encouragement by government or GPES actions. The Medium case reflects the expected PEV adoption resulting from construction of the CCN and modest government and private incentives. The difference between these two adoption scenarios reflects the incremental impact of the CCN and was compared to the rate-based charging facilities and operating costs of the CCN over the next few years. There are several significant caveats to be made about these tables. First, inflation and discounting rates have been removed from Table 6-7 to observe the real monetary impacts of the growth in vehicle adoption. The use of real escalation rates eliminates the benefits that may accrue when inflation rates and discount rates differ. The net annual benefits contained in these tables illustrate the real incremental growth in benefits over time attributable to the CCN moving PEV adoption from the low to medium adoption scenario.

Table 6-7
GPES net benefits of incremental (medium minus low) PEV adoption without inflation

Year	Low PEV	Medium PEV	Delta PEVs	Per PEV Revenue $/yr	Incremental Revenue $/yr	Annual CCN O&M	Net Annual Benefit $/yr
2014	845	845	0	$381.04			
2015	1,213	1,225	12	$381.04	$4,572		$4,572
2016	1,589	1,830	241	$381.04	$91,831		$91,831
2017	2,016	2,885	869	$381.04	$331,124	$199,000	$132,124
2018	2,501	4,502	2,001	$381.04	$762,461	$199,000	$563,461
2019	2,957	6,745	3,788	$381.04	$1,443,380	$199,000	$1,244,380
2020	3,421	9,540	6,119	$381.04	$2,331,584	$199,000	$2,132,584
2021	3,884	13,060	9,176	$381.04	$3,496,423	$199,000	$3,297,423
2022	4,412	17,355	12,943	$381.04	$4,931,801	$199,000	$4,732,801
2023	4,993	22,337	17,344	$381.04	$6,608,758	$199,000	$6,409,758
2024	5,639	28,041	22,402	$381.04	$8,536,058	$199,000	$8,337,058
2025	6,457	34,569	28,112	$381.04	$10,711,796	$199,000	$10,512,796
2026	7,369	42,001	34,632	$381.04	$13,196,177	$199,000	$12,997,177
2027	8,425	50,462	42,037	$381.04	$16,017,778	$199,000	$15,818,778
2028	9,619	60,238	50,619	$381.04	$19,287,864	$199,000	$19,088,864
2029	10,935	71,326	60,391	$381.04	$23,011,387	$199,000	$22,812,387
2030	12,340	84,027	71,687	$381.04	$27,315,614	$199,000	$27,116,614
2031	13,860	98,432	84,572	$381.04	$32,225,315	$199,000	$32,026,315
2032	15,478	114,818	99,340	$381.04	$37,852,514	$199,000	$37,653,514
2033	17,155	133,168	116,013	$381.04	$44,205,594	$199,000	$44,006,594
2034	18,873	153,513	134,640	$381.04	$51,303,226	$199,000	$51,104,226
2035	20,622	175,911	155,289	$381.04	$59,171,321	$199,000	$58,972,321

Table 6-8 shows the net annual benefits for the incremental PEV adoption with inflation and illustrates the incremental growth in benefits over time attributable to the CCN moving PEV adoption from the low to medium adoption scenario. This table shows that for the combined GPES service territories, the annual value of incremental net benefits from increased PEV adoption exceeds the annual CCN capital carrying costs of $2,158,000 for all GPES jurisdictions in 2020.

Similar tables for each GPES service territory are contained in Appendices A, B and C.

Table 6-8
GPES net benefits of incremental (medium-low) PEV adoption with inflation

Year	Low PEV	Medium PEV	Delta PEVs	Per PEV Revenue $/yr	Incremental Revenue $/yr	Annual CCN O&M	Net Annual Benefit $/yr
2014	845	845	0	$362.23	$0		
2015	1,213	1,225	12	$371.51	$4,458		$4,572
2016	1,589	1,830	241	$381.04	$91,831		$91,831
2017	2,016	2,885	869	$390.57	$339,402	$199,000	$140,402
2018	2,501	4,502	2,001	$400.33	$801,061	$203,975	$597,086
2019	2,957	6,745	3,788	$410.34	$1,554,362	$209,074	$1,345,287
2020	3,421	9,540	6,119	$420.60	$2,573,632	$214,301	$2,359,331
2021	3,884	13,060	9,176	$431.11	$3,955,882	$219,659	$3,736,223
2022	4,412	17,355	12,943	$441.89	$5,719,377	$225,150	$5,494,227
2023	4,993	22,337	17,344	$452.94	$7,855,736	$230,779	$7,624,957
2024	5,639	28,041	22,402	$464.26	$10,400,358	$236,548	$10,163,809
2025	6,457	34,569	28,112	$475.87	$13,377,566	$242,462	$13,135,104
2026	7,369	42,001	34,632	$487.76	$16,892,223	$248,524	$16,643,699
2027	8,425	50,462	42,037	$499.96	$21,016,713	$254,737	$20,761,977
2028	9,619	60,238	50,619	$512.46	$25,940,032	$261,105	$25,678,927
2029	10,935	71,326	60,391	$525.27	$31,721,451	$267,633	$31,453,818
2030	12,340	84,027	71,687	$538.40	$38,596,248	$274,324	$38,321,924
2031	13,860	98,432	84,572	$551.86	$46,671,864	$281,182	$46,390,683
2032	15,478	114,818	99,340	$565.66	$56,192,269	$288,211	$55,904,058
2033	17,155	133,168	116,013	$579.80	$67,264,038	$295,417	$66,968,622
2034	18,873	153,513	134,640	$594.29	$80,015,523	$302,802	$79,712,721
2035	20,622	175,911	155,289	$609.15	$94,594,243	$310,372	$94,283,871

Present Value of Net Benefits of Incremental PEV adoption from CCN

Table 6-9 shows that for the combined GPES service territories, the present value of incremental net benefits from increased PEV adoption exceeds the present value of the capital carrying costs of $15,348,900 by 2024 and total over $36 million over the 10-year analysis period.

