Strategies for Integrating Electric Vehicles into the Grid

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Abbreviations and Glossary of Terms

ACEEE	American Council for an Energy-Efficient Economy
AFDC	Alternative Fuels Data Center
ANL	Argonne National Laboratory
ASE	Alliance to Save Energy
CAISO	California Independent System Operator
CARB	California Air Resources Board
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
CSIS	Center for Strategic and International Studies
CUB	Citizens Utility Board
DOE	Department of Energy
DOT	Department of Transportation
DR	Demand response
DSM	Demand-side management
DTE	Detroit Electric Company
EDTA	Electric Drive Transportation Association
EE	Energy Efficiency
EIA	Energy Information Administration
ESN	Energy Services Network
EV	Electric vehicle
EVSE	Electric vehicle supply equipment (EV charging equipment)
EVTC	Electric Vehicle Transportation Center
FTC	Federal Trade Commission
GCC	Georgetown Climate Center
GHG	Greenhouse gas emissions
GPSC	Georgia Public Service Commission
GWh	Gigawatt hours
HECO	Hawaiian Electric Company
HEI	Health Effects Institute
IEA	International Energy Agency
IER	Institute for Energy Research
IPL	Indianapolis Power & Light
KCP&L	Kansas City Power & Light
KWh	Kilowatt hours
LEED	Leadership in Energy and Environmental Design
Level 1 charging	Also called home charging; EVs charged at 110V wall outlet.
Level 2 charging	EVs charged at 240V outlet; needs additional charging equipment.

Level 3 charging	Also called DC fast charging; typically 208/480V AC three-phase input.
MOU	Memorandum of understanding
MRSC	Municipal Research and Services Center
NPR	National Public Radio
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
OpenADR	Open automated demand response
PEVC	Plug-in Electric Vehicle Collaborative
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
PUC	Public utility commission
RAP	Regulatory Assistance Project
SCAG	Southern California Association of Governments
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
TOU	Time-of-use
TVA	Tennessee Valley Authority
USGBC	US Green Building Council
V1G	Controlled or managed charging of EVs
V2B	Vehicle-to-building
V2G	Vehicle-to-grid two-way power flow
V2H	Vehicle-to-house
VEIC	Vermont Energy Investment Corporation
ZEV	Zero-emission vehicle
ZTF	Multi-State ZEV Task Force

Executive Summary

Electric vehicles (EVs) are becoming more prominent in the US vehicle market and are expected to number in the tens of millions globally within a decade. EVs have the potential to dramatically reduce transportation-sector energy use and the associated emissions, as well as to support the transition to a more sustainable transportation system. Barriers to EV adoption include high upfront vehicle costs, limited access to charging infrastructure, and limited range.

Large-scale EV adoption will create both opportunities and challenges for the electric power sector. While EV charging represents an opportunity for growth for utilities—some of which have been experiencing flat or declining sales in recent years—EVs also can be used to more efficiently deploy existing resources and the growing renewable power supply. However EVs could place high demand on local distribution infrastructure and add to peak demand, so utility resource planning processes will need to consider future EV adoption.

Maximizing broader societal benefits from a shift to EVs will require collaboration between utilities and other stakeholders. Utilities are uniquely positioned to guide EVs' interaction with the grid, but they will need to develop strategies that complement those of state and local governments to ensure that both power sector and societal benefits follow from EV adoption.

This report focuses on five categories of utility strategies to integrate EVs into the grid: rate design, smart charging, charging station investment and ownership, vehicle purchase incentives, and coordination with state and local efforts. We describe these strategies and identify major issues associated with each. To gain insight into some of these strategies in action, we provide case studies of three utilities that have created multifaceted EV integration plans: Southern California Edison, Indianapolis Power & Light, and Georgia Power Company. The report concludes with our findings on utility strategies to accommodate and promote EV growth, which we now summarize.

SUMMARY OF FINDINGS

Rate Design

Certain rate structures can benefit EV owners and utilities alike by incentivizing charging when power demand is low. With time-of-use (TOU) rates, EV owners save money by charging at off-peak hours while utilities reduce peak demand and promote grid stability. EV-specific TOU rates can be designed to treat utility customers equitably. Dynamic rates could be beneficial for fast charging of EVs but may prove challenging for most EV owners, who typically cannot adjust charging times to respond to variable and unpredictable pricing. Demand charges, which charge customers based on maximum power draw, are a potential concern for DC fast charging (Level 3 charging). Overall, utilities can help to maximize EVs' pollution reduction benefits by using rate structures that promote EV charging with electricity from renewables or other low-carbon generation sources.

Smart Charging

While still in the exploratory stage, smart charging offers opportunities to increase EVs' value to owners and utilities. Pilot projects can test solutions to smart charging's technical challenges and gauge customer receptivity. Integrated assessment of the system benefits and emissions impacts of charging algorithms will help to maximize the benefits of smart charging. In the future, vehicle-to-grid (V2G) capabilities may open the door to new business models involving utilities, automakers, and EV owners.

Charging Equipment Investment and Ownership

Most states have yet to address utility investment in charging infrastructure, and utility efforts have been limited to pilot programs, shareholder investment, or public–private partnerships. Several states permit utility investments in charging stations and cost recovery for those investments, though the investments are often subject to public-interest evaluation. Where EV adoption is projected to benefit the power system, the public at large, or underserved communities, some utilities are considering investing customer funds in EV charging equipment.

Vehicle and Charger Purchase Incentives

A variety of EV stakeholders, including utilities, offer purchase incentives to boost sales of EVs and chargers. The motivation for offering incentives, whether to create new business opportunities for the utility, to permit more efficient deployment of generation resources, or to support state and local goals, influences the funding source and design. Utilities are exploring opportunities to enter into partnerships to make EVs accessible to all potential owners, users, and communities.

Coordination with State and Local EV Efforts

Collaboration between utilities and state and local governments can create a supportive environment for accelerating EV ownership, while ensuring that EVs help jurisdictions realize their visions for transportation's future. Utilities' EV policies can support state and local energy and greenhouse gas targets and action plans, as well as complement their purchase incentives. Multi-stakeholder efforts and decision making can help ensure that EV deployment benefits all stakeholder groups. Emerging mobility options could give residents access to EVs without their having to purchase them and simultaneously increase the use of other modes. Utilities can help to ensure that charging infrastructure is accessible to municipal vehicle fleets, shared-use fleets, and underserved communities, and that it supports the use of other modes of transportation. Rate structures can also be designed to support the use of EVs in municipal fleets, shared-use fleets, and underserved communities, and to encourage public transit use during peak commute hours.

EVs are gaining a foothold in the transportation sector. Utilities can take advantage of this new business opportunity by carefully designing policy options that encourage EV adoption, provide customer benefits, and achieve the full measure of EV system benefits. Further, utility coordination between states and cities can result in environmental gains from EVs and, more broadly, can facilitate a scenario in which EVs complement existing transportation choices and create a more sustainable, equitable, and low-cost transportation system in the United States.

Introduction

Electric vehicles (EVs) are becoming more prominent on US roads. More than half a million EVs were sold between 2012 and 2016, and 200,000 were sold between July 2016 and June 2017 (Klippenstein 2017). Car manufacturers including BMW, Ford, GM, Honda, and Nissan have introduced various consumer-friendly battery electric and plug-in hybrid models to the American market in recent years. EV sales also continue to grow globally. A 2016 analysis projects that more than 37 million EVs will be in use globally by 2025 (Navigant 2017). The Paris Declaration on Electro-Mobility and Climate Change and Call to Action sets a global deployment target of 100 million electric cars, out of an expected 1.5–2 billion total car population, by 2030 (IEA 2016).

Several factors are contributing to growth in EV production and sales in the United States, including battery improvement and cost reduction, purchase incentives at the state and federal levels, and state sales mandates. The introduction of many new EV models from both domestic and foreign manufacturers have given consumers more options, which has led to a growth in consumer interest in buying EVs (Cooper and Gillis 2017). Focus at the local level on electrifying the transportation system has further contributed to this EV ramp-up. Thus, technology advances, manufacturing strategy, consumer interest, and public policy all play important roles in these developments. At the same time, EV adoption faces multiple barriers, including high vehicle purchase cost, inadequate charging infrastructure, and limited vehicle range.

As we discuss below, EVs can provide substantial environmental benefits over petroleum-fueled vehicles. EV motors are far more efficient than internal combustion engines. Consequently, an EV typically uses less than half the energy and produces fewer than half the carbon dioxide (CO_2) emissions than the average gasoline-powered vehicle, even when upstream emissions from power generation are taken into account (AFDC 2017b). Because the magnitude of environmental and other benefits of EVs vary greatly depending on how they are introduced and used, careful planning among the many parties involved is essential.

Given EVs' large potential benefits, various jurisdictions and private-sector entities are moving to prepare for and accelerate their adoption. Among these entities are utilities, which stand to benefit from added electricity sales due to EV charging and from EV benefits to the electricity system, including improved system reliability, smooth net load, and additional revenues (VEIC and RAP 2015). Many utilities across the country have recently taken steps to attract EVs in their service territories.

Utilities can guide and plan for EV growth in ways that also benefit society at large, ensuring that the environmental benefits of EVs are realized while taking advantage of the new business opportunities they present. This report discusses the strategies of utilities and others to integrate EVs with the grid, and how they relate to broader environmental goals.

Planning for EVs requires coordination among utilities and state and local governments, so we also discuss how these parties can work together to create a supportive policy environment and an infrastructure network that promotes vehicle electrification while ensuring that the vehicles provide public benefits.

Implications of EV Adoption

ENVIRONMENTAL IMPLICATIONS

The electrification of vehicles could dramatically reduce the transportation sector's environmental impact. While the electricity used to charge EVs generates both greenhouse gas (GHG) and smog-forming pollutants, EVs are energy efficient relative to vehicles with internal combustion engines; they thus deliver net reductions in energy use and emissions. DOE calculations show that EVs result in less than half the CO_2 emissions associated with an average gasoline vehicle in almost all US regions (AFDC 2017b). GHG emissions from EVs will decrease further with the trend toward lower carbon intensity in the US electricity sector (Denis, Colburn, and Lazar 2016). Figure 1 shows a comparison of well-to-wheels CO_2 emissions for different vehicle technologies based on average national electricity generation mix. Detailed assumptions for this analysis are available at the Alternative Fuels Data Center (AFDC 2017b).

