

ELECTRIC VEHICLES AS DISTRIBUTED ENERGY RESOURCES

BY GARRETT FITZGERALD, CHRIS NELDER, AND JAMES NEWCOMB



AUTHORS & ACKNOWLEDGMENTS

AUTHORS

Garrett Fitzgerald, Chris Nelder, and James Newcomb

*Authors listed alphabetically. All authors are from Rocky Mountain Institute unless otherwise noted.

ADDITIONAL CONTRIBUTORS

Jim Lazar, Regulatory Assistance Project

Riley Allen, Regulatory Assistance Project

CONTACTS

Chris Nelder (cneider@rmi.org)

James Newcomb (jnewcomb@rmi.org)

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Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. In 2014, RMI merged with Carbon War Room (CWR), whose business-led market interventions advance a low-carbon economy. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

ABOUT e-LAB

e-Lab is a multiyear, multistakeholder forum to address complex electricity system challenges no individual stakeholder can solve alone. e-Lab supports practical innovation across traditional institutional boundaries to overcome barriers to the economic deployment of distributed energy resources in the U.S. electricity sector. e-Lab participants convene and collaborate on solutions and engage in on-the-ground projects that address the biggest challenges facing the sector: new business, pricing, and regulatory models; grid security; customer engagement; and grid integration of low-carbon renewable energy. These changes are critical steps towards a more resilient, affordable, and sustainable electricity system. Please visit <http://www.rmi.org/eLab> for more information.



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EXECUTIVE SUMMARY

EXEC



EXECUTIVE SUMMARY

WHILE STILL SMALL in both absolute size and market share, the electric vehicle (EV) market is one of the most rapidly changing and fastest growing high-tech sectors in the global economy. According to some estimates, sales of electric vehicles could account for one-fifth of new car sales globally by 2025; more bullish projections see EVs taking 50% of sales or more by 2030. China and India are considering initiatives that would dramatically increase their adoption of EVs. And with the disruptive potential of emerging technologies like electric autonomous vehicles and services, the portion of our transportation system that is powered by electricity may grow at a rapid and unpredictable pace in the next decade. The implications for electric utilities, customers, service providers, and vehicle owners are far-reaching and rapidly evolving.

Today's fast-changing EV-charging market represents the beginnings of a demand-side opportunity like no other: intelligent, interactive electricity demand that is movable in time and space. A car with a 30 kWh battery stores as much electricity as the average U.S. residence consumes in a day. Even without vehicle-to-grid power flows, the ability to flexibly manage charging while still meeting customer requirements can provide a new kind of distributed resource at the grid edge.

Considered as a pooled resource, the growing number of electric vehicle batteries could provide a wide range of valuable grid services, from demand response and voltage regulation to distribution-level services, without compromising driving experience or capability. Electric utility companies can use new communications and control technologies, together with innovative tariffs and incentive structures, to tap the sizeable value potential of smart electric-vehicle charging to benefit utility customers, shareholders, vehicle owners, and society at large. This will mean influencing, with increasing precision, where and when EVs are charged through a combination of partnerships, incentives, and market structures. In its early stages, the interesting challenges and opportunities related to vehicle grid integration will be local or even hyper-local, at the scales where grid-related issues will first emerge.

Our review of the literature and numerous pilot projects, as well as some original modeling of state-level load profiles, confirms that EV charging alone can be integrated into the electricity system in ways that deliver net benefits to utility customers, shareholders, vehicle owners, and society at large.

If utilities anticipate the load of charging EVs and plan for it proactively, they can not only accommodate the load at low cost, but also reap numerous benefits to the entire system. Shaping and controlling EV charging can:

- Avoid new investment in grid infrastructure
- Optimize existing grid assets and extend their useful life
- Enable greater integration of variable renewables (wind and solar photovoltaics) without needing new natural-gas generation for dispatchable capacity, while reducing curtailment of renewable production
- Reduce electricity and transportation costs
- Reduce petroleum consumption
- Reduce emissions of CO₂ and conventional air pollutants
- Improve energy security
- Provide multiplier benefits from increased money circulating in the community
- Supply ancillary services to the grid, such as frequency regulation and power factor correction¹

But if utilities respond to EV loads late and reactively, that could:

- Shorten the life of grid infrastructure components
- Require greater investment in gas-fired peak and flexible capacity
- Make the grid less efficient
- Increase the unit costs of electricity for all consumers
- Inhibit the integration of variable renewables, and increase curtailment of renewable generation when supply exceeds demand
- Increase grid-power emissions
- Make the grid less stable and reliable

To tap these opportunities, utilities and regulators will need to understand the big forces now driving change in the EV sector and engage with industry partners to influence the paths of technical and market development. These partners could include automakers, owners and aggregators of charging stations, employers with large numbers of EV-driving employees, campuses and military bases, and emerging providers of mobility as a service. By engaging with high-penetration EV adoption sites in workplaces, shopping centers, and residential neighborhoods, utilities and their partners can develop capabilities that will serve them well in a high distributed-resource future.