Table 6-9
GPES PV net benefits of incremental (medium-low) PEV adoption

Year	Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $	75% Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $
2016	241	$91,831	$90,207	181	$68,873	$67,656
2017	869	$140,402	$215,550	652	$55,551	$115,048
2018	2,001	$597,086	$727,780	1,501	$396,820	$454,452
2019	3,788	$1,345,287	$1,813,584	2,841	$956,697	$1,225,809
2020	6,119	$2,359,331	$3,597,841	4,589	$1,715,923	$2,522,709
2021	9,176	$3,736,223	$6,237,666	6,882	$2,747,253	$4,462,920
2022	12,943	$5,494,227	$9,879,074	9,707	$4,064,382	$7,155,888
2023	17,344	$7,624,957	$14,612,014	13,008	$5,661,023	$10,669,014
2024	22,402	$10,163,809	$20,521,984	16,802	$7,563,720	$15,066,361
2025	28,112	$13,135,104	$27,673,992	21,084	$9,790,712	$20,396,628
2026	34,632	$16,643,699	$36,160,714	25,974	$12,420,643	$26,729,267
2027	42,037	$20,761,977		31,528	$15,507,798	
2028	50,619	$25,678,927		37,964	$19,193,919	
2029	60,391	$31,453,818		45,293	$23,523,455	
2030	71,687	$38,321,924		53,765	$28,672,862	
2031	84,572	$46,390,683		63,429	$34,722,717	
2032	99,340	$55,904,058		74,505	$41,855,991	
2033	116,013	$66,968,622		87,010	$50,152,612	
2034	134,640	$79,712,721		100,980	$59,708,840	
2035	155,289	$94,283,871		116,467	$70,635,310	

Table 6-9 also presents the results of a sensitivity analysis to test the case where CCN stimulated PEV adoption may not achieve the levels projected by the medium adoption scenario. For this sensitivity analysis, it was assumed that the delta increase in PEV was 75% of the low-medium delta. Table 6-9 shows that under the lower adoption rate, the present value of benefits still exceeds the present value of the capital carrying costs of $15,348,900 by 2025 and totals over $26 million over the 10-year analysis period.

Similar tables for each GPES service territory are contained in the Appendices A, B and C.

RIM Test for CCN Investment with Increased PEV adoption

Table 6-10 presents the ratepayer impact for rate-basing the construction of the CCN and the accelerated adoption of PEVs for each of the GPES service territories. The RIM test is a comparison of the revenue the consumption produces to the incremental costs of the utility equipment, including electricity supply, capital, installation and maintenance costs. RIM test values in excess of 1.0 produce benefits in excess of costs, and avoid cross subsidization between participants and non-participants. For the combined GPES service territories, the present value of the CCN net benefits (increased revenues less marginal operating costs) of $36.1 million exceeded the present value of the CCN capital carrying costs of $15.3 million for a RIM test factor of 2.35 and produces over $20 million in additional benefits for all ratepayers.

These results are based on PEV adoption scenarios and charging patterns described in this section. The base analysis assumes that PEV adoption follows the Medium Adoption projection and that the incremental difference between the low and medium adoption projections reflects the incremental impact of the CCN. The 75% adoption sensitivity analysis presented earlier evaluated the case where the Medium Adoption projection is not fully achieved. Under the 75% adoption sensitivity scenario, the CCN still achieved a RIM test factor of 1.74 and produced over $11 million in ratepayer benefits.

The PEV net benefits summarized in Table 6-10 are based on the charging patterns described earlier in this section and are reflective of both the increased charging revenues less the marginal operating costs. The increased revenues reflect the home, workplace, and community charging percentages outlined in Table 6-1, with 80% of the home charging occurring under a TOU rate and the remainder unmanaged under the standard residential rate. The marginal operating costs include the marginal costs of energy, generation capacity and distribution capacity along with the operating and maintenance costs of the CCN stations.

Table 6-10
Ratepayer impact of Clean Charge Network

	# Stations	Est. Capital Investment	PV Capital Carrying Cost.	PV Net Benefits	RIM Test
PEV Medium Adoption Scenario					
GMO	275	$3,712,500	$4,242,144	$8,027,588	1.892
KCP&L-MO	440	$5,940,000	$6,787,430	$14,846,153	2.187
KCP&L-KS	280	$3,780,000	$4,319,274	$13,286,973	3.076
GPES Total	995	$13,432,500	$15,348,848	$36,160,714	2.356
75% Sensitivity Analysis Scenario					
GMO	275	$3,712,500	$4,242,144	$5,912,575	1.394
KCP&L-MO	440	$5,940,000	$6,787,430	$10,961,620	1.615
KCP&L-KS	280	$3,780,000	$4,319,274	$9,855,072	2.282
GPES Total	995	$13,432,500	$15,348,848	$26,729,267	1.741

The current CCN infrastructure investment is alleviating some of the range anxiety that exists for the current state of PEV technology. Accelerating PEV adoption will also accelerate the energy and non-energy benefits generally recognized when replacing internal combustion engines. Some have suggested that PEVs will be the dominant form of personal transportation in the not too distant future. If that is the case, then early adoption allows for a longer transformation period, giving utilities time to manage this growth and the resultant impact on their network. The potential grid impacts of PEV adoption provided in this report could be anticipated and strategies put in place to manage the PEV charging to minimize the grid impact. Managed growth is almost always less costly than sporadic or unconstrained growth.

7
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KCP&L-GMO SPECIFIC TABLES AND GRAPHS

Table A-1
GMO Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2014	157	157	157
2015	228	230	250
2016	307	356	442
2017	401	592	767
2018	517	970	1,244
2019	627	1,495	1,927
2020	739	2,155	3,084
2021	849	3,027	5,045
2022	971	4,140	7,958
2023	1,121	5,465	11,865
2024	1,286	7,014	16,793
2025	1,501	8,811	22,928
2026	1,739	10,892	30,581
2027	2,026	13,284	39,789
2028	2,340	16,085	50,670
2029	2,702	19,276	63,258
2030	3,085	22,945	77,739
2031	3,491	27,137	93,291
2032	3,926	31,926	109,725
2033	4,378	37,319	126,952
2034	4,836	43,303	144,947
2035	5,319	49,906	163,603
2036	5,796	57,048	182,457
2037	6,273	64,716	201,381
2038	6,754	72,881	220,272
2039	7,237	81,536	239,064
2040	7,704	90,637	257,652
2041	8,165	100,046	275,613

Table A-1 (continued)
GMO Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2042	8,614	109,770	292,957
2043	9,044	119,766	309,634
2044	9,478	130,046	325,641
2045	9,887	140,551	340,976
2046	10,290	151,132	355,357
2047	10,676	161,739	368,848
2048	11,061	172,369	381,487
2049	11,422	182,985	393,332
2050	11,794	193,603	404,436

Table A-2
GMO generation and transmission system capacity impact with medium PEV adoption scenario