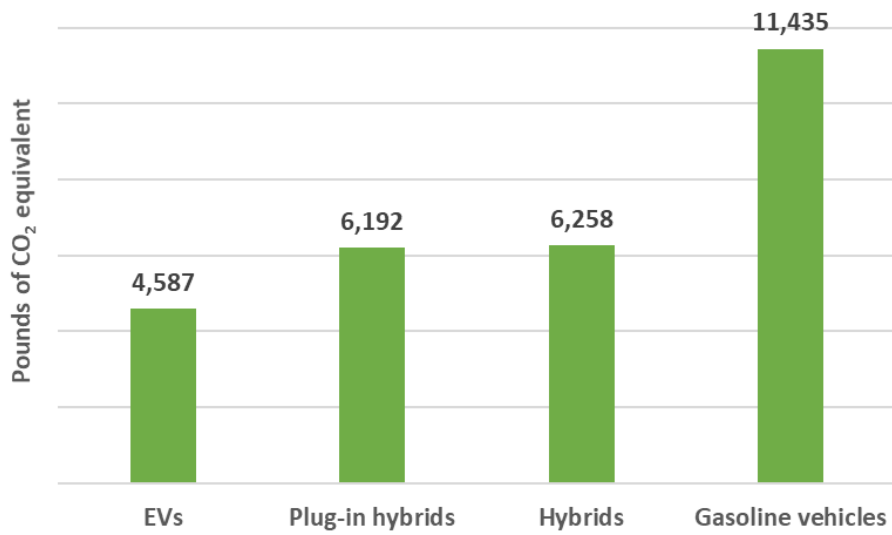

Figure 1. Annual CO_2 equivalent emissions per vehicle with average national grid mix. *Source:* AFDC 2017b.

To ensure these net emissions reduction benefits, however, sound management of the additional load from EVs is required. If additional coal power generation were required to charge EVs, for example, then EVs would typically have negative emissions impacts.

Because EVs do not produce emissions while on the road, they reduce air pollution in the immediate vicinity of roadways. Local air pollution often poses an elevated health risk to humans, especially those who live near highways and major transport corridors. Traffic-generated pollution can cause the onset of asthma, impaired lung function, cardiovascular disease, and premature death for those who live closest to main thoroughfares (HEI 2010). A 2013 Massachusetts Institute of Technology study found that, of all sectors, the transportation sector was the greatest contributor to premature emissions–related deaths in the United States, resulting in 53,000 early deaths per year from vehicle tailpipe emissions (Caiazzo et al. 2013).

EVs may offer other societal benefits as well. EVs generate less urban heat and less noise pollution than other vehicle types, benefitting dwellers in congested cities (Schaal 2016). They are also compatible with future transportation scenarios that include shared mobility and a high level of vehicle automation.

IMPLICATIONS FOR UTILITIES

The arrival of EVs in large numbers will create both opportunities and challenges for utilities. EVs could create sizeable loads on the grid and associated distribution systems. In particular, the potential for neighborhood clusters of early EV adopters has raised concerns about local transformer capacity. Unless managed correctly, multiple Level 2 chargers in a single neighborhood could strain the power distribution system when many EVs are charging simultaneously (CUB 2017). Yet these impacts remain limited today, even in areas with high EV penetration. In California, where approximately half of US EVs are registered, only a tiny fraction has required a service line or distribution system upgrade to support the load at residential charging locations (SCE, SDG&E, and PG&E 2016).

EV growth also presents three key opportunities for utilities.

Increased electricity sales. Large-scale EV adoption will provide new end-use electric loads at a time when many utilities have been experiencing negative growth. Retail sales of electricity dropped from 3.765 million-gigawatt hours (GWh) in 2007 to 3.759 million GWh in 2015 (EIA 2017). EV charging systems could increase electricity consumption by a modest to substantial amount in 2040, depending on their penetration in the vehicle stock. For example, EVs could increase electricity sales in the southeastern United States by as much as 60,000 GWh in 2040 relative to business as usual (Nadel 2017). Importantly, despite this increase, EV deployment will reduce combined utility and transportation energy consumption, assuming the EVs replace internal combustion engine vehicles that are less efficient on a well-to-wheels basis and do not increase vehicle miles traveled. In addition, the increased demand from EVs will not necessarily require major new generating capacity as long as the vehicles are charged primarily during off-peak hours (AFDC 2017a).

Diversified electricity consumers. In terms of electricity, residential and commercial buildings consume the most with 37% and 36% shares, respectively, in 2015, followed by the industrial sector at 26% (EIA 2017). The transportation sector—which is the second largest overall energy consumer in the United States—consumed less than half a percent of total electricity usage in 2015. Therefore EVs could represent an important opportunity for utilities looking to diversify their consumer rate base. The industry recognizes transportation electrification as a long-term opportunity for load growth, system benefits, and new types of customer engagement, in which customers and investors who care about the environment and corporate sustainability can participate and give feedback (EEI 2014).

Optimized grid capacity. If EVs were to charge at off-peak hours when utilities have underutilized capacity, it could reduce cost per kilowatt-hour of generation and sales, because the fixed capital costs of generating capacity would be spread over more kilowatt-hours of usage. Thus, for vertically integrated utilities, EVs' use of this underutilized capacity could reduce rates for all customers (Salisbury and Toor 2016). EVs can also reduce the cost of renewables by providing a new, flexible load to use renewable energy that would otherwise be curtailed due to lack of demand. Moreover, if electric system planners and operators are able to control EV charging in real time, EVs could become a demand response (DR) resource for optimizing the grid by balancing electricity supply and demand. DR can also help lower the cost of electricity and potentially lead to lower retail rates. In the future, bidirectional electricity flow between the grid and EVs during charging could allow them to provide vehicle-to-grid (V2G) services of distributed storage, generation service, and frequency regulation (Jacobson 2015).

Given these potential benefits, many utilities support public policies that will accelerate EV adoption. Some have voiced their support for strong federal fuel efficiency and GHG standards for light-duty vehicles to incentivize EV production. These utilities also have committed to reducing GHG emissions from the grid and providing support for increased market penetration of EVs (Bradley 2017).

Strategies for EV Integration

Given the potential for major EV growth in the coming decades, utilities across the country are folding EVs into their planning processes. Utilities are experimenting with various approaches to achieve the full range of benefits that EVs can provide. They seek to ensure that customer EV charging activity supports utility and system objectives, and many are working to accelerate EV adoption by addressing barriers such as high upfront vehicle costs, limited access to charging infrastructure, and range anxiety. Some utilities are also focused on ensuring that EV deployment delivers environmental and other societal benefits.

In this section, we discuss five strategies for achieving these results:

- Rate design
- Smart charging
- Charging equipment investment and ownership
- Vehicle and charger purchase incentives
- Coordination with state and local efforts

RATE DESIGN

Utilities typically offer multiple electricity rates for their residential and commercial customers. Residential rates have historically included a fixed customer charge to pay for billing, metering, and customer care, as well as a charge that varies with electricity usage. Utilities are gradually moving from flat energy rates to rates based on the time of day or season; in some cases, they also include demand charges based on maximum power draw (Faruqui et al. 2016; Baatz 2017). These rates are designed to spread costs equitably and can also be used to lower peak demand and encourage customers' end-use energy efficiency.

Rate design options include time-of-use (TOU) rates and dynamic rates, which help shift electricity demand out of high-demand periods. Such shifts, however, change the carbon-intensity of the power. Some utilities are reliant on traditional baseload resources during off-peak periods, so adjusting rate structures to incentivize off-peak charging may reduce or increase emissions, depending on the utility's coal or nuclear capacity, for example. Rate design can also facilitate the integration of more-intermittent generation resources, such as wind and solar.

Time-of-Use Rates

Residential TOU rate plans for utility customers regularly and predictably vary electricity rates with the time of day (afternoon, night, or morning hours), type of day (weekday or weekend), or season. This rate structure, which reflects the cost to produce and deliver electricity at various times, makes electricity more expensive at peak hours when the grid has high demand and offers cheaper electricity at off-peak hours.

More than 200 utilities, including most of the largest, offer some form of TOU rates (McDonald 2016). Forty-eight percent of investor-owned utilities (IOUs) offer them (Hledik, Faruqui, and Warner 2017). Of the 52 utilities surveyed in ACEEE's recently released *2017 Utility Energy Efficiency Scorecard*, 39 offered residential TOU rates (Relf, Baatz, and Nowak 2017). Utility commissions generally support TOU structures on the premise that they reflect cost differentiation and provide signals to shift electric consumption to off-peak periods (Erban and Long 2018).

However few customers participate in TOU rates. Among the utilities ACEEE surveyed in 2017, the number of residential customers on TOU rates was very low (less than 3% of total residential customers), primarily because most of these rates are optional and customers must opt into them. Other contributing factors include a lack of smart meters and little consumer information about TOU rates (Relf, Baatz, and Nowak 2017).

TOU rate structures vary widely. During off-peak hours, residential users can reduce their electricity cost by as much as 80%, while super off-peak rates can be as little as 5–10% of peak hour rates. As table 1 shows, for some utilities, super off-peak rates are negligible compared to on-peak rates. Peak hours also vary, often in relation to geographic location and weather.

Table 1. TOU rates offered by utilities (summer only)

Name of utility	On-peak rate ($/kWh)	Summer/all year off-peak ($/kWh)	Super off-peak rate ($/kWh)	Super off-peak time (summer/all year)	Comments
Pacific Gas & Electric	0.36	0.24	0.17	9 p.m.–10 a.m.	
Southern California Edison TOU-D-A	0.45	0.28	0.13	10 p.m.–8 a.m. (super off-peak)	<700 kWh consumption
San Diego Gas & Electric	0.46	0.40	0.36	Midnight–5 a.m. (super off-peak)	TOU-DR
Georgia Power Company	0.10	0.01		7 p.m.–2 p.m. (off-peak)	
DTE Energy	0.13	0.04		11 p.m.–9 a.m.	Whole-house rate

Rates are rounded to two decimal places. TOU rates are also offered in winter but not discussed in this report.
Sources: PG&E 2017; SCE 2017c; SDG&E 2017; Georgia Power 2017d; DTE Energy 2017.

In general, peaks are moving toward the evening, as is evident in the case studies we describe later. Abundant solar energy in the afternoon hours may also shift peaks toward evening hours, as we see in the case of Hawaiian Electric Company in figure 2 (HECO 2017).

Although utilities can adjust TOU rates to reduce system peak demand, they cannot always tune them finely enough to adjust to moving peaks (Faruqui and Sergici 2013). Extended peaks will make it more difficult for customers to adjust their usage in response to the rates (Lazar and Gonzalez 2015). Furthermore, as more customers begin to take advantage of TOU rates, they may create a new peak for utilities. As we explain below, utilities can respond to this by changing the peak period and adopting dynamic rates.

EV-Specific TOU Rates

In addition to residential TOU rates, some utilities provide EV-specific TOU rates. Such rates can be used both to incentivize EV purchase and to help manage charging behavior. EV users may need a separate meter to be eligible for EV-specific TOU rates. Absent a separate meter, the entire residential load including EV charging would fall under either residential whole-home TOU or EV-TOU rates, which may not give the full extent of intended benefits. While EVs create a much larger load than most other household appliances, their load is also more flexible. Appliances draw electricity while in use, while EVs can draw electricity any time when they are not in use (Allison and Whited 2017). Therefore peak and off-peak hours may be different for EVs than for household electricity use. Without TOU rates, most EV charging would take place in the evening peak hours when people return from work.