Several key forces are combining to accelerate the pace of electric vehicle adoption:

- **Customer interest** is increasing. The Tesla Model 3 attracted nearly 400,000 reservations in a two-week period. At the \$35,000 list price for the basic model, that would represent \$14 billion in orders—an unprecedented success for any product launch.²
- Ongoing advances in **battery technology**, largely driven by the EV market's expected volume, are dramatically boosting the performance and reducing the costs of electric vehicles. According to Goldman Sachs, battery cost and weight for EVs will decline by 63% and 52%, respectively, in the next five years, while capacity and range will improve by 50% and 72%.³
- Advances in **manufacturing technology, materials, and processes** will make unsubsidized electric vehicles as affordable to buy as their gasoline counterparts in the next six years (some models are already cheaper on a total-cost-of-ownership basis). Bloomberg New Energy Finance estimates that by 2040, long-range electric vehicles will cost less than \$22,000 in today's dollars.⁴

- **Increased scale of production** will help to drive costs down and market share up. Tesla and Chevrolet plan to start selling electric cars with a range of more than 200 miles priced in the \$30,000–\$35,000 range by 2018, and other manufacturers are likely to follow suit. Goldman Sachs projects that electric vehicles will account for 22% of the global car market by 2025—a share reached in Norway in 2015. Bloomberg New Energy Finance estimates the worldwide EV market share will reach 35% by 2040, or even more in some scenarios.⁵
- The emergence of new business models to deliver **mobility as a service** through providers such as Uber and Lyft, self-driving vehicles, and better integration with multimodal transport could open the door to fast uptake of electric vehicles that provide low costs for high-mileage vehicles used in urban areas.
- Policies at the state and city level, including **climate action plans and innovative transportation policies**, are speeding the adoption of EVs in some communities and regions based on local environmental and health criteria.
- Growing numbers of **leading companies** are promoting electric vehicle use by their employees through financial incentives, workplace charging benefits, and preferred parking for EVs.
- **Public charging outlets** in the U.S. are becoming more prevalent, increasing 30% in 2014 and 27% in 2015, according to the U.S. Department of Transportation.⁶ Walmart, Whole Foods, and some other leading retailers find free charging beneficial because it increases shopping time in the store.



Equally, changing incentives and emerging technological options are shifting the way utilities and other grid operators perceive EV charging opportunities:

- Regulators in a growing number of key jurisdictions, including New York, California, and a number of other states, are looking to **strengthen incentives for utilities to use distributed energy resources to reduce or avoid grid costs.**
- Leading-edge utilities are finding that they can effectively **shape the load profiles** of electric vehicle charging with a combination of customer-facing charging apps and time-varying pricing, and they can **use their flexible-demand capacity to support increased penetration of renewables.**
- Regulators in some jurisdictions, notably California, are concluding that **allowing utilities to participate in the build-out of electric vehicle charging infrastructure**, including owning and operating charging stations, may be in the public interest. Especially in jurisdictions with high solar penetration, daytime workplace charging is getting increased attention as an area in which utilities may be crucial partners.
- New technologies being deployed by **EV charging aggregators** are opening the door to transparent and verifiable control of EV charging to deliver demand response, ancillary services, and other valuable services to grid controllers and local utilities.

Together, these two sets of forces are creating new opportunities and increased scale for smart EV-charging solutions. As this transition unfolds, important questions loom for regulators and policymakers:

What role should utilities play in owning or managing charging infrastructure?

Under alternative regulatory arrangements, utilities could serve as facilitators, managers, or providers of EV charging stations. Each of these scenarios has different implications for market structure and competition, and various options are currently being explored around the country. For example, regulators in California have reversed their previous stance and decided to allow utilities to own charging infrastructure, in order to serve public policy objectives to reduce greenhouse gases by

accelerating the adoption of EVs. In other jurisdictions, utilities will play a more useful role by supporting private charging companies. But whatever the arrangement, utilities have an essential role to play in enabling and connecting EV charging infrastructure by helping to speed its development, usefully informing the siting of charging infrastructure to keep its costs low and ensure adequate grid capacity, and supporting development in areas that might otherwise be overlooked or underserved, such as low-income and multiunit dwellings.