	Cumulative No. PEVs in GMO	Share of Total Vehicles	Annual PEV Consumption at the Meter	Peak Capacity* for Unmanaged Charging	Peak Capacity* for Managed Charging
2014	157	0.02%	1 GWh	0 MW	0 MW
2015	230	0.03%	1 GWh	0 MW	0 MW
2016	356	0.05%	2 GWh	0 MW	0 MW
2017	592	0.09%	3 GWh	1 MW	0 MW
2018	970	0.14%	4 GWh	1 MW	1 MW
2019	1,4	0.22%	7 GWh	2 MW	1 MW
2020	2,155	0.31%	10 GWh	3 MW	1 MW
2021	3,027	0.44%	13 GWh	4 MW	2 MW
2022	4,140	0.60%	18 GWh	6 MW	2 MW
2023	5,465	0.78%	24 GWh	8 MW	3 MW
2024	7,014	0.99%	31 GWh	10 MW	4 MW
2025	8,811	1.23%	39 GWh	12 MW	5 MW
2026	10,892	1.51%	49 GWh	15 MW	6 MW
2027	13,284	1.82%	59 GWh	19 MW	7 MW
2028	16,085	2.18%	72 GWh	22 MW	8 MW
2029	19,276	2.59%	86 GWh	27 MW	10 MW
2030	22,945	3.06%	102 GWh	32 MW	12 MW
2031	27,137	3.58%	121 GWh	38 MW	14 MW
2032	31,926	4.17%	142 GWh	45 MW	17 MW
2033	37,319	4.83%	166 GWh	52 MW	20 MW
2034	43,303	5.55%	193 GWh	60 MW	23 MW
2035	49,906	6.34%	222 GWh	70 MW	26 MW

Table A-3
GMO net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016 $)
2014	157	157	157	$52,100	$52,100	$52,100	139	$46,127
2015	228	230	250	$75,662	$76,326	$82,963	195	$64,711
2016	307	356	442	$101,878	$118,139	$146,678	303	$100,551
2017	401	592	767	$133,072	$196,455	$254,529	*435	$144,355
2018	517	970	1,244	$171,566	$321,895	$412,821		
2019	627	1,495	1,927	$208,070	$496,116	$639,475		
2020	739	2,155	3,084	$245,237	$715,137	$1,023,425		
2021	849	3,027	5,045	$281,741	$1,004,510	$1,674,183		
2022	971	4,140	7,958	$322,226	$1,373,859	$2,640,862		
2023	1,121	5,465	11,865	$372,004	$1,813,560	$3,937,400		
2024	1,286	7,014	16,793	$426,759	$2,327,596	$5,572,757		
2025	1,501	8,811	22,928	$498,107	$2,923,930	$7,608,657		
2026	1,739	10,892	30,581	$577,087	$3,614,510	$10,148,305		
2027	2,026	13,284	39,789	$672,328	$4,408,295	$13,203,980		
2028	2,340	16,085	50,670	$776,529	$5,337,807	$16,814,840		
2029	2,702	19,276	63,258	$896,659	$6,396,741	$20,992,167		
2030	3,085	22,945	77,739	$1,023,757	$7,614,298	$25,797,687		
2031	3,491	27,137	93,291	$1,158,488	$9,005,413	$30,958,618		
2032	3,926	31,926	109,725	$1,302,843	$10,594,643	$36,412,241		
2033	4,378	37,319	126,952	$1,452,839	$12,384,310	$42,129,021		
2034	4,836	43,303	144,947	$1,604,827	$14,370,101	$48,100,662		
2035	5,319	49,906	163,603	$1,765,110	$16,561,306	$54,291,656		
2036	5,796	57,048	182,457	$1,923,403	$18,931,379	$60,548,355		
2037	6,273	64,716	201,381	$2,081,695	$21,476,005	$66,828,285		
2038	6,754	72,881	220,272	$2,241,315	$24,185,560	$73,097,263		
2039	7,237	81,536	239,064	$2,401,598	$27,057,722	$79,333,388		
2040	7,704	90,637	257,652	$2,556,572	$30,077,888	$85,501,816		
2041	8,165	100,046	275,613	$2,709,555	$33,200,265	$91,462,174		
2042	8,614	109,770	292,957	$2,858,556	$36,427,175	$97,217,780		
2043	9,044	119,766	309,634	$3,001,251	$39,744,347	$102,752,043		
2044	9,478	130,046	325,641	$3,145,274	$43,155,765	$108,063,966		
2045	9,887	140,551	340,976	$3,281,001	$46,641,849	$113,152,886		

Table A-3 (continued)
GMO net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016 $)
2046	10,290	151,132	355,357	$3,414,737	$50,153,154	$117,925,220		
2047	10,676	161,739	368,848	$3,542,831	$53,673,087	$122,402,209		
2048	11,061	172,369	381,487	$3,670,593	$57,200,653	$126,596,461		
2049	11,422	182,985	393,332	$3,790,391	$60,723,572	$130,527,224		
2050	11,794	193,603	404,436	$3,913,839	$64,247,156	$134,212,087		

*Estimated based on 2017 Q3 registered PEVs plus 2017 Q4 sales

Table A-4
Summary of GMO Hotspotter results—number of likely transformer overloads (90% confidence level) for three scenarios with incremental impacts of medium PEV adoption in 2025

	Low PEV Adoption			Medium PEV Adoption		
	Unmanaged	Managed	Net Reduction w/ TOU	Unmanaged	Managed	Net Reduction w/ TOU
5 to 6 PM	10	2	8	49	6	43
0 to 1 AM	1	7	-6	3	30	-27

Table A-5
GMO net benefits of incremental (medium-low) PEV adoption with inflation

Year	Low PEV	Medium PEV	Delta PEVs	Per PEV Revenue $/yr	Incremental Revenue $/yr	Annual CCN O&M	Net Annual Benefit $/yr
2014	157	157	0	$315.46	$0		
2015	228	230	2	$323.55	$647		$647
2016	307	356	49	$331.85	$16,260		$16,260
2017	401	592	191	$340.14	$64,967	$55,000	$9,967
2018	517	970	453	$348.65	$157,937	$56,375	$101,562
2019	627	1,495	868	$357.36	$310,190	$57,784	$252,406
2020	739	2,155	1,416	$366.30	$518,675	$59,229	$459,446
2021	849	3,027	2,178	$375.45	$817,738	$60,710	$757,028
2022	971	4,140	3,169	$384.84	$1,219,558	$62,227	$1,157,330
2023	1,121	5,465	4,344	$394.46	$1,713,538	$63,783	$1,649,755
2024	1,286	7,014	5,728	$404.32	$2,315,959	$65,378	$2,250,581
2025	1,501	8,811	7,310	$414.43	$3,029,487	$67,012	$2,962,475
2026	1,739	10,892	9,153	$424.79	$3,888,114	$68,687	$3,819,427
2027	2,026	13,284	11,258	$435.41	$4,901,857	$70,405	$4,831,453
2028	2,340	16,085	13,745	$446.30	$6,134,342	$72,165	$6,062,178
2029	2,702	19,276	16,574	$457.45	$7,581,838	$73,969	$7,507,869
2030	3,085	22,945	19,860	$468.89	$9,312,156	$75,818	$9,236,338
2031	3,491	27,137	23,646	$480.61	$11,364,558	$77,714	$11,286,845
2032	3,926	31,926	28,000	$492.63	$13,793,573	$79,656	$13,713,916
2033	4,378	37,319	32,941	$504.94	$16,633,337	$81,648	$16,551,689
2034	4,836	43,303	38,467	$517.57	$19,909,245	$83,689	$19,825,556
2035	5,319	49,906	44,587	$530.51	$23,653,673	$85,781	$23,567,892