With EV TOU rate programs, EV charging is likely to move to late night hours, based on customer responses to price differences in pilot programs (IPL 2014). Alternatively, utilities with access to abundant afternoon solar may be able to store this electricity for peak-hour use or encourage EV charging during these times (see figure 2). EV TOU rates also entail some challenges, especially for neighborhoods that have high EV adoption. EV TOU rates will incentivize these EV owners to charge at the same time, potentially creating new local peaks and increasing distribution system costs (Allison and Whited 2017), although a large off-peak window may help address this issue.

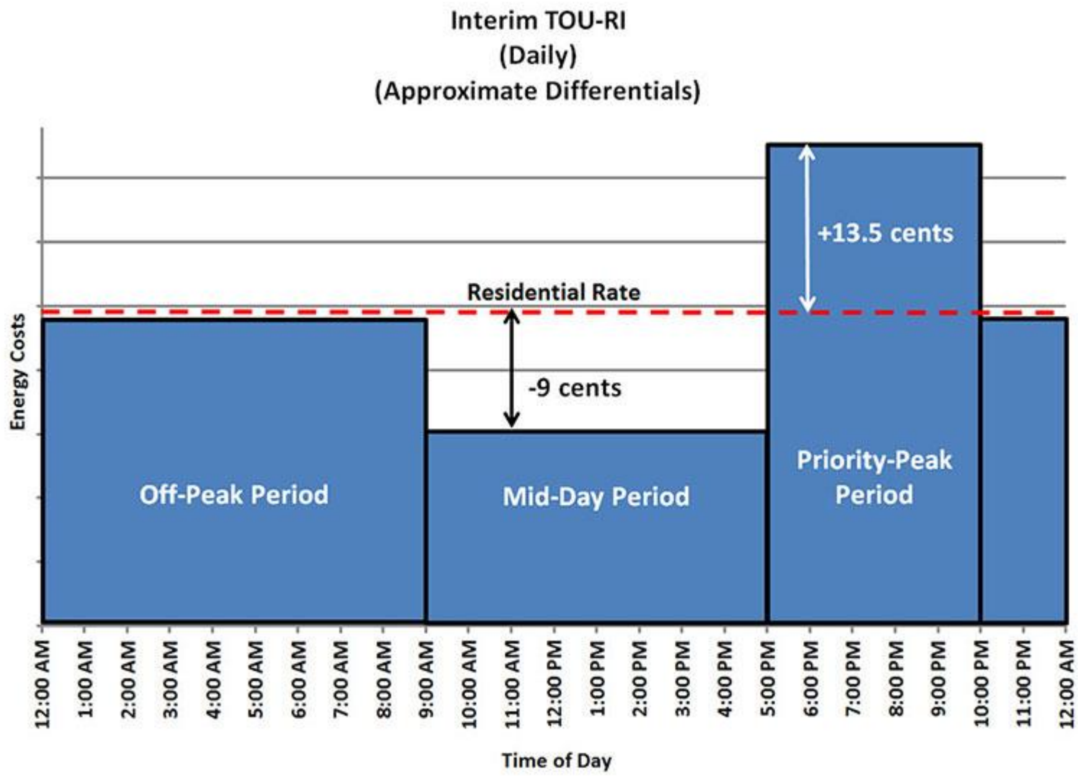

Figure 2. TOU rates offered by Hawaiian Electric Company. *Source:* HECO 2017.

Table 2 shows examples of utility EV TOU rates. These rates are summer-specific (except for DTE Energy, which provides the same rate year-round). As the table shows, EV TOU on-peak rates were found to be higher than residential TOU on-peak rates for the same utility, with the exception of Southern California Edison (SCE). Also, off-peak EV-TOU rates are generally lower than residential TOU rates, especially for California utilities, indicating a strong preference to move EV charging out of the peak or possibly a subsidy to increase EV adoption. EV TOU rates for peak hours are very high, which is unlikely to suit public and workplace charging, which typically occur during peak hours. While usage during peak should be discouraged, excessive rates will discourage EV ownership. As the table further shows, super off-peak rates are higher for California utilities than for others, but we were unable to draw broader conclusions without examining all of the EV TOU rates being offered.

Table 2. EV TOU residential rates offered by utilities (summer only)

Utility	On-peak rate ($/kWh)	Off-peak rate ($/kWh)	Super off-peak rate ($/kWh)	Peak hours
Pacific Gas & Electric	0.45	0.25	0.12	2–9 p.m.
Southern California Edison	0.34		0.14	12–9 p.m.
San Diego Gas & Electric	0.50	0.24	0.19	4–9 p.m.
Georgia Power Company	0.20	0.07	0.01	2–7 p.m.
DTE Energy	0.16	0.04		11 a.m.–7 p.m.

Rates rounded to two decimal places. Southern California Edison has only two rates, on-peak and super off-peak; DTE's rate is year-round. *Sources:* PG&E 2017; SCE 2017c; SDG&E 2017; Georgia Power 2017d; DTE Energy 2017.

Demand Charge and Dynamic Rates

Six percent of all TOU rates include demand charges, and they are common for commercial and industrial customers. They are used to recover the on-fuel costs of providing electricity to large commercial and industrial customers and are designed to incentivize them to have consistent load and avoid fluctuations (RAP 2017). Some utilities are now proposing them for residential customers, and 19 already have residential demand charges (Faruqui, Hledik, and Hansen 2016). However very few utilities employ these charges in their EV rate design (Erban and Long 2018).

Demand charges could adversely affect EV adoption. For example, businesses may discourage workplace EV charging to avoid demand charges from simultaneous charging, which in turn will discourage EV ownership among people without convenient residential or public charging options. Utilities are aware of the consequences of demand charges on EV charging and are taking remedial measures. For example, Portland General Electric Company, which charges 50¢ for each kW of demand in excess of 40% of maximum demand, adjusts these charges downward in many cases, including when the excess is associated with EV charging (PGE 2016).

Some utilities also offer dynamic rates, which track electricity production and distribution changes from hour to hour. Dynamic rates can shorten the highest-rate period to a few hours, improving customer response (Lazar and Gonzalez 2015). Dynamic rate structures have not been widely adopted, although a few utilities offer hourly pricing. Commonwealth Edison in Illinois, for example, offers all residential customers the hourly pricing option; enrolled customers are informed of the next day's electricity prices each day at 4:30 p.m. (ComEd 2015).

Dynamic rates can provide windows of low-cost EV charging in periods that would be peak hours under a TOU rate structure. These windows could create low-cost charging opportunities for Level 3 fast charging, which provides 60–80 miles of range in 20 minutes.

However, while fast chargers are increasingly common, most charging uses Level 1 or 2 chargers and requires a longer charge period. Hence shifting peaks under dynamic rates could be challenging for most EV owners, as they would have to adjust charging time on a day-to-day basis; because most EV drivers plug in out of necessity, they may not have this flexibility.

SMART CHARGING

Smart charging varies charging activity in real time to optimize outcomes for the utility and/or the EV customer. Examples range from a charger that responds to constraints set by the vehicle owner to V2G technology that lets the vehicle communicate directly with the utility. In its most basic form, smart charging adjusts a vehicle's time of charging to take advantage of a utility's changing rates. In an advanced form, smart charging can trigger automated, dynamic decisions regarding the timing and rate of bidirectional electricity flow between the EV and the grid, making the vehicle a new type of grid resource. Various interim levels of smart charging have been deployed under pilot programs, with a variety of benefits to the utility and vehicle owner.

The development of advanced meters and chargers will help utilities maximize system benefits from EVs and minimize the challenges arising from the extra load. Smart meters let EV chargers interact with the utility, responding to a variety of constraints with or without direct action on the vehicle owner's part. Two-way communication can make this interaction possible even without advanced metering infrastructure. With automated smart chargers, vehicle charging could be triggered based on predefined load limitations within a building or particular location, or by a change in rates, whether TOU or dynamic. Each utility will weigh the advantages and disadvantages of various smart charging methods according to their unique circumstances (Silver Spring Networks 2010).

Evolving Business Models

Many smart charging concepts require a break from traditional utility business models that define how utilities create and capture value from their assets. With EV adoption expected to increase (Navigant 2017), utilities are wise to consider not only how to manage additional load on existing infrastructure, but how EVs can provide value to the utility. The relationship between a utility and its customers must evolve, with the utility working to build additional trust and ensure a mutual benefit with its customers. To secure participation in DR charging programs, the utility must ensure that the vehicle is available for the owner's commute. Regardless of the type of utility program, vehicle owners will likely demand full discretionary use of the vehicle, requiring utilities to find value in an asset that can be unpredictable and, at times, unavailable.

Vehicle-to-grid operation utilizing the vehicle's energy storage capability will result in additional battery cycles and consequently will decrease battery life (Ayre 2017; EVTC 2017). To date, automakers have tended to treat these energy storage cases as outside the vehicle's expected use and hence sufficient to void the warranty (Fitzgerald, Nelder, and Newcomb 2016).

Concepts such as battery swapping and battery leasing can address some of these concerns. Utility or third-party battery ownership and leasing can drive down vehicle purchase costs, addressing one of the largest market barriers to EV adoption (Ewing 2017). Consumers must be convinced to diverge from the concept of full vehicle ownership, trusting that the utility and automakers will provide reliable, uninterrupted use of the vehicle. However an Israeli startup's effort to develop cars capable of battery swapping with the necessary infrastructure fell short (Gunther 2013). A Renault battery leasing program in France has leased its 100,000th EV battery, but as battery costs decline, such an option may be less appealing to car buyers (Go GreenAutos 2017; Kane 2017).

To access their EVs' full potential market value, automakers will need to collaborate with EV owners and utilities to address the warranty issue while keeping the price of energy storage capability low. Similarly, utilities and grid operators will need to adequately compensate owners for use of their vehicles as a grid resource, while both promoting the opportunity to opt-in or opt-out and ensuring transparency to protect consumers. As this storage usage becomes better understood, utilities and automakers could form new relationships and modify their own business models to reflect such mixed battery uses. The utility must also ensure that vehicles maintain enough charge to be available for personal use when needed. Finally, the grid operator will need to both make its programs sufficiently attractive to draw customer participation and be responsible for administering the program (Steward 2017).

Finally, barriers associated with battery cost and longevity relate to today's available battery chemistries. Researchers are making progress on new types of batteries that promise to extend battery lifetime and capacity (Chandler 2015) and achieve far higher charge and discharge rates (WardsAuto 2017).