What lessons are being learned from experiments in managing the timing of vehicle charging?

Early pilot projects are demonstrating that EV-charging load profiles can be effectively shifted to off-peak hours under time-of-use pricing if the off-peak pricing is around one-third of the on-peak price. Customers have various means to ensure that their vehicles mainly recharge during hours when grid power costs are low, including onboard controls, charging station controls, and smartphone-based apps. While most of these pilots have focused on home charging, new emphasis is being placed on workplace charging in some jurisdictions, notably California and Hawaii, where abundant solar generation makes daytime charging especially attractive, and where it would incur the least emissions. As battery capacity increases and charging infrastructure becomes better developed, users may have increasing flexibility to charge at work and while shopping, and only need to top off their batteries at home. Utility incentives may influence both tariffs and the build-out of charging infrastructure in ways that influence the early trends in charging behavior—for example, whether workplace charging becomes conventional.

What roles might aggregators, automakers, and other parties play in managing charging in order to provide value?

Communications and control systems can enable many different models for control and dispatch of demand response and other services that aggregations of EVs could provide to grid operators. In California, active programs today involve aggregators, such as eMotorWerks, and automakers, such as BMW, in managing groups of charging EVs. Multiple types of





aggregation could operate in parallel. Regulators, utilities, grid operators, and other institutions may influence what types of aggregation are allowed and how these entities can provide services at various levels of the electricity system.

How can utilities be encouraged to facilitate EV integration for the greatest overall benefit to customers, shareholders, and society at large?

EV charging touches on several aspects of utility regulation, including utility treatment of distributed energy resources (DER). Under traditional regulation, utilities may have incentives to increase electricity sales and to build their rate bases (the costs of capital projects that can be recovered through general customers' utility rates). Under new forms of performance-based regulation, utilities may be rewarded for helping to reduce the cost of charging stations (for example, by identifying locations where the cost of building charging station infrastructure would be lower) and ensuring their utilization (for example, by managing EV charging directly, or contracting management services from private companies) to minimize the need for new investments in the grid. And in the long run, it may deliver the greatest benefit to society to build clean renewable power generators and structure incentives so that EVs will use that power instead of existing fossil-fueled power.

What can regulators do to remove barriers to greater EV integration?

A large EV charging facility, such as one at a shopping center or a “charging hub” (described herein), provides both a charging service to retail customers and a dispatchable demand response service to a wholesale electricity market, but existing regulations don’t clearly distinguish between those two uses in how the electricity consumption of the chargers should be billed. How can charging stations get proper treatment for their various services? How can FERC-jurisdictional wholesale interconnections be streamlined and adapted to permit greater access to charging stations, particularly in a vehicle-to-grid-enabled future? And how can the full integrative value of EVs as a dispatchable grid resource be recognized and captured by EV and EV charging facility owners and operators to enhance the business case for their participation?



THE ELECTRIFICATION CHALLENGE/ OPPORTUNITY

01

THE ELECTRIFICATION CHALLENGE/OPPORTUNITY

EVs ARE COMING! How many, where, and how quickly remains to be seen. But the strategic importance of this emerging market for the future of the electricity industry is unquestionably high. If utilities and regulators hope to shape how and where EV users charge their vehicles, they will need to act early to engage other stakeholders to influence the evolution of technology, infrastructure, policy, and customer expectations.

Our review of the literature and numerous pilot projects, as well as some original modeling of state-level load profiles, confirms that EV charging can be integrated into the electricity system in ways that deliver net benefits to utility customers, shareholders, vehicle owners, and society at large. Smart EV charging, even without vehicle-to-grid functionality, can tap many different sources of value ranging from distribution-system to wholesale-market levels in the electricity system. For example, increased demand from EVs can help pay for investments in some nonenergy components of grid infrastructure (such as communication and information systems) and make the use of those components more efficient, delivering long-term savings to customers.⁷

Creating the institutional, market, and technological frameworks to access the multiple sources of value that smart charging can provide will take time and attention from utilities, regulators, and other stakeholders.