Table A-6
GMO GPES PV net benefits of incremental (medium-low) PEV adoption

Year	Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $	75% Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $
2016	49	$16,260	$16,260	37	$12,195	$12,195
2017	191	$9,967	$25,599	143	-$6,275	$6,316
2018	453	$101,562	$114,755	340	$62,077	$60,811
2019	868	$252,406	$322,356	651	$174,858	$204,630
2020	1,416	$459,446	$676,415	1,062	$329,778	$458,764
2021	2,178	$757,028	$1,223,007	1,634	$552,594	$857,749
2022	3,169	$1,157,330	$2,005,930	2,377	$852,441	$1,434,417
2023	4,344	$1,649,755	$3,051,591	3,258	$1,221,370	$2,208,556
2024	5,728	$2,250,581	$4,388,114	4,296	$1,671,591	$3,201,243
2025	7,310	$2,962,475	$6,036,454	5,483	$2,205,103	$4,428,176
2026	9,153	$3,819,427	$8,027,588	6,865	$2,847,398	$5,912,575
2027	11,258	$4,831,453		8,444	$3,605,988	
2028	13,745	$6,062,178		10,309	$4,528,592	
2029	16,574	$7,507,869		12,431	$5,612,409	
2030	19,860	$9,236,338		14,895	$6,908,299	
2031	23,646	$11,286,845		17,735	$8,445,705	
2032	28,000	$13,713,916		21,000	$10,265,523	
2033	32,941	$16,551,689		24,706	$12,393,355	
2034	38,467	$19,825,556		28,850	$14,848,245	
2035	44,587	$23,567,892		33,440	$17,654,473	

B

KCP&L-MO SPECIFIC TABLES AND GRAPHS

Table B-1
KCP&L-MO Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2014	326	326	326
2015	487	491	537
2016	648	754	937
2017	836	1,213	1,575
2018	1,036	1,902	2,441
2019	1,227	2,860	3,694
2020	1,424	4,058	5,607
2021	1,622	5,508	8,637
2022	1,837	7,238	12,909
2023	2,080	9,214	18,439
2024	2,343	11,435	25,238
2025	2,672	13,943	33,509
2026	3,047	16,785	43,648
2027	3,465	19,989	55,699
2028	3,938	23,674	69,746
2029	4,465	27,827	85,854
2030	5,027	32,562	104,221
2031	5,630	37,887	123,745
2032	6,267	43,908	144,165
2033	6,922	50,612	165,400
2034	7,605	58,006	187,395
2035	8,277	66,102	210,030
2036	8,964	74,793	232,708
2037	9,662	84,065	255,290
2038	10,330	93,888	277,703
2039	10,998	104,236	299,811
2040	11,666	115,097	321,532
2041	12,298	126,258	342,358

Table B-1 (continued)
KCP&L-MO Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2042	12,908	137,711	362,294
2043	13,497	149,464	381,310
2044	14,075	161,473	399,386
2045	14,620	173,708	416,554
2046	15,154	185,958	432,566
2047	15,638	198,199	447,457
2048	16,121	210,400	461,302
2049	16,591	222,533	474,172
2050	17,037	234,598	486,160

Table B-2
KCP&L-MO generation and transmission system capacity impact with medium PEV adoption scenario

	Cumulative No. PEVs in KCP&L-MO	Share of Total Vehicles	Annual PEV Consumption at the Meter	Peak Capacity* for Unmanaged Charging	Peak Capacity* for Managed Charging
2014	326	0.04%	1 GWh	0 MW	0 MW
2015	491	0.06%	2 GWh	1 MW	0 MW
2016	754	0.10%	3 GWh	1 MW	0 MW
2017	1,213	0.16%	5 GWh	2 MW	1 MW
2018	1,902	0.25%	8 GWh	3 MW	1 MW
2019	2,860	0.37%	13 GWh	4 MW	1 MW
2020	4,058	0.52%	18 GWh	6 MW	2 MW
2021	5,508	0.70%	25 GWh	8 MW	3 MW
2022	7,238	0.92%	32 GWh	10 MW	4 MW
2023	9,214	1.16%	41 GWh	13 MW	5 MW
2024	11,435	1.42%	51 GWh	16 MW	6 MW
2025	13,943	1.72%	62 GWh	19 MW	7 MW
2026	16,785	2.05%	75 GWh	23 MW	9 MW
2027	19,989	2.41%	89 GWh	28 MW	10 MW
2028	23,674	2.83%	105 GWh	33 MW	12 MW
2029	27,827	3.30%	124 GWh	39 MW	15 MW
2030	32,562	3.82%	145 GWh	45 MW	17 MW
2031	37,887	4.40%	169 GWh	53 MW	20 MW
2032	43,908	5.05%	196 GWh	61 MW	23 MW
2033	50,612	5.77%	225 GWh	71 MW	27 MW
2034	58,006	6.55%	258 GWh	81 MW	30 MW
2035	66,102	7.40%	294 GWh	92 MW	35 MW

Table B-3
KCP&L-MO net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016$)
2014	326	326	326	$122,586	$122,586	$122,586	265	$99,648
2015	487	491	537	$183,127	$184,631	$201,928	388	$145,900
2016	648	754	937	$243,667	$283,527	$352,340	641	$241,035
2017	836	1,213	1,575	$314,361	$456,124	$592,247	*972	$365,501
2018	1,036	1,902	2,441	$389,567	$715,209	$917,889		
2019	1,227	2,860	3,694	$461,389	$1,075,446	$1,389,055		
2020	1,424	4,058	5,607	$535,467	$1,525,930	$2,108,400		
2021	1,622	5,508	8,637	$609,921	$2,071,173	$3,247,771		
2022	1,837	7,238	12,909	$690,767	$2,721,705	$4,854,171		
2023	2,080	9,214	18,439	$782,142	$3,464,740	$6,933,617		
2024	2,343	11,435	25,238	$881,038	$4,299,903	$9,490,245		
2025	2,672	13,943	33,509	$1,004,752	$5,242,986	$12,600,389		
2026	3,047	16,785	43,648	$1,145,763	$6,311,664	$16,412,957		
2027	3,465	19,989	55,699	$1,302,944	$7,516,464	$20,944,495		
2028	3,938	23,674	69,746	$1,480,806	$8,902,134	$26,226,588		
2029	4,465	27,827	85,854	$1,678,974	$10,463,787	$32,283,680		
2030	5,027	32,562	104,221	$1,890,303	$12,244,289	$39,190,223		
2031	5,630	37,887	123,745	$2,117,049	$14,246,649	$46,531,832		
2032	6,267	43,908	144,165	$2,356,580	$16,510,725	$54,210,365		
2033	6,922	50,612	165,400	$2,602,880	$19,031,630	$62,195,362		
2034	7,605	58,006	187,395	$2,859,708	$21,811,996	$70,466,142		
2035	8,277	66,102	210,030	$3,112,400	$24,856,335	$78,977,581		
2036	8,964	74,793	232,708	$3,370,733	$28,124,412	$87,505,189		
2037	9,662	84,065	255,290	$3,633,202	$31,610,962	$95,996,699		
2038	10,330	93,888	277,703	$3,884,390	$35,304,705	$104,424,659		
2039	10,998	104,236	299,811	$4,135,578	$39,195,863	$112,737,930		
2040	11,666	115,097	321,532	$4,386,766	$43,279,925	$120,905,678		
2041	12,298	126,258	342,358	$4,624,417	$47,476,796	$128,736,879		
2042	12,908	137,711	362,294	$4,853,795	$51,783,467	$136,233,413		
2043	13,497	149,464	381,310	$5,075,277	$56,202,948	$143,383,999		
2044	14,075	161,473	399,386	$5,292,622	$60,718,692	$150,181,118		
2045	14,620	173,708	416,554	$5,497,559	$65,319,419	$156,636,801		