Controlled Charging (V1G)

Controlled charging, also called *managed charging* or *V1G*, is a one-way communication infrastructure that lets utilities control vehicle charging remotely, helping them to manage load. V1G can control vehicle charging time and speed, similar to many load curtailment programs that can remotely control thermostats or signal customers to decrease load. At its basic level, V1G might even require manual participation from vehicle owners. In 2017, a Smart Electric Power Alliance survey of utilities showed that only 3% of respondents have implemented V1G programs, with 69% planning, researching, or considering them (Meyers 2017).

In an Electric Power Research Institute pilot, EV owners were given smart chargers that let them input their next departure time. When the chargers received a signal from the utility to halt charging, they would determine whether doing so would conflict with their owner's needs (Jacobson 2015). Other V1G pilots let EV owners choose how the charger would respond to pricing signals (SCE 2016). An SCE pilot used workplace charging to develop afternoon peak and load reduction strategies. During a load management event, the charger would use the driver's price tolerance (high, medium, or low) to continue charging, charge more slowly, or halt charging. By responding to a load management event, customers can maintain a satisfactory charge rate for their own needs, while the utility benefits from increased response to such events.

Another V1G project was conducted by Austin Energy in 2014 with funding from the Advanced Research Projects Agency–Energy. Using a combined thermostat and home charging infrastructure, Austin Energy was able to shed load during the peak. Customers were found to be much more open to EV charging disruption than to the utility's main DR program, which was directed at air-conditioning load. Also, an open standards approach—in this case, Open Automated Demand Response (OpenADR)—was quicker to implement and more effective than an alternative path of using application programming interfaces (K. Popham, manager, electric vehicles and emerging technologies, Austin Energy, pers. comm., December 12, 2017).

Vehicle-to-Building (V2B)

V2B chargers, including vehicle-to-house (V2H) chargers, differ from V1G in that they allow electricity to flow to and from a vehicle plugged into a capable charger. V2B chargers need not have communication with the utility. The technology allows bidirectional power flow behind the utility meter, letting owners power a building from an EV's charged batteries. Doing so requires special equipment beyond the charger: the building's distribution panel must contain equipment to monitor demand. Likewise, it requires that the vehicle itself be capable of two-way power flow, which is not a universal property of EVs today.[1]

In 2017, Pacific Northwest National Laboratory began a project to develop standardized communication pathways between vehicles and building management systems (PNNL 2016). The technology will respond to internal signals, allowing EV chargers to take advantage of onsite renewable generation and minimize grid demand.

Although V2B does not make stored energy available to utilities (Briones et al. 2012), it is likely of interest to them as it can reduce peak demand and increase resilience by providing demand response. The utility may even benefit from a greater reduction in demand with V2B than with a V1G charger because V2B displaces or flattens the building's load on the grid. The technology became especially popular in Japan following the 2011 earthquake as it

[1] The Nissan Leaf in Japan is capable of two-way power flow (V2G). In the United States, there are several V2G pilot projects, but the technology is not yet commercially available here.

enabled owners to power their homes during power outages (SCE 2016). Businesses and homeowners could find value in EVs with the ability to temporarily power their building or home. However some US areas might have regulatory obstacles that prevent the use of such capabilities.

As with other smart charging technologies, the business case for V2B must be made for each application. Further, V2B must be made sufficiently attractive by offsetting the EVs' upfront cost to owners by offering value to building owners through lower utility charges and backup power, and by providing value to the utility through load-shedding capabilities.

Vehicle-to-Grid (V2G)

Combining characteristics of both V1G and V2B, V2G offers two-way communication and two-way energy flow with the grid through the meter. V2G chargers are currently the most capable of all smart chargers. V2G also requires that the vehicle itself be capable of two-way power flow. V2G lets utilities use EVs as a new type of distributed grid resource, offering several potential services and revenue streams. V2G's technical feasibility is a work in progress, however; for example, cybersecurity issues have not yet been fully addressed.

Through V2G, EVs become grid-connected energy storage devices. This could be especially important as a cost-effective solution to renewable energy's energy storage requirements. Even though the cost of energy storage is falling, it may not be economical for some time (D'Aprile, Newman, and Pinner 2016). Energy markets already exist in many parts of the country that reflect the value of DR and energy efficiency resources (Relf, Baatz, and Nowak 2017). With the appropriate markets in place, purchasing and trading EVs as grid resources might accelerate the energy storage market and promote EV adoption. So, while individuals and businesses may buy EVs primarily for transportation purposes, their energy storage capability could provide a source of revenue for the customer, utility, and grid operator.

Effective V2G deployment will require vehicle manufacturers, vehicle owners, and grid operators to share costs and benefits and to ensure all parties' confidence in the fairness of the arrangement. By enabling EV owners to sell energy back to the grid, V2G should reduce the total cost of EV ownership and offset any added purchase costs relative to internal combustion engine vehicles.

V2G can also provide ancillary services that support power grid operation and reliability. Unlike the traditional assets that provide ancillary services, V2G is capable of providing nearly instantaneous spinning reserves and voltage or frequency response. Because EVs will be plugged in across a region, they become a distributed energy resource. This provides additional benefit to the utility by reducing the need for investment in grid infrastructure, optimizing and extending the life of existing assets. V2G could be central to new business models that utilities develop while accommodating increased EV deployment (Fitzgerald, Nelder, and Newcomb 2016). At the same time, optimal usage of EVs can be expected to change over time. For example, as models of urban mobility evolve, shared-use vehicles may become more widespread, reducing the availability of EVs and their batteries as grid resources.

CHARGING EQUIPMENT INVESTMENT AND OWNERSHIP

Charging equipment for EVs, also known as EV supply equipment (EVSE), includes the vehicle charger, connectors, and protection components. Home charging is prevalent for personal EV owners, but a comprehensive charging network is nonetheless critical for EV uptake. Lack of investment in and construction of EVSE has been identified as a major barrier to greater EV deployment (CSIS 2016; Baumhefner, Hwang, and Bull 2016).

In recent years, the number of charging stations has gradually increased across the country as private entities and state and local governments have started investing in charging networks. The United States has about 19,000 charging stations, the majority of which are privately owned; the next largest share is owned by local government, followed by utilities, state government, and federal government shares (AFDC 2017b). These stations are not sufficient to meet EV needs, however. Some utilities are helping to fill this infrastructure gap by building EVSE to open up a new business opportunity (UBS 2017) and generate new revenues. These revenues could be invested in clean resources such as renewable energy and end-use energy efficiency, though there is no guarantee that utilities will do so (CUB 2017; Powers 2015).

Utility investment in public charging stations raises many questions, including about the source of funds to be invested, the extent and nature of system benefits of increased EV adoption, and the population to be served by the charging stations. All are important considerations. For example, it can be argued that spending customer money on public charging is justified only when it delivers public benefits, brings EV access to underserved areas, or responds to state and local policies. Another concern is that allowing distribution utilities, which are regulated monopolies, to invest in EV charging infrastructure could give them undue competitive advantage and potentially stifle other, independent EVSE suppliers. Utility partnerships with private charging companies will not necessarily address concerns about market competition. In any case, the merits of the various ownership models should become clearer as implementation progresses.

California decided to allow utilities to invest customer money in EV charging infrastructure in some circumstances, but only after extended debate (CSIS 2016). The California Public Utilities Commission (CPUC) approved an expanded role for utility activity in developing and supporting EVSE in 2014. Doing so required that CPUC lift earlier restrictions, which it had passed on the rationale that allowing utilities to own EVSE could limit competition in the market and prevent other public or private entities from participating. CPUC ultimately agreed to let utilities own EVSE, as stakeholders almost unanimously felt that utilities could play a key role in EVSE support and development. The commission plans to decide utilities' role on a case-by-case basis, with a balancing test that would include evaluation of the utility's proposed EVSE program and examination of its potential competitive impacts (CPUC 2014).

Following that 2014 CPUC decision, several utilities stepped in to fill the gaps in EVSE. San Diego Gas & Electric (SDG&E) obtained approval from the CPUC to own and install charging stations at up to 350 businesses and multifamily communities throughout the region, with 10 chargers at each location for a total of 3,500 separate chargers. At least 10% of these chargers will be located in disadvantaged communities (SDG&E 2016). SDG&E

owns and operates charging stations along with distribution lines, transformers, and other infrastructure. SDG&E also partners with private companies to provide charging facilities. Other California utilities, including SCE and Pacific Gas & Electric (PG&E), have taken a different approach. SCE, for example, applied to CPUC to raise $570 million over five years to install fast charging stations for buses and trucks, provide rebates to encourage residential charging stations, and offer rate incentives to encourage customers to charge EVs during off-peak hours. The SCE plan would increase customer bills by an average of 0.5% (St. John 2017). In January 2018, CPUC approved $41 million of the utilities' plans (Mulkern 2018).

On the East Coast, New York City and Con Edison are also stepping up their efforts to provide charging points. New York City currently has only 307 publicly available charging facilities citywide, which house 526 Level 2 chargers and just 16 fast chargers (NYC 2017). Con Edison is proposing to invest $25 million in an EV demonstration project that includes 1,000 public fast chargers and 500 private chargers (ConEd 2017). The City of New York has set a target of 20% EVs among all new registrations in 2025. It will invest $10 million to develop fast charging. New York City's partnership with Con Edison would create at least one charging hub in each of its five boroughs with a capacity to charge 12,000 EVs every week by 2018 (NYC 2017). Meanwhile, the Massachusetts Department of Public Utilities has approved a $45 million investment in EVSE to spur EV adoption and address the barrier of charging availability (Walton 2017).

Other utilities also own and operate charging stations. Kansas City Power & Light (KCP&L) launched a $20 million project in 2015 to install and operate 1,000 charging stations for its 800,000 customers to lower EV ownership costs (NPR 2017). Charging at these stations was free for the first two years. KCP&L proposed adding a monthly fee to customers' bills for the installation and maintenance of chargers, but it did not get approval from Kansas and Missouri regulators. In arguing against the proposal, the state of Kansas and Kansas's Citizens Utility Ratepayer Board staffers primarily stated that, contrary to standard practice, KCP&L invested shareholder funds in its Clean Charge Network without demonstrating demand for charging stations (KCC 2016). KCP&L then obtained funding from investors and has built 850 charging stations to date (NPR 2017).

Utilities seek funds from other sources as well. For example, Austin Energy is leading a program called "EVs are for EVeryone" with support from the Schmidt Family Foundation. The program is developing EV sharing programs for low-to-moderate-income communities (Austin Energy 2017). Utilities can also partner with EVSE providers and offer subsidies for construction. For example, as we discuss later in the case studies, SCE will pay the cost of bringing electric service to a charge-point location.