A good starting point, however, is to view EV charging as a distributed energy resource—like energy efficiency, distributed generation, and storage systems—that can be targeted to create value for the grid. EV charging demand must be managed, temporally and geographically, to minimize potential increases to overall electric system costs while still meeting customers' needs.

EVs can be a flexible load, increasing demand when grid assets are underutilized or renewable generation is abundant and power is cheap, and decreasing demand at peak times when power generation is most expensive and grid congestion is more likely. In grid-operator terms, EVs are *flexible*, and hold the potential to be both *dispatchable* and *responsive*. And while there remain many uncertainties about how EV charging technologies

and practices will evolve, the opportunities to get the solutions right from a societal perspective are equally great.

Perhaps most importantly, viewing EV charging as a distributed energy resource allows utilities and regulators to focus in the near term on getting incentives right for the long term. And utilities and regulators should engage early and with a long-term view toward shaping this new market, because experience so far indicates that customer charging behavior can be effectively influenced during the first few months after a customer acquires a first EV, but that it becomes much more difficult after that.⁸

⁷ In this paper, we use the generic term EV inclusively to refer to plug-in electric vehicles that are variously referred to in the literature as plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs), all-electric vehicles (AEVs), battery electric vehicles (BEVs), and plug-in electric vehicles (PEVs), although these latter distinctions are used where appropriate. Hybrid vehicles that cannot be plugged in but that have on-board electrical generators that drive an electric motor are excluded from the vehicle category under consideration here.

LOCATION MATTERS

Viewed at a system-wide level, EVs will remain a small share of overall electricity demand for most U.S. utilities over the next decade or more, even under the most optimistic forecasts. But this perspective is deceptive. Because EV adoption tends to be concentrated in certain areas, utilities may encounter challenges on the distribution grid, and discover opportunities to reduce costs and realize benefits from managing charging, even while overall penetration is still quite low.

EV charging is often highly concentrated geographically for a number of reasons:

- In *residential neighborhoods*, demographic patterns of wealth and other factors often lead to high levels of local concentration, even to the level of particular neighborhoods and streets. In the San Diego area, for



example, there are already four five-digit ZIP codes with EV ownership penetrations of higher than 3% compared with 84 ZIP codes with less than 1% penetration (see Figure 1). The clustering of EV chargers behind a single transformer can create local problems for the grid, where multiple chargers may turn on at precisely the same time in response to time-of-use utility rates. Similarly, high-adoption hot spots are emerging in other cities with relatively high overall EV purchases.

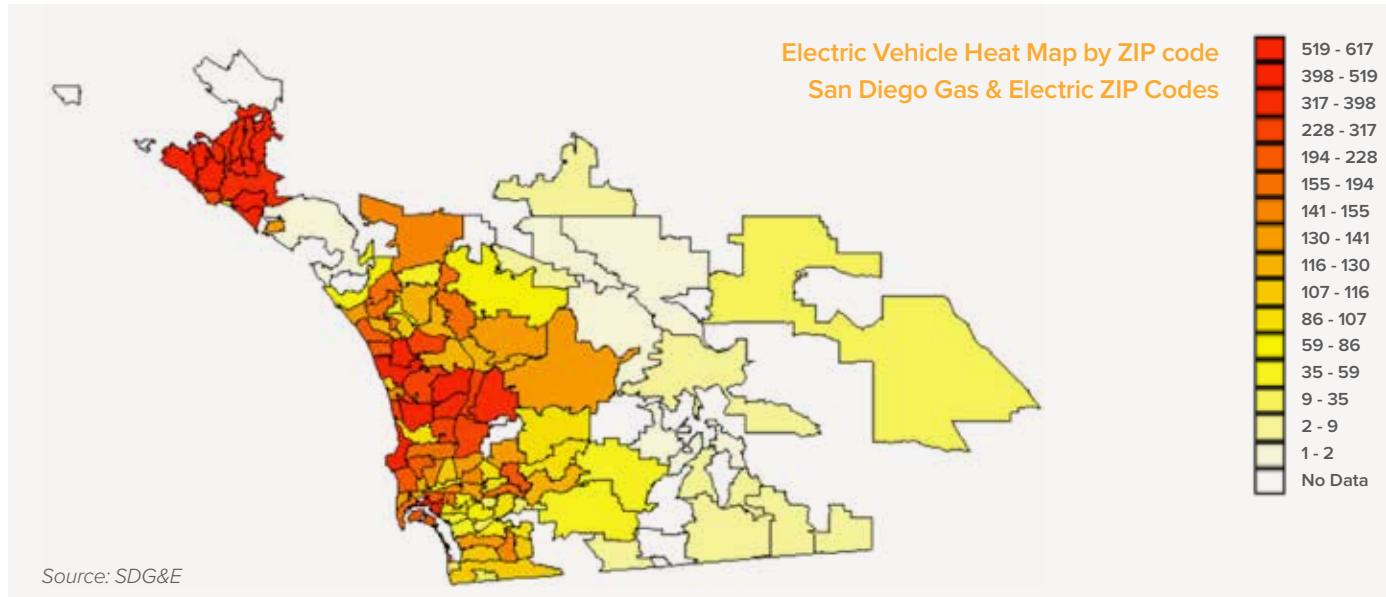
- **Military bases, university campuses, corporate facilities, and large retailers** increasingly feature supportive policies or other factors that encourage adoption. In California, for example, the U.S. Navy plans to purchase up to 600 EVs, with deployment concentrated at a number of key bases. Google has hundreds of EV chargers at its Mountain View, California, headquarters alone, and completes more than 1,000 charging sessions each day across several campuses that it maintains.⁹ Shopping destinations may offer high-speed public charging facilities as vehicle adoption accelerates. Such concentrations give charging-station operators opportunities to experiment with integration of multiple dozens or even hundreds of stations into local electricity distribution systems where the microscale impacts are potentially significant.
- Emerging **businesses delivering mobility as a service** could have needs for high-speed charging hubs to serve their fleets. These hubs, being developed and installed by