Table B-3 (continued)
KCP&L-MO net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**PEVs**	**(2016$)**
2046	15,154	185,958	432,566	$5,698,359	$69,925,787	$162,657,793		
2047	15,638	198,199	447,457	$5,880,357	$74,528,770	$168,257,256		
2048	16,121	210,400	461,302	$6,061,980	$79,116,712	$173,463,391		
2049	16,591	222,533	474,172	$6,238,714	$83,679,084	$178,302,897		
2050	17,037	234,598	486,160	$6,406,423	$88,215,886	$182,810,745		

* Estimated based on 2017 Q3 registered PEVs plus 2017 Q4 sales.

Table B-4
Summary of KCP&L-MO Hotspotter results—number of likely transformer overloads (90% confidence level) for three scenarios with incremental impacts of medium PEV adoption in 2025

	Low PEV Adoption			Medium PEV Adoption		
	Unmanaged	**Managed**	**Net Reduction w/ TOU**	**Unmanaged**	**Managed**	**Net Reduction w/ TOU**
5 to 6 PM	7	1	6	30	4	26
0 to 1 AM	0	3	-3	1	12	-11

Table B-5
KCP&L-MO net benefits of incremental (medium-low) PEV adoption with inflation

Year	Low PEV	Medium PEV	Delta PEVs	Per PEV Revenue $/yr	Incremental Revenue $/yr	Annual CCN O&M	Net Annual Benefit $/yr
2014	326	326	0	$357.47	$0		
2015	487	491	4	$366.63	$1,467		$1,467
2016	648	754	106	$376.03	$39,859		$39,859
2017	836	1,213	377	$385.43	$145,308	$88,000	$57,308
2018	1,036	1,902	866	$395.07	$342,130	$90,200	$251,930
2019	1,227	2,860	1,633	$404.95	$661,277	$92,455	$568,822
2020	1,424	4,058	2,634	$415.07	$1,093,294	$94,766	$998,528
2021	1,622	5,508	3,886	$425.45	$1,653,285	$97,136	$1,556,150
2022	1,837	7,238	5,401	$436.08	$2,355,283	$99,564	$2,255,719
2023	2,080	9,214	7,134	$446.98	$3,188,790	$102,053	$3,086,737
2024	2,343	11,435	9,092	$458.16	$4,165,586	$104,604	$4,060,981
2025	2,672	13,943	11,271	$469.61	$5,293,013	$107,219	$5,185,793
2026	3,047	16,785	13,738	$481.35	$6,612,838	$109,900	$6,502,938
2027	3,465	19,989	16,524	$493.39	$8,152,737	$112,647	$8,040,089
2028	3,938	23,674	19,736	$505.72	$9,980,935	$115,464	$9,865,471
2029	4,465	27,827	23,362	$518.37	$12,110,051	$118,350	$11,991,701
2030	5,027	32,562	27,535	$531.32	$14,630,020	$121,309	$14,508,711
2031	5,630	37,887	32,257	$544.61	$17,567,407	$124,342	$17,443,065
2032	6,267	43,908	37,641	$558.22	$21,012,064	$127,450	$20,884,613
2033	6,922	50,612	43,690	$572.18	$24,998,472	$130,636	$24,867,836
2034	7,605	58,006	50,401	$586.48	$29,559,320	$133,902	$29,425,418
2035	8,277	66,102	57,825	$601.14	$34,761,203	$137,250	$34,623,953

Table B-6
KCP&L-MO PV net benefits of incremental (medium-low) PEV adoption

Year	Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $	75% Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $
2016	106	$39,859	$39,859	80	$29,895	$29,895
2017	377	$57,308	$93,554	283	$20,981	$49,553
2018	866	$251,930	$314,715	650	$166,398	$195,628
2019	1,633	$568,822	$782,577	1,225	$403,503	$527,513
2020	2,634	$998,528	$1,552,090	1,976	$725,204	$1,086,390
2021	3,886	$1,556,150	$2,675,714	2,915	$1,142,829	$1,911,573
2022	5,401	$2,255,719	$4,201,762	4,051	$1,666,898	$3,039,270
2023	7,134	$3,086,737	$6,158,339	5,351	$2,289,539	$4,490,531
2024	9,092	$4,060,981	$8,570,144	6,819	$3,019,585	$6,283,853
2025	11,271	$5,185,793	$11,455,771	8,453	$3,862,540	$8,433,159
2026	13,738	$6,502,938	$14,846,153	10,304	$4,849,728	$10,961,620
2027	16,524	$8,040,089		12,393	$6,001,905	
2028	19,736	$9,865,471		14,802	$7,370,238	
2029	23,362	$11,991,701		17,522	$8,964,188	
2030	27,535	$14,508,711		20,651	$10,851,206	
2031	32,257	$17,443,065		24,193	$13,051,214	
2032	37,641	$20,884,613		28,231	$15,631,598	
2033	43,690	$24,867,836		32,768	$18,618,218	
2034	50,401	$29,425,418		37,801	$22,035,588	
2035	57,825	$34,623,953		43,369	$25,933,652	