The recent Volkswagen settlement provides an additional source of EVSE funding and may influence how utilities invest in charging stations. In response to the discovery that Volkswagen installed defeat devices on its newer-generation diesel vehicles, a Clean Air Act settlement with Volkswagen requires the company to invest $2 billion in activities to improve infrastructure, access, and education to support and advance zero-emission vehicles (ZEVs), including EVs (FTC 2016). The investments will be made over 10 years. In addition, states will be able to spend part of a separate settlement pot worth $2.7 billion for investments in charging infrastructure. The Volkswagen funds, while substantial, will not address all charging needs. Of the $2 billion funding pot, $800 million will go to California. Electrify America, which is responsible for allocating these funds, has planned construction of 2,000–3,000 Level 2 and fast charging points in California by 2019 (Volkswagen 2017). However, according to a National Renewable Energy Laboratory study, the state will need between 83,000 to 146,000 Level 2 and fast charging points by 2020 (Melaina and Eichman 2015). Hence state electrification investments pursuant to the Volkswagen settlement will meet only a fraction of charging infrastructure needs.

VEHICLE AND CHARGER PURCHASE INCENTIVES

High purchase price is a key barrier to entering the market for advanced technology vehicles such as EVs. Hence financial incentives, including tax credits, rebates, and sales tax exemptions, can be important policy levers to encourage consumers to purchase these vehicles. Currently, the federal government provides the largest incentive, allowing EV buyers to claim a tax credit of up to $7,500; state and local incentives are discussed below. While a few automakers (e.g., Tesla and General Motors) will come close to meeting their sales caps for the federal credits by 2019, the rebate is still available to customers of many other vehicle brands.

Some utilities also offer incentives such as purchase rebates to promote EV adoption. A recent study found that 44 US utility companies are currently offering rebates or other incentives—including discounted rates to EV buyers—up from 28 companies in 2015 (McDonald 2017).

Incentives vary in nature and scope. The Sacramento Municipal Utility District introduced two years of free charging for EV owners or a free Level 2 charger for new EV customers (SMUD 2016). Utilities in California and Vermont are paying direct rebates to customers in an effort to jump-start EV sales. California's three major utilities, PG&E, SCE, and SDG&E, offer credits of $200–500 to EV owners. Utilities earn credits under the state's Low Carbon Fuel Standard for power used to charge EVs, and these three utilities return the credits' value to their EV customers through a Clean Fuel Rebate (CARB 2017b).

JEA, the Jacksonville, Florida, utility provider, gives its customers a rebate for EV purchases that varies with the vehicle's battery size. Vermont's utilities are establishing direct rebates to comply with 2015 legislation to boost clean power. The state renewable energy standard requires electric companies to contribute to meeting state emissions reduction targets by investing customer money in programs that green the grid and electrify vehicles and buildings, or else pay into a state fund at the end of the year (Vermont PUC 2017). The Vermont Electric Cooperative is offering customers a $250 credit for the purchase of a new or used plug-in EV (VEC 2017). The Burlington Electric Department, a municipal utility, began offering a $1,200 rebate on the purchase or lease of a new EV or a $600 rebate for the purchase or lease of a new plug-in hybrid EV (Burlington Electric Department 2017). The utility is also partnering with dealers to offer a promotion to customers: with an added $10,000 rebate provided by Nissan, Burlington Electric customers can get a new 2017 Nissan Leaf for as little as $11,300. Similar purchase incentives have been offered by Georgia Power and Indianapolis Power & Light (IPL) to employees and customers as part of their partnerships with Nissan North America.

Some utilities offer rebates for EVSE installation, while others offer rebates for charging their EVs only at off-peak hours. For example, any Georgia Power business customer can qualify for a $500 rebate for each new Level 2 workplace charger, while any residential customer can qualify for $250 rebate for a Level 2 home charger, provided the customer has a dedicated circuit and the EVSE is not used for business (Georgia Power 2017a). Con Edison offers $50 for installing a connected car device that allows access to charging and driving data. Customers will also receive $5 per month for keeping the device connected and charging the EV in the utility territory. In the summer, Con Edison customers can also earn a one-time $20 bonus for avoiding peak hour charging and $0.05 per kWh if they charge their EVs at super off-peak hours (ConEd 2016).

COORDINATION WITH STATE AND LOCAL EFFORTS

To deploy EVs in a way that ensures utilities benefit and society can reap the vehicles' positive environmental impacts, coordination between utilities and state and local governments is required. The diverse drivers of stakeholder interest in EVs suggest that a diverse array of strategies is needed. However achieving complementarity and alignment of utilities' actions and those of other parties will be a key determinant of success.

State and local policies can provide an appropriate framework for utilities and shape EV deployment in a way that benefits society by identifying key deployment goals, user groups, and supporting policies. These policies can also ensure that EVs support reliable, efficient deployment of electricity infrastructure by requiring resource-planning activities from their respective utilities. Finally, incorporating EVs into existing transportation networks needs to align with each city or state's vision for its transportation future. Utilities can craft their policies and programs to support these state and local objectives regarding EV impact on the built environment. Utilities can also work within a set policy framework to create beneficial rate structures for EVs, support the build-out of EVSE, and help locate charging stations in a way that allows for greatest access.

Coordinated EV deployment policies and programs can achieve net reductions in energy consumption and emissions. However it will be important to ensure that EV ownership growth will not overwhelm electricity infrastructure or impose costs inequitably.

State Actions

Several states have made EV adoption a priority in their efforts to address transportation energy use and emissions. California, in particular, has long been the leading state in planning and incorporating EVs into emissions reduction efforts due to its ambitious reduction targets for criteria pollutants and, more recently, for GHGs. California GHG goals call for an 80% reduction in emissions below 1990 levels by 2050. In 2015, SB 350 was adopted, establishing an interim GHG reduction target of 40% below 1990 levels. As of 2015, the transportation sector accounted for 39% of total California emissions (CARB 2017a). Moreover, California's electricity is relatively clean. These two circumstances, together with the state's interest in being a leader in green technologies, make EV adoption a high-priority strategy.

California's long-standing ZEV program serves as the guiding regulation for EV deployment. The ZEV program requires automakers to ramp-up production of ZEVs based on the percentage of their vehicle sales within the state. Between 2018 and 2025, the percentage of total vehicle sales that must be ZEVs will increase from approximately 4% to 15.4% (Shulock 2016). Recent projections show that by 2025, California will likely have only a 6% EV penetration rate, however, due to differences between projected and actual characteristics of EVs purchased and how they are treated under the program (Trabish 2017). To date, California's ZEV mandate has been adopted by the District of Columbia and nine states: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont (Berg et al. 2017).

In 2012, Governor Jerry Brown issued Executive Order B-16-12, calling for 1.5 million ZEVs on California roads by 2025 and identifying several intermediate milestones to help the state meet this target (California 2016). A ZEV Action Plan was subsequently released in 2013 and updated in 2016 in an effort to provide state government agencies with concrete actions to encourage deployment of these vehicles. The 2012 executive order directed the Air Resources Board, the CPUC, the California Energy commission, and many other state agencies to collaborate with the Plug-In Electric Vehicle Collaborative (PEVC) to create the action plan for EV deployment. PEVC's steering committee for the plan and its subsequent updates include key California utilities such as SDG&E and PG&E as well as local representatives for air quality management districts around the state. In line with SB 350—which calls for accelerated, widespread transportation electrification—the plan's 2016 edition emphasizes the continuation of California's successful purchase rebate programs, highlighting the consumer benefits associated with EVs and ensuring that ZEVs can be equitably accessed by all (California 2016).

As a follow up to the executive order, California partnered with seven other states in 2013 to sign a memorandum of understanding (MOU) on EV deployment. The MOU identified the critical role EVs play in achieving GHG reduction targets and was an effort to formalize coordinated actions to accelerate the ZEV vehicle market across the eight states: California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont. Signatories to the MOU jointly committed to 3.3 million ZEV vehicles on the road by 2025 and participation in a ZEV Program Implementation Task Force (Brown et al. 2013). The task force released a multistate action plan covering 11 key actions states should take to meet the 3.3 million vehicle target. These actions include purchase incentives, policies to encourage infrastructure investment, and providing access to charging. Like the California action plan, the multistate plan involved close collaboration with a number of stakeholders, most particularly the major utilities in each of the MOU states. Utilities have taken the lead in evaluating their grids' reliability with respect to increased EV load as well as in coming up with rate structures that support EV deployment (Multi-State ZEV Task Force 2014).

The California executive order and multistate action plan have benefited utilities interested in growing their EV-related business. California has set aside a growing pool of funding for utilities to use for pilots targeting innovative EV-related programs for their customers; SCE and PG&E have both received state funding for their smart charging pilots. Likewise, utilities in the seven other MOU states have embarked on various pilot projects to demonstrate the benefits of EVs to customers and to the grid. In January 2018 the CPUC authorized $41 million for California utilities to spend on EV programs. The utilities will implement 15 pilot projects that cover passenger, transit, and freight vehicles and provide access to EVs and charging infrastructure in low-income and minority communities. Along with pilot projects that involve building and installing EV charge points and converting fleets, SDG&E will initiate an innovative program offering incentives to car dealers to sell EVs (Mulkern 2018).

Beyond California and the MOU states, there is plenty of activity focused on EV deployment. The governors of Arizona, Utah, Colorado, Idaho, Montana, Nevada, New Mexico, and Wyoming signed the REV West Plan Memorandum of Understanding in 2017 to provide a framework for creating an EV corridor connecting the states and to launch a regional strategy for EV deployment with economic development in mind (Hickenlooper et al. 2017). Additionally, with the creation of two significant pots of money for EV deployment through the Volkswagen settlement—one targeted specifically at state activities, and the other at emissions mitigation—state focus on EVs is likely to increase in the near future.

In addition to helping to ensure that EV adoption advances their environmental priorities, states will bring utility policy priorities to the table through their public service commissions (PSCs) or public utility commissions (PUCs). Among the responsibilities of these commissions are improving system reliability and protecting customers, both of which must be addressed in setting EV policy. PUCs and PSCs can also ensure that the utility regulatory process and goals are aligned with the overarching statewide energy strategy.

Ownership of EV infrastructure has been a particular topic of interest to state PUCs in recent years. A number of PUCs are grappling with decision making regarding utility ownership of charging infrastructure and the subsequent impacts on market competition and customer rates. The Oregon PUC is currently evaluating proposals from PacifiCorp and Portland General Electric for a $10 million investment in EVSE in addition to other EV-related programs. However critics of the proposals say that utility ownership of charging stations may distort the EV market and limit competition from private companies (Howland 2017). Missouri's Public Service Commission recently denied Ameren's proposal to install charging stations along Interstate 70 and charge a fee to customers on the basis that this would create regulated monopolies for infrastructure ownership (Uhlenhuth 2017). On the opposite end of the spectrum, Texas state law requires public utilities to be the sole provider of electric services, including EV charging. In addition, as we discussed earlier, California's PUC has defined utilities' role in funding and in some cases owning charging stations.