C

KCP&L-KS SPECIFIC TABLES AND GRAPHS

Table C-1
KCP&L-KS Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2014	359	359	359
2015	492	496	532
2016	629	714	866
2017	780	1,078	1,376
2018	944	1,626	2,071
2019	1,098	2,389	3,064
2020	1,249	3,321	4,623
2021	1,408	4,502	7,180
2022	1,588	5,956	10,873
2023	1,786	7,645	15,728
2024	2,009	9,587	21,780
2025	2,282	11,802	29,222
2026	2,589	14,313	38,385
2027	2,939	17,182	49,319
2028	3,327	20,483	62,120
2029	3,764	24,228	76,875
2030	4,226	28,506	93,754
2031	4,731	33,396	111,857
2032	5,271	38,974	130,957
2033	5,831	45,238	150,978
2034	6,419	52,202	171,882
2035	7,007	59,899	193,546
2036	7,601	68,198	215,399
2037	8,207	77,103	237,282
2038	8,812	86,592	259,115
2039	9,410	96,614	280,769
2040	10,003	107,163	302,175
2041	10,594	118,091	322,872

Table C-1
KCP&L-KS Cumulative number of PEVs by adoption projection

YEAR	Low Adoption	Medium Adoption	High Adoption
2042	11,180	129,375	342,854
2043	11,748	141,021	362,080
2044	12,306	152,987	380,530
2045	12,863	165,244	398,228
2046	13,414	177,595	414,892
2047	13,945	189,996	430,556
2048	14,477	202,438	445,252
2049	15,009	214,891	459,069
2050	15,531	227,344	472,086

Table C-2
KCP&L-KS generation and transmission system capacity impact with medium PEV adoption scenario

	Cumulative No. PEVs in KCP&L-KS	Share of Total Vehicles	Annual PEV Consumption at the Meter	Peak Capacity* for Unmanaged Charging	Peak Capacity* for Managed Charging
2014	359	0.05%	2 GWh	1 MW	0 MW
2015	496	0.07%	2 GWh	1 MW	0 MW
2016	714	0.10%	3 GWh	1 MW	0 MW
2017	1,078	0.15%	5 GWh	2 MW	1 MW
2018	1,626	0.23%	7 GWh	2 MW	1 MW
2019	2,389	0.34%	11 GWh	3 MW	1 MW
2020	3,321	0.46%	15 GWh	5 MW	2 MW
2021	4,502	0.62%	20 GWh	6 MW	2 MW
2022	5,956	0.81%	27 GWh	8 MW	3 MW
2023	7,645	1.03%	34 GWh	11 MW	4 MW
2024	9,587	1.27%	43 GWh	13 MW	5 MW
2025	11,802	1.55%	53 GWh	16 MW	6 MW
2026	14,313	1.85%	64 GWh	20 MW	8 MW
2027	17,182	2.19%	77 GWh	24 MW	9 MW
2028	20,483	2.58%	91 GWh	29 MW	11 MW
2029	24,228	3.01%	108 GWh	34 MW	13 MW
2030	28,506	3.49%	127 GWh	40 MW	15 MW
2031	33,396	4.04%	149 GWh	47 MW	18 MW
2032	38,974	4.65%	174 GWh	54 MW	20 MW
2033	45,238	5.34%	201 GWh	63 MW	24 MW
2034	52,202	6.09%	232 GWh	73 MW	27 MW
2035	59,899	6.90%	267 GWh	84 MW	31 MW

Table C-3
KCP&L-KS net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016$)
2014	359	359	359	$143,970	$143,970	$143,970	401	$160,813
2015	492	496	532	$197,307	$198,911	$213,348	556	$222,973
2016	629	714	866	$252,248	$286,335	$347,292	909	$364,536
2017	780	1,078	1,376	$312,803	$432,310	$551,817	*1,382	$554,223
2018	944	1,626	2,071	$378,572	$652,075	$830,533		
2019	1,098	2,389	3,064	$440,331	$958,061	$1,228,756		
2020	1,249	3,321	4,623	$500,886	$1,331,821	$1,853,962		
2021	1,408	4,502	7,180	$564,650	$1,805,437	$2,879,395		
2022	1,588	5,956	10,873	$636,836	$2,388,535	$4,360,399		
2023	1,786	7,645	15,728	$716,240	$3,065,874	$6,307,400		
2024	2,009	9,587	21,780	$805,669	$3,844,675	$8,734,433		
2025	2,282	11,802	29,222	$915,150	$4,732,956	$11,718,899		
2026	2,589	14,313	38,385	$1,038,267	$5,739,942	$15,393,537		
2027	2,939	17,182	49,319	$1,178,627	$6,890,497	$19,778,399		
2028	3,327	20,483	62,120	$1,334,227	$8,214,297	$24,911,984		
2029	3,764	24,228	76,875	$1,509,477	$9,716,155	$30,829,181		
2030	4,226	28,506	93,754	$1,694,753	$11,431,761	$37,598,167		
2031	4,731	33,396	111,857	$1,897,273	$13,392,798	$44,858,013		
2032	5,271	38,974	130,957	$2,113,829	$15,629,743	$52,517,686		
2033	5,831	45,238	150,978	$2,338,406	$18,141,795	$60,546,707		
2034	6,419	52,202	171,882	$2,574,212	$20,934,568	$68,929,838		
2035	7,007	59,899	193,546	$2,810,017	$24,021,296	$77,617,752		
2036	7,601	68,198	215,399	$3,048,229	$27,349,444	$86,381,461		
2037	8,207	77,103	237,282	$3,291,253	$30,920,616	$95,157,200		
2038	8,812	86,592	259,115	$3,533,876	$34,725,990	$103,912,888		
2039	9,410	96,614	280,769	$3,773,692	$38,745,112	$112,596,792		
2040	10,003	107,163	302,175	$4,011,503	$42,975,578	$121,181,240		
2041	10,594	118,091	322,872	$4,248,512	$47,358,034	$129,481,358		
2042	11,180	129,375	342,854	$4,483,515	$51,883,256	$137,494,740		
2043	11,748	141,021	362,080	$4,711,300	$56,553,652	$145,204,942		
2044	12,306	152,987	380,530	$4,935,075	$61,352,377	$152,603,946		
2045	12,863	165,244	398,228	$5,158,449	$66,267,801	$159,701,375		

Table C-3 (continued)
KCP&L-KS net revenue increase by PEV adoption projection

	Projected No. of PEVs			Annual Net Revenue Increase			Actual	Net Revenue
YEAR	Low	Med	High	Low	Med	High	PEVs	(2016$)
2046	13,414	177,595	414,892	$5,379,416	$71,220,923	$166,384,139		
2047	13,945	189,996	430,556	$5,592,363	$76,194,096	$172,665,873		
2048	14,477	202,438	445,252	$5,805,711	$81,183,711	$178,559,410		
2049	15,009	214,891	459,069	$6,019,059	$86,177,738	$184,100,441		
2050	15,531	227,344	472,086	$6,228,397	$91,171,764	$189,320,649		

*Estimated based on 2017 Q3 registered PEVs plus 2017 Q4 sales.