Local Actions

Sustainable transportation systems must be efficient, clean, well connected, and reliable. In urban areas, such systems can include a range of services, from ride sharing to public transportation. Many cities also have begun to promote and prepare for EVs, having identified the role they can play in meeting climate and other goals. While simply increasing the number of EVs in urban centers will not guarantee an overall improvement in a transportation system's efficiency, they can be incorporated in innovative mobility options that could substantially reduce energy use and local air pollution while making cities more livable. Many cities are working to achieve mobility systems that are multimodal, emphasize active transportation, prioritize safety and sustainability, and shrink the combined footprint of motor vehicles.

In recent years, new urban transportation models have emerged that favor shared vehicles and decrease the need for personal vehicle ownership altogether. These new mobility services provide a valuable testing ground for advanced technology vehicles, including both EVs and autonomous vehicles. From a business perspective, the high usage rate and low fuel and maintenance costs of shared EV fleets can rapidly offset high purchase costs. Consequently, new mobility services may provide an important opportunity to build EV fleets, especially if the majority of urban car travel occurs in shared vehicles within the next two decades, as some experts predict (ITF 2016).

Obstacles to EV adoption to date have included high upfront costs and inadequate charging station networks. An emerging secondary market for used EVs, along with growing charging networks, makes EVs accessible to a broader swathe of the population. Further, as part of ride-sharing and car-sharing programs, EVs could provide valuable services to all urban residents. Already, several car-sharing companies, including ZipCar and car2go, have incorporated EVs into their fleets.

Many cities have begun incorporating EVs into their future transportation plans. The US Department of Transportation (DOT) Smart Cities Challenge, launched in December 2015, highlighted a variety of EV-focused strategies to enhance smart mobility in urban areas. When DOT issued a call for ideas on developing an integrated transportation system using data, applications, and technology to help people and goods move more quickly, cheaply, and efficiently, 78 cities applied (DOT 2017a).

According to DOT, all seven finalist cities proposed converting a portion of their municipal and transit fleets to EVs. Several others went a step further, outlining support for EV use by taxi and transportation network companies such as Uber and Lyft and for installing the required charging infrastructure (DOT 2017b). For almost all seven finalists, the local electric utility played an active role in crafting portions of the submitted application, participating in multi-stakeholder planning processes as well as contextualizing the city’s electrification strategy within overarching GHG targets. As an example, Austin Energy took the lead in outlining the vision for electrifying transportation fleets—including buses and transportation network company fleets—as part of Austin’s Smart Cities Challenge application. The application also outlined a detailed strategy for EV outreach and incentives, and for creating innovative financing programs. This sustained local focus on addressing EVs’ role in the future of transportation has also spurred interest from industry stakeholders. In September of 2017, the Smart Cities Council and the Edison Electric Institute partnered on a series of initiatives to encourage smarter, electrified, resilient cities. Focused on electric companies’ role in creating these smart cities, the collaboration aims to highlight successful city and utility projects and how the electric power industry can work with local governments to create supportive policies and programs (Smart Cities Council 2017).

Utilities can help design rate plans and siting strategies for charging infrastructure in coordination with local governments and EV interest groups. As we noted above, many urban EVs in the future may belong to shared-use fleets. Utilities will be able to support these shared-use fleets by choosing accessible charging site locations and creating rate structures that ensure fair and predictable charging costs. Municipal fleets also need convenient access and affordable rates. Municipal fleet procurement is an effective way to lead by example and can signal local interest in effective EV deployment. These efforts could serve as an incentive for deeper electrification of municipal passenger and local transit fleets and address persistent pollution problems that diesel-fueled transit fleets cause.

Finally, to support an integrated urban transportation system, utilities can install chargers near transit hubs to boost regional and local transit ridership. The City of Huntington, New York, installed charging stations at Long Island Railroad stations to encourage EV owners to do the bulk of their commute on public transit (NYSERDA 2017). Additionally, utilities can offer TOU rates that encourage public transit use during peak commute hours and shift charging to off-peak hours.

Standards Setting

As utilities work to accommodate a growing number of EVs, state and local governments can create policies, including setting codes and standards, that benefit both EV owners and utilities.

EV-READY BUILDING CODES

States and cities can use building codes to support the planning and construction of charging infrastructure to accommodate EV growth. For example, building codes can require that new construction incorporate EV readiness—that is, that garage or parking areas are wired to the electrical panel and that there is sufficient electrical capacity for charging facilities and stations. This requirement removes the need to retrofit buildings down the road.

Building codes can also require that a percentage of a building's parking spots are designated for EVs and charging stations, or that charging station installation is classified as a minor project, enabling expedited processing for the required permits (NYSERDA 2012). Such code updates make the process of installation easier, reduce home/building owner costs, and ensure access to charging facilities. The US Green Buildings Council's Leadership in Energy and Environmental Design (LEED) program, for instance, requires building projects to set aside 2% of all parking spaces for EV charging (USGBC 2017). San Francisco is in the process of proposing legislation that mirrors the LEED requirement and would make all new residential and commercial buildings EV-ready by designating that 10% of all parking spaces be wired for EV charging (Lambert 2017).

In addition to ensuring that EV buyers can easily install and access charge points, these code provisions could prompt utilities to plan for load growth and offer EV drivers supportive rate structures for charging. However these codes do not decide who will situate, install, own, and manage charging infrastructure. Utilities could play a leading role in developing a uniform protocol for installation; depending upon state policies, utility commission rules, and business considerations, utilities could own charging facilities outright or enter into public–private partnerships.

ZONING CODES FOR EV PARKING SPACES

Like building codes, local zoning codes can be used to support a growing fleet of EVs. Because land use planning and zoning are municipal functions, cities are largely responsible for this form of regulatory support.

Zoning codes can be changed in two key ways to accommodate charging infrastructure. First, they can ensure that EV charging facility placement is identified as a land use and that this use is allowed in as many zoning district types as possible. In 2009, Washington State adopted 2SBH 1481 to prepare for increased EV penetration; the legislation requires all counties and cities statewide to allow EV charging stations as a use in all land use zones (MRSC 2017).

The second approach targets the use of parking requirements. Instead of requiring the standard two spots per unit of residential or commercial space, zoning codes can instead set aside a portion of parking space specifically for charging units and count these spots toward minimum urban parking requirements (SCAG 2012). The Georgia Department of Planning and Community Development amended the Atlanta zoning ordinance to create an incentive program for EVs and charging stations by allowing each charging station to count as a parking space. This reduced the minimum parking requirement in the city zoning code by one space (Atlanta 2015). Amending parking codes gives utilities more options for locating and installing EV charging infrastructure and, since parking spaces can be expensive to create, can be a cheaper option for developers.

Once again, utilities can play a significant role in ensuring that the location of charging infrastructure is accessible to all key groups, included underserved and low-income communities.

Incentives

VEHICLE PURCHASE INCENTIVES

As noted above, the federal government offers a tax incentive of up to $7,500 for the purchase of an EV. Some states have sweetened the EV pot with additional tax credits in recent years, and several states, the District of Columbia, and Puerto Rico offer some sort of financial incentive to EV buyers (Berg et al. 2017). California offers residents the highest rebate—$7,000 for light-duty EV purchases—followed by Colorado, which offers a $5,000 tax credit. Other states, including Louisiana and Maryland, let buyers claim as much as $3,000 per vehicle.

City-level incentives can also play a significant role in EV uptake, yet few cities currently provide supplemental financial or non-financial incentives to the federal and state tax credits. Indeed, only 5 of the 51 large cities evaluated in ACEEE's *2017 City Energy Efficiency Scorecard* offer an incentive of any kind. These cities are: Chicago; Jacksonville; Milwaukee; Riverside, California; and Washington, DC (Ribeiro et al. 2017).

Some utilities have further reduced the upfront costs of EV purchasing by supplementing state and local financial incentives with their own rebates. These utilities can coordinate with state and local governments to create effective incentive packages. Coordinated programs can ensure that EVs are available to all customers, across all communities, by covering both new and used vehicles and setting conditions on vehicle price or purchaser income.

EVSE INCENTIVES

While some workplaces have privately invested in EVSE access for employees, cities and states can do a lot to ensure that investment in charging infrastructure is consistent and networks are well connected. A number of cities have begun evaluating their EV readiness, using tools such as the DOE Plug-In Electric Vehicle Readiness Scorecard and developing policies and incentives that encourage consistent EVSE access (DOE 2017). Nine of 51 large cities in ACEEE's *2017 City Energy Efficiency Scorecard* offered incentives for building and implementing EV charging stations (Berg et al. 2017).

Utility incentives can go a step further in reducing EVSE installation and permitting costs. Incentives designed for different targets (multifamily, municipal, or residential) could help create a comprehensive network of charging facilities for private and public use that ensures access to all communities.

Case Studies

To demonstrate these strategies in action, we examined three leading US utilities: SCE, IPL, and Georgia Power Company. We chose these utilities not only to highlight their detailed, multifaceted EV integration plans but also to demonstrate that EV integration planning is happening in utilities of various sizes and types across the country. SCE is the largest utility included here and, given its California location, is at the forefront of the smart promotion of EVs. IPL's efforts are impressive for a municipally regulated utility with a much smaller service territory, while Georgia Power Company's efforts show that even utilities with significant rural coverage are considering ways to smartly deploy EVs.

SOUTHERN CALIFORNIA EDISON

SCE is one of the nation's largest utilities. It provides electricity service to 15 million people over a 50,000 square-mile area across central, coastal, and southern California, excluding the City of Los Angeles. SCE delivered more than 87 billion kWh of electricity in 2015 (SCE 2018).

As we discussed earlier, California has long been a leader in promoting EV adoption, and thus many of its utilities are taking the lead in developing strategies to accommodate EVs and accelerate their adoption. SCE has emerged as a leader in this regard. SCE recognizes the opportunity to reduce GHG emissions that EVs provide as well as the importance of incorporating these vehicles in grid planning. As part of the company's growing focus on EVs, SCE submitted a Plan for the Expansion of Electric Transportation to the CPUC in January 2017. The plan outlines a variety of infrastructure and rate design approaches that cover at-home and public charging for light-, medium-, and heavy-duty vehicles to reduce GHG emissions. SCE has emphasized that these projects are designed to be inclusive and will prioritize the needs of low-income and other disadvantaged communities.

Rate Design

SCE provides three basic rate plans for residential customers: a tiered plan based on energy usage (Tier 1, Tier 2, and High Usage), which is a traditional billing plan; a TOU plan; and an EV-specific plan that provides a reduced rate for EV charging. Table 3 compares weekday summer electricity rates for the three plans. SCE provides longer hours for off-peak and super off-peak for EVs compared to residential TOU rates. As mentioned earlier, TOU charges not only help EV owners save money when charging their vehicles, but they also help shift EV charging loads to off-peak hours, thus enhancing grid reliability.