Table C-4
Summary of KCP&L-KS Hotspotter results—number of likely transformer overloads (90% confidence level) for three scenarios with incremental impacts of medium PEV adoption in 2025

	Low PEV Adoption			Medium PEV Adoption		
	Unmanaged	Managed	Net Reduction w/ TOU	Unmanaged	Managed	Net Reduction w/ TOU
5 to 6 PM	6	1	5	26	4	22
0 to 1 AM	0	4	-4	1	14	-13

Table C-5
KCP&L-KS net benefits of incremental (medium-low) PEV adoption with inflation

Year	Low PEV	Medium PEV	Delta PEVs	Per PEV Revenue $/yr	Incremental Revenue $/yr	Annual CCN O&M	Net Annual Benefit $/yr
2014	359	359	0	$381.23	$0		
2015	492	496	4	$391.00	$1,564		$1,564
2016	629	714	85	**$401.03**	$34,087		$34,087
2017	780	1,078	298	$411.05	$122,494	$56,000	$66,494
2018	944	1,626	682	$421.33	$287,348	$57,400	$229,948
2019	1,098	2,389	1,291	$431.86	$557,537	$58,835	$498,702
2020	1,249	3,321	2,072	$442.66	$917,194	$60,306	$856,888
2021	1,408	4,502	3,094	$453.73	$1,403,834	$61,814	$1,342,020
2022	1,588	5,956	4,368	$465.07	$2,031,430	$63,359	$1,968,071
2023	1,786	7,645	5,859	$476.70	$2,792,972	$64,943	$2,728,029
2024	2,009	9,587	7,578	$488.62	$3,702,726	$66,566	$3,636,159
2025	2,282	11,802	9,520	$500.83	$4,767,907	$68,231	$4,699,676
2026	2,589	14,313	11,724	$513.35	$6,018,530	$69,936	$5,948,594
2027	2,939	17,182	14,243	$526.19	$7,494,454	$71,685	$7,422,769
2028	3,327	20,483	17,156	$539.34	$9,252,912	$73,477	$9,179,435
2029	3,764	24,228	20,464	$552.82	$11,312,974	$75,314	$11,237,660
2030	4,226	28,506	24,280	$566.64	$13,758,110	$77,197	$13,680,914
2031	4,731	33,396	28,665	$580.81	$16,648,914	$79,127	$16,569,788
2032	5,271	38,974	33,703	$595.33	$20,064,410	$81,105	$19,983,306
2033	5,831	45,238	39,407	$610.21	$24,046,678	$83,132	$23,963,545
2034	6,419	52,202	45,783	$625.47	$28,635,833	$85,211	$28,550,622
2035	7,007	59,899	52,892	$641.11	$33,909,347	$87,341	$33,822,006

Table C-6
KCP&L-KS PV net benefits of incremental (medium-low) PEV adoption

Year	Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $	75% Delta PEVs	Net Annual Benefit $/yr	Cumulative PV Benefits 2016 $
2016	85	$34,087	$34,087	64	$25,566	$25,566
2017	298	$66,494	$96,397	224	$35,871	$59,179
2018	682	$229,948	$298,310	512	$158,111	$198,013
2019	1,291	$498,702	$708,650	968	$359,318	$493,666
2020	2,072	$856,888	$1,369,335	1,554	$627,590	$977,555
2021	3,094	$1,342,020	$2,338,945	2,321	$991,062	$1,693,598
2022	4,368	$1,968,071	$3,671,382	3,276	$1,460,213	$2,682,201
2023	5,859	$2,728,029	$5,402,083	4,394	$2,029,786	$3,969,927
2024	7,578	$3,636,159	$7,563,725	5,684	$2,710,478	$5,581,265
2025	9,520	$4,699,676	$10,181,766	7,140	$3,507,699	$7,535,294
2026	11,724	$5,948,594	$13,286,973	8,793	$4,443,961	$9,855,072
2027	14,243	$7,422,769		10,682	$5,549,156	
2028	17,156	$9,179,435		12,867	$6,866,207	
2029	20,464	$11,237,660		15,348	$8,409,416	
2030	24,280	$13,680,914		18,210	$10,241,386	
2031	28,665	$16,569,788		21,499	$12,407,559	
2032	33,703	$19,983,306		25,277	$14,967,203	
2033	39,407	$23,963,545		29,555	$17,951,876	
2034	45,783	$28,550,622		34,337	$21,391,664	
2035	52,892	$33,822,006		39,669	$25,344,669	

D
HOTSPOTTER INPUTS

This appendix summarized the more detailed inputs to the Hotspotter tool.

GPES Service Transformer Inputs

GPES provided data for service transformers in their service territory, including asset rating, location, overhead vs. underground asset, and number of residences served by the asset. A 24-hour load shape is provided for each transformer representing loading prior to the addition of PEVs.

The Hotspotter analysis focused on GPES residential transformers (load class RS) with a rating greater than zero, and with annual kilowatt-hour consumption greater than zero. Table D-1 summarizes the number of assets with data in each GPES jurisdiction, with the majority in GMO. These 125,831 secondary transformers serve a total of 559,145 residences across GPES jurisdictions. Note that only 2,745 residential transformers were excluded from the Hotspotter analysis where no loading data was available.

Table D-1
Number of residential service transformers and connected residences by jurisdiction

	Number of Transformers	Number of Connected Residences
GMO	66,343	241,801
KCP&L-KS	34,037	155,007
KCP&L-MO	25,451	162,337
GPES Total	125,831	559,145

Table D-2 illustrates the breakout of service transformers by kVA rating by jurisdiction. The majority (67.4%) of GPES assets fall into the 25-kVA and 50-kVA categories. Thirty-four transformer ratings and a total of 482 transformers were excluded from this list where the category represented less than 100 transformers. Most of these were in GMO where there are many ratings with only a handful of assets.

Table D-2
Number of transformers for select ratings by jurisdiction, with share of total GPES residential assets

kVA Rating	GMO	KCP&L-KS	KCP&L-MO	GPES Total	Share of GPES Total
5 kVA	415	66	43	524	0.4%
10 kVA	4,768	3,044	1,717	9,529	7.6%
15 kVA	8,770	1,090	1,333	11,193	8.9%
25 kVA	29,326	10,352	6,281	45,959	36.5%
37 kVA	3,717	1,206	2,249	7,172	5.7%
38 kVA	937	42	60	1,039	0.8%
50 kVA	15,235	13,284	10,357	38,876	30.9%
75 kVA	2,194	3,685	2,572	8,451	6.7%
100 kVA	654	1,007	559	2,220	1.8%
167 kVA	91	166	129	386	0.3%
Total	66,107	33,942	25,300	125,349	99.6%

The probability of overload is based on the transformer rating, the number of attached residences, and the current load expected on the transformer. Each home has the same probability of PEV adoption and mix, therefore the capacity per residence served by a transformer may be indicative of the likelihood of overload in a transformer rating category. For instance, with equal likelihood of PEV adoption at each home, a 25-kVA transformer serving five homes may have a higher probability of overload than a 50-kVA transformer serving five homes.