Table 3. SCE residential rate plans

Plan	Description
Tiered rate	$0.16/kWh for Tier 1; $0.25/kWh for Tier 2; $0.31/kWh for Tier 3
TOU rate (<700 kWh/month)	$0.45/kWh from 2 to 8 p.m.; $0.28/kWh from 8 to 10 p.m. and from 8 a.m. to 2 p.m.; $0.13 from 10 p.m. to 8 a.m.
TOU EV rate	$0.34/kwh from 12 to 9 p.m.; $0.14/kWh from 9 to 12 p.m.

Source: SCE 2017c

For commercial customers, some SCE rates apply exclusively to EV users and cover different vehicle and customer types. These dynamic rates use up-to-date information about grid load and capacity to send price signals that reflect current grid conditions and effectively push EV charging to periods with less activity. For the first five years of these rate plans, customers will pay only consumption charges, not monthly utility demand charges. These demand charges will be reintroduced and phased-in over the subsequent five-year period, but the final rates will still be substantially lower than other commercial electricity rates.

SCE is also undertaking a submetering pilot to separately monitor and measure the electricity used to charge EVs for residential customers.[2] Through this program, owners can measure their EV energy use for billing purposes. Phase 2 of the pilot program is currently underway and includes installation of 500 submeters by April 2018, which will allow the utility to apply different rate structures and charges for electricity used to charge EVs. More information on the pilot is available on SCE's Sub-metering & Billing for Electric Vehicles page (SCE 2017d).

SMART CHARGING AND DEMAND RESPONSE

Smart charging programs let utilities take advantage of EV owners' flexibility in when they charge their vehicles. Smart charging practices are nascent, however, and only a few utilities understand how they can impact the grid. SCE is among these; as we now describe, it has conducted pilot projects to determine how smart charging can impact the grid and the customer.

In 2015, SCE initiated a pilot project to evaluate how pricing options affect charging decisions. Using 80 Level 2 chargers at nine different SCE facilities, SCE gave EV-owning employees three options to choose from. The highest-priced option let owners charge at full power and high speed. The mid-priced option reduced charging power by 50% when SCE signaled that a DR event was occurring. The last option was not to use the chargers. Employees could opt into the first two options via the Greenlots smart charging platform. At the end of the pilot, SCE used the data it had collected to evaluate customer charging decisions for future DR events.

[2] A submeter is a secondary meter for a single load and is connected to the meter that registers the customer's total electricity use.

SCE is also a leader in V2G interactions and testing. V2G gives utilities an opportunity to use their large batteries' energy storage capacity to regulate and provide flexibility in the grid. In 2013, SCE partnered with the Department of Defense, the California Energy Commission, Lawrence Berkley National Laboratory, and various other research partners on a V2G pilot project at the Los Angeles Air Force Base. A second phase of the pilot began in 2015 and was expected to be completed in 2017. While initial activities focused on technology validation, the primary questions in the second phase were: How much revenue can be generated using V2G as a DR mechanism? How can system operators manage the grid on a consistent basis using these technologies? (Ruiz 2016)

The pilot involved 40 plug-in hybrids and pure EVs with bidirectional charging and discharging capabilities. As in the workplace-charging initiative, this pilot used the OpenADR secure communications protocol to allow utilities and the California Independent System Operator (CAISO) to communicate with charging sites about rates for providing energy and other ancillary services over existing Internet Protocol (IP) communications networks. In addition, the LA Air Force Base pilot used various fleet-management software tools to ensure that each vehicle maximized returns from participating in the CAISO system.

Infrastructure Support

CHARGE READY PROGRAM

SCE kicked off the Charge Ready Program in 2016, with CPUC authorization of $22 million to support installation of publicly accessible EV charging stations within the utility service territory, emphasizing sites where cars are parked for extended time periods (SCE 2017a). These sites include workplaces, apartment buildings, school campuses, and recreational areas.

Participants in the Charge Ready program (for example, apartment building management companies) host charging stations. These hosts are responsible for owning, operating, and maintaining the stations, while SCE owns, operates, and maintains the electric facilities (electric lines, conduits, meters, and so on) needed to support them (SCE 2017a). Rebates are also available for hosts to purchase charging equipment. SCE aims to encourage the installation of approximately 30,000 charging stations under this pilot program, with approximately 10% of the total installed in disadvantaged communities. Low-income communities, particularly those near key thoroughfares, often bear the overwhelming burden of emissions impacts. Access to EVs and charging infrastructure can help to address this issue.

As of March 2017, as many as 50 different sites were scheduled for participation, installing a total of 800 EV charging points within SCE's service territory. SCE's 2017 plans include extending the Charge Ready program to residential customers to offset installation and permitting costs for personal EV charging facilities.

SCE has also broadened its approach to infrastructure deployment to cover medium- and heavy-duty vehicles in its 2017 CPUC filings. SCE's service territory covers the Port of Long Beach, which is the second busiest seaport in the country and supports numerous industries that transport large volumes of goods by multiple modes of freight. As a result, many of SCE's smart EV deployment policies are focused on heavy-duty vehicles and freight transportation.

As with its passenger vehicle Charge Ready program, SCE proposes to deploy, own, and maintain the electric infrastructure needed for charging stations for medium- and heavy-duty EVs and other off-road equipment near key goods-movement facilities (SCE 2017a). Hosts will procure, operate, and maintain these stations. Charge Ready will provide procurement rebates to the hosts.

Market Education and Outreach

SCE has identified customers' limited understanding of EV benefits as a barrier to EV adoption and has taken steps to remove this barrier. The SCE website has comprehensive information on EV purchase, ownership, benefits, and charging for residential customers. For example, the EV benefits page highlights emissions reductions, cost savings, and state and federal incentives associated with EVs (SCE 2017b).

INDIANAPOLIS POWER & LIGHT

IPL, a subsidiary of the AES Corporation, provides retail electric services to more than 480,000 residential, commercial, and industrial customers in Indianapolis and other central Indiana communities. The company has made a significant transition from coal-based power generation (79% in 2007) to natural gas (44% projected in 2018) and renewables (11% from wind, solar, and battery projected in 2018). In 2036, the majority of IPL's power generation is projected to come from renewables (41%), followed by natural gas (32%). IPL also offers demand-side management (DSM), including both energy efficiency (EE) and DR programs to help customers lower their energy usage and costs. It was the first Indiana utility to offer special EV rates including TOU options for home or fleet charging (IPL 2017). IPL also developed partnerships with EV manufacturers and an EV car-sharing company to expand its business.

IPL conducted an EV pilot program from January 2011 through December 2012 following the receipt of a US Department of Energy Smart Grid Investment Grant award in April 2010. The Indiana Office of Energy and Development provided additional funding through the Energy Systems Network to run the pilot. The pilot's objectives were as follows (IPL 2014):

- Accommodate EV use in IPL's service territory by offering TOU rates to EV customers to promote charging during off-peak periods
- Foster EV adoption by installing public charging stations at convenient locations to reduce range anxiety
- Gain further insight into the potential system impact of EV use
- Educate the public about electric transportation
- Understand customer expectations

IPL was one of the first investor-owned utilities to install public charging stations in the United States. As of March 31, 2013, IPL had 162 chargers in 111 locations, including 89 residential, 11 fleet, and 8 public stations. The eight public stations had a total of 22 chargers.

Rate Design

IPL implemented a TOU rate for EVs in its jurisdiction during the pilot described above. This rate is still in use and provides two rate structures for EVs: one for charging EVs at home and the other for using public chargers (see table 4).

Table 4. IPL charging rates for EVs ($ per kWh)

Charging type	Summer peak rate	Summer mid-peak rate	Summer off-peak rate	Winter peak rate	Winter off-peak rate
Home charging	0.122	0.055	0.0233	0.069	0.028
Public charging	$2.50 per charging session				

Rates shown are effective from March 31, 2016. *Source:* IPL 2017.

The different rates for home charging reflect electricity generation and use costs in different seasons and times of day. The high peak rate's primary objective was to discourage home charging at peak hours. The TOU rate succeeded in pushing approximately 76% of the electricity demand for residential EV charging to off-peak hours (IPL 2014).

Assuming that a 30-kWh EV[3] plugs into a public charger with just 30% charge remaining, charging the vehicle up to 100% would cost $0.12 per kWh, which is equal to the summer peak-hour charging rates for residential customers. Despite this high rate, the frequency of public charging greatly outpaced residential charging during the pilot period, which could be attributed to lack of home EVSE and indicate a need for workplace charging (IPL 2014). Furthermore, public charging increased more than twofold from 2012 to 2013, again highlighting the need for public EVSE.

The pilot project provided little insight into EVs' impact on the grid due to the small number of EVs in Indianapolis. As of late 2015, there were just 1,700 EVs registered in Indiana, with approximately 300 registered in the greater Indianapolis area (IPL 2016). For the near future, EV penetration in the Indianapolis area is expected to be low. EV sales in 2036 are projected to be marginal, growing to 4,421 units from 1,092 units in 2017 (IPL 2016).

Indianapolis Mayor Greg Ballard has been a champion of EVs in the city. In 2012, he signed an executive order making Indianapolis the first major US city to pledge to convert its entire municipal non-police fleet to EVs by 2025 (Indianapolis 2012). The city is leading the transition by adopting 425 plug-in vehicles in its non-police pursuit fleet (ESN 2017).

Public–Private Partnerships

To further encourage the deployment of EVs, IPL has partnered with numerous companies to provide access to EVs and infrastructure. We now describe two such partnerships.

NISSAN PARTNERSHIP

IPL partnered with the Greater Indiana Clean Cities Coalition and the Nissan Motor Corporation to offer special incentives for purchasing a Nissan Leaf all-electric vehicle. Any

[3] The Ford Focus EV battery, for example, has a capacity of 33.5 kWh.

IPL employee or customer could claim a discount of up to $10,000 off the manufacturer's suggested retail price (MSRP) of a 2016 or 2017 Leaf from participating Nissan dealerships. This was in addition to a federal tax credit of up to $7,500, for a maximum of $17,500 in savings off the vehicle's price (Nissan USA and Duke Energy 2017). The program was valid through March 31, 2017.

BLUEINDY PARTNERSHIP

BlueIndy is a 100% EV car-sharing program that was launched in Indianapolis in 2014. A partnership that includes the City of Indianapolis, Energy Services Network (ESN), the French car-sharing company Bolloré, and IPL, BlueIndy aims to transform urban mobility in Indianapolis by providing a large number of EVs that could be used by all residents, students, tourists, and convention goers for short point-to-point trips around the city (EDTA 2014). Users must purchase one of four membership options: daily, weekly, monthly, or annually, followed by pay-as-you-go. As of September 2016, the partnership had 240 vehicles and 80 charging sites, with a long-term goal of 500 cars and 200 charging sites (Walsh and Nigro 2017).[4] Once the $40 million project is complete, Indianapolis will have the largest EV car-sharing program in United States (ESN 2017).

GEORGIA POWER COMPANY

Background

Georgia Power is the primary power utility for the state of Georgia. It is an investor-owned, fully regulated public utility serving more than 2.4 million customers in 155 of Georgia's 159 counties (GPSC 2017). Georgia Power is the largest subsidiary of Southern Company, one of the nation's largest utility holding companies and generators of electricity. Georgia Power sold about 84,000 gigawatt-hours (GWh) of electricity in 2015, which came from diverse energy sources including oil and gas, coal, nuclear, and renewables such as hydro, solar, and wind.

Georgia Power has taken several steps to grow the EV market and expand EV charging access throughout the state. These steps include adopting an EV-specific TOU rate, providing EV infrastructure rebates for both commercial and residential customers, and partnering with EV manufacturers to provide purchase rebates.

Rate Design

Georgia Power offers innovative rate structures for its EV customers, including Real Time Pricing, Demand Plus Energy Credit, and TOU plans, all of which were found to be effective in reducing peak demand (Georgia Power 2016).

Georgia Power offers three whole-house rate options for customers with plug-in EVs: a standard residential rate, a rate for nights and weekends, and an EV rate. The EV rate is voluntary, but it requires a 12-month commitment. Georgia Power offers EV TOU rates in three different time periods: peak, off-peak, and super off-peak. Table 5 shows the EV-TOU rates, effective from January 2016.

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[4] Each site has five charging stations or ports.

Table 5. Georgia Power EV TOU rates

Rate	Time	$/kWh
Peak	2 to 7 p.m. (June–September)	0.203
Off-peak	7 a.m.to 2 p.m. and 7 to 11 p.m. (June–September)	0.066
Super off-peak	11 p.m. to 7 a.m. (year-round)	0.014

Source: Georgia Power 2017d

Georgia Power also has special rates for commercial charging (see table 6). Total cost to charge is somewhat higher using DC fast chargers than using Level 2 chargers at home during peak hours or in public places. Full charging for an EV with DC fast chargers costs $7.50, while Level 2 charging at home during peak hours and in public places costs $6 (ChargePoint 2016). A conventional gasoline vehicle would require approximately $10 in gasoline to drive similar miles, so EV driving is cheaper, even with fast charging. Level 2 charging at home at super off-peak hours makes EV driving far cheaper—less than $1 for a full charge.

Table 6. Georgia Power EV rates for public charging

Charging type	Rate
DC fast chargers	$0.25/minute
Level 2 chargers	$1/hour for first three hours; $0.10/minute thereafter

Source: Georgia Power 2017d

Rebate Programs

In 2014, Georgia Power adopted a two-year rebate program for EVSE installation for business owners and extended it through the end of 2017 (Georgia Power 2014). Any Georgia Power business customer can qualify for a $500 rebate for each new Level 2 workplace charger, provided it has a dedicated circuit and is not used for commercial charging. To qualify for the rebate, EVSE installation had to be completed by the end of 2017.

Georgia Power also offered an EVSE rebate for residential customers in 2015. Any Georgia Power residential customer could qualify for a $250 rebate for a new Level 2 charger if the customer had a single-family home and a dedicated 40-amp circuit.

Like IPL, Georgia Power and Clean Cities Georgia developed a partnership with Nissan Motor Corporation in which Nissan North America offered a special incentive on the purchase of a new 2017 Leaf for employees and customers of Georgia Power and Clean Cities Georgia. Any Georgia Power employee or customer could claim a $10,000 discount off the MSRP from a participating Nissan dealership. This incentive was scheduled to expire in September 2017, or while supplies lasted (Georgia Power 2017b).

Other EV Initiatives

Georgia Power has two other EV initiatives. In partnership with ChargePoint, Georgia Power introduced the *Power Card*, which gives its customers access to the state's public EVSE network and all Level 2 and DC fast chargers across the country (Georgia Power 2017e). Georgia Power Card owners also qualify for special rebate offers and discounts and have input in deciding the state's future charger locations.

In its second initiative, Georgia Power committed to buying alternative fuel and advanced technology vehicles including EVs for its fleet. Since 2004, it has allocated 5% of its fleet replacement budget for this program. Georgia Power has 32 EVs and 7 bucket trucks with battery-operated booms in its fleet. To support these EVs, Georgia Power has 32 chargers in its corporate headquarters and 20 chargers across the state (Georgia Power 2017c).

Findings

This section summarizes our findings on utility strategies to integrate EVs with the grid, emphasizing those strategies that can provide both societal benefits and benefits to the utilities adopting them.

RATE DESIGN

Certain rate structures can benefit EV owners and utilities alike by incentivizing charging when power demand is low. EV owners can save money by charging at off-peak hours while utilities reduce peak demand and thus promote grid stability.

Time-of-Use Rates

- EV TOU rates can help make EVs an attractive option for drivers and shift peak load. Utility commissions are generally supportive of these structures when they are equitable, reflect actual costs, and help to shift electricity consumption to off-peak periods.

Dynamic Pricing

- Dynamic rates in the form of real-time pricing could be beneficial for fast charging, but they may prove challenging for most EV owners, who typically cannot adjust charging times to respond to variable and unpredictable pricing.
- Demand charges are a potential concern for EV charging, which requires high power levels. Some utilities are taking steps to address the resulting high costs for EV owners.

Designing for Low Emissions

- Utilities can help maximize EV pollution reduction benefits through rate structures that promote EV charging with electricity from renewables or other low-carbon generation sources.

SMART CHARGING

Although still mostly in the exploratory stage, smart charging can increase EVs' value to both owners and utilities. Pilot projects with charging equipment providers, software companies, universities, and auto companies can test solutions to the technical challenges of smart charging, including communications, charging algorithms, grid response, and vehicle battery impacts. V2G capabilities may open the door to new business models involving utilities, automakers, and EV owners.

Exploratory Activities

- Integrated assessment of the system benefits (e.g., cost minimization, increased reliability) and emissions impacts of charging algorithms will help maximize the benefits of smart charging.
- Exploring the receptivity of customers (including household, corporate, and transportation network companies) will help utilities design suitable charging options in anticipation of the availability of smart chargers.
- The added benefit of selling electricity back to the grid could make EVs a more attractive option for many drivers.

CHARGING EQUIPMENT INVESTMENT AND OWNERSHIP

The appropriateness of utility investment in and ownership of EVSE depends on multiple factors, including the existence of other entities prepared to provide EVSE, the source of utility funds to be invested, the distribution of benefits from the EVSE network, and the extent to which investments leverage and support other EV goals and programs.

EVSE Investment and Ownership

- Most states have yet to address the issue of whether regulated utility investment in EVSE is desirable, and utility efforts have been limited to pilot programs, shareholder investment, and public–private partnerships.
- Only a few states permit utility investments in charging stations and cost recovery for those investments. They are often subject to public interest evaluation.
- Some utilities are considering investing customer funds in EVSE when EV adoption is projected to be a source of system benefits, public benefits, or benefits to underserved communities.
- Utilities may partner with EVSE providers and offer subsidies for procuring charging stations.

VEHICLE AND CHARGER PURCHASE INCENTIVES

A variety of EV stakeholders, including utilities, offer purchase incentives to boost sales of EVs and chargers.

Financial Incentives

- Some utilities are providing financial incentives for EV and EVSE purchase. Their reasons for promoting EVs influence the funding source and design of such incentives. These include creating new business opportunities for the utility, permitting more efficient deployment of generation resources, and supporting state and local goals.

Partnerships

- Utilities are exploring partnering opportunities to make EVs accessible to all potential owners, users, and communities. For example, the Los Angeles Department of Water and Power contributed $400,000 toward the efforts of the City of Los Angeles and the BlueLA EV ridesharing company to bring EVs to low-income neighborhoods. Austin Energy is also developing more inclusive EV programs.

COORDINATION WITH STATE AND LOCAL EV EFFORTS

Collaboration among utilities, state, and local governments can create a supportive environment for accelerating EV ownership while ensuring that EVs help jurisdictions realize their vision of their transportation future. Emerging mobility options could give residents access to EVs without purchase or ownership and simultaneously increase the use of other modes.

Public Engagement

- Utilities can develop EV policies that support state and local energy and greenhouse gas targets and action plans. Engaging high-level state and local officials early and often will help ensure the success of utility EV programs.
- Utility participation in multi-stakeholder efforts and decision making can help reconcile the various priorities for EV deployment and ensure that it benefits all stakeholder groups.

Purchase Incentives and Programs

- Utilities can design purchase incentives to complement federal, state, and local programs
- Careful incentive design can ensure that EVs are available to all customers and communities.

EVSE and Rate Structures

- Utilities can help make charging infrastructure accessible to municipal vehicle fleets, including heavy-duty vehicles.
- To the extent that utilities construct and own charging infrastructure, they can support shared-use EV fleets by choosing accessible charging locations.
- Utilities can help ensure that EVSE installation sites and incentive programs complement the use of other modes of transportation and create a connected, universally accessible system. They can also boost regional and local transit ridership by installing chargers near transit hubs.
- Utilities can design rate structures to support the use of EVs in municipal fleets, shared-use fleets, and underserved communities. They can offer rates that encourage the use of public transit during peak commute hours and shift charging to off-peak hours for electricity use.

Conclusion

Mass adoption of EVs is becoming a market reality thanks to battery improvements and cost reduction, state policies, consumer incentives, availability of many new EV models with consumer-friendly features, and other private- and public-sector initiatives. EVs have the potential to greatly reduce transportation-sector fossil fuel energy use and associated emissions, and otherwise support the emergence of a more sustainable transportation system.

EVs are also generating strong interest from utilities. Increased electricity demand from EV charging systems presents utilities with new business opportunities at the same time as the prospect of large-scale EV adoption requires them to be prepared for this demand. Planning and preparation for EVs can lead to reliable, accessible, and affordable EV charging while maximizing utility benefits.

Some utilities have adopted policies and programs to harness these benefits as they prepare for the growing number of EVs on the road. Others are considering steps to promote and accommodate EVs in their service territories and can learn from the experience of these early adopters.

Intelligent rate design, adoption of smart charging, and public/private investment to create a complete EVSE network can lead to a full measure of EV system benefits. Utilities can help ensure that EVs will reduce emissions and energy consumption by coordinating with states and cities. These strategies hold the promise of complementing existing transportation choices and creating a more sustainable, equitable, and low-cost transportation system in the United States.

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