The average kilovolt-amp capacity per home is provided for various transformer ratings and by jurisdiction as shown in Table D-3. Note that above the 10-kVA rating the capacity per home rises to the 10-15 kVA/home range, with an average 13 kVA per residence across all jurisdictions. Compared to estimates from GPES AMI data, residential customers were found to have an average 8-kVA 15-minute peak demand. Considering that most new PEVs will charge at 6.6 kVA or higher, adding a single PEV in a home could have significant impacts on individual customer peak demand.

Table D-3
Average kilovolt-amp capacity per residence for select transformer ratings, by jurisdiction

Transformer Rating	Transformer Rated Capacity per Residence			
	GMO	KCP&L-KS	KCP&L-MO	GPES Overall
5 kVA	5 kVA	5 kVA	5 kVA	5 kVA
10 kVA	9 kVA	9 kVA	9 kVA	9 kVA
15 kVA	12 kVA	12 kVA	10 kVA	12 kVA
25 kVA	13 kVA	16 kVA	12 kVA	14 kVA
37 kVA	10 kVA	7 kVA	6 kVA	9 kVA
38 kVA	13 kVA	9 kVA	7 kVA	12 kVA
50 kVA	14 kVA	15 kVA	10 kVA	13 kVA
75 kVA	20 kVA	14 kVA	12 kVA	15 kVA
100 kVA	21 kVA	15 kVA	17 kVA	17 kVA
167 kVA	22 kVA	30 kVA	34 kVA	29 kVA
Overall	13 kVA	14 kVA	11 kVA	13 kVA

To estimate existing hourly loading for the service transformers, the annual kilowatt-hour consumption at each transformer was used along with a peak-day 24-hour residential load shape that differs by jurisdiction. Without hourly loading available for the transformers, this analysis assumes that all transformers within a jurisdiction have the same load shape, and the load shape is scaled to match annual transformer consumption. This assumes that each day of the year has the same load shape and peak, which is the best available information for this study. The 24-hour load shape for each transformer is used as a baseline to which PEV charging is added.

Vehicle Inputs

The vehicle assumptions provided in this section are for the United States as a whole, location-specific data is not publicly available. The probability of the number of vehicles at a home, the miles driven per vehicle each day, and unmanaged charging home arrival time are based on data from the 2009 National Household Travel Survey [43] to estimate individual vehicles usage. Table D-4 provides the probability for the number of vehicles at a home, where the majority of homes would have two vehicles.

Table D-4
Probability of number of vehicles at each home for the United States

Vehicle Count	Probability
0	3.8%
1	28.8%
2	67.4%

Table D-5 shows the six PEV types applied to the GPES service territories in this analysis. Each vehicle type has different maximum charge power, battery capacity, and assumed probability of adoption. All PEVs are assumed to use 350 Wh/mile and vehicle charging is assumed to be 100% efficient in all scenarios.

Table D-5
PEV types and characteristics

	PEV Type	Maximum Charge Power	Battery Capacity	PEV Probability
Toyota Plug-in Prius	PHEV	2.8 kW	4 kWh	9.7%
Chevy Volt or Cadillac ELR	PHEV	3.3 kW	12 kWh	15.0%
Ford C-MAX or Fusion Energi	PHEV	3.8 kW	7.6 kWh	8.2%
Mainstream BEV—includes Nissan Leaf	BEV	7.2 kW	22 kWh	55.7%
Toyota RAV4 or Tesla Base Level 2 Charger	BEV	9.6 kW	62.5 kWh	7.1%
Tesla Wall Charger	BEV	19.2 kW	85 kWh	4.4%

Table D-6 shows the probabilities for the miles a PEV drives before arriving home to charge. The weighted average is 34.6 miles/day.

Table D-6
Miles driven options and probabilities

Miles Driven in a Day	Probability
5	24%
11	23%
22	23%
41	16%
138	14%

Together the previous three tables determine what the vehicle mix and energy needs are for a chosen PEV population.

Hotspotter Scenarios

Unmanaged vs. Managed Home Arrival Times

To model the shift in charging if vehicle charging were managed to mitigate system impacts, the probability of home arrival time for vehicles was adjusted. The probability of a vehicle arriving home in each hour of the day was based on the weekday managed and unmanaged charging profiles developed in Section 5. The unmanaged (base scenario) and managed charging assumptions are provided in Table D-7. The managed charge profile from Section 5 is adjusted here to lump vehicles arriving between 5:00 PM and midnight into the midnight -1:00 AM hour. This analysis assumes that PEVs begin charging when they arrive home and that they charge at their designated maximum charge power until they are fully recharged.

Table D-7
Probability of PEV home arrival in each hour of the day for unmanaged and managed charging

Charge Starting Hour	Probability of Home Arrival	
	Unmanaged	Managed
0*	0.7%	18.9%
1	0.4%	11.4%
2	0.2%	4.6%
3	0.1%	1.2%
4	0.1%	0.6%
5	0.2%	0.6%
6	0.6%	0.8%
7	0.9%	1.0%
8	1.4%	1.1%
9	1.8%	1.2%
10	2.8%	1.3%
11	4.1%	1.3%
12	4.4%	1.3%
13	5.1%	1.3%
14	7.2%	1.4%
15	9.9%	1.4%
16	12.8%	1.4%
17*	13.2%	0.0%
18	10.5%	0.0%
19	7.9%	0.0%
20	6.4%	0.0%
21	4.6%	0.0%
22	3.2%	0.0%
23	1.5%	0.0%

* The focus of this study is on system impacts during hours beginning 0 and 17.

Low and Medium PEV Adoption Scenarios

This Phase 2 assessment provides a high-level screen of residential service transformer capacity assuming a statistically representative population of PEVs are adopted throughout the GPES service territories. EPRI's Hotspotter tool was used to estimate how many transformers may be overloaded in a Medium Adoption scenario vs. a Low Adoption scenario. The Low Adoption scenario presented in Section 2 was used to represent baseline PEV adoption, or a business-as-usual scenario for adoption, assuming no third party or utility inducements are provided. The Medium Adoption scenario presented in Section 2 represents an above-and-beyond adoption scenario assuming that the GPES Clean Charge Network drives additional adoption.

Table D-8 shows the probability of PEV adoption for each home, in 2017 and 2025 by jurisdiction. These are based on the PEV forecasts provided in Section 2.

Table D-8
PEV adoption for low and medium adoption scenarios, in 2017 and 2025, by jurisdiction

	2017		2025	
	Low	**Medium**	**Low**	**Medium**
GMO	0.06%	0.09%	0.21%	1.23%
KCP&L-KS	0.11%	0.15%	0.30%	1.55%
KCP&L-MO	0.11%	0.16%	0.33%	1.72%

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