Tesla, NRG, Greenlots, and other companies, will likely feature Level 3 chargers.¹⁰ On-site storage at the hubs could be used to smooth out a hub's load, avoid peak-hour rates or high demand charges, back up a hub in the event of a grid outage, improve a hub's economics if charger utilization is low, or even to protect EV batteries. For example, joint projects between charging station provider ChargePoint and energy storage company Green Charge Networks are using on-site batteries and EV-charger scheduling and control to smooth out the grid demand of charging stations, helping their hosts to avoid incurring costly demand charges.¹⁰ Integrating these types of facilities into the grid could have significant implications for distribution-system operations.

As the EV market grows, grid technology evolves, and renewables capture a greater share of the electricity generation market, it will be critical for utilities and regulators to understand the future demand of EVs in an integrated way and implement the best practices for managing EV load growth.

⁹ For descriptions of different types of charging stations, see "Types of Chargers" on p. 68.

FIGURE 1: CONCENTRATIONS OF EV's IN SDG&E SERVICE TERRITORY



A collage of images featuring BMW cars and people. The top right image shows four people in blue suits standing behind a dark-colored BMW car. The bottom left image shows a close-up of a BMW car's front wheel and headlight. The bottom right image shows the front of an orange BMW i3 electric car.

DRIVERS OF EV ADOPTION

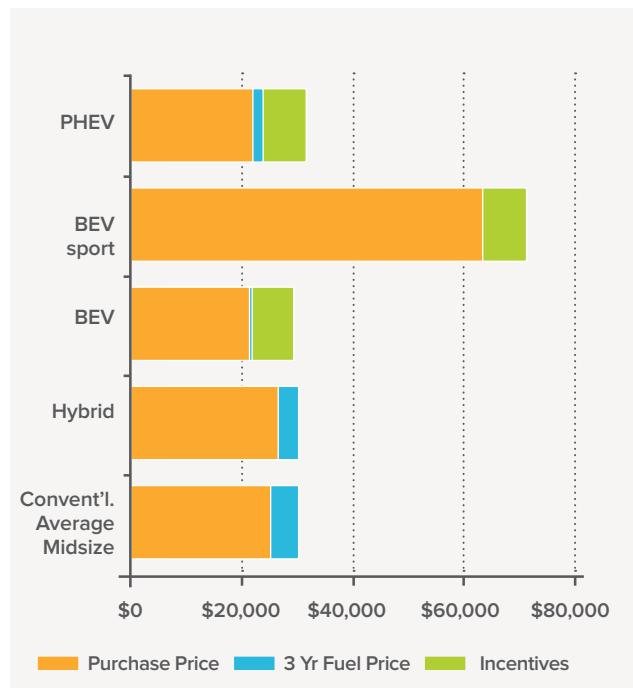
02

DRIVERS OF EV ADOPTION

THE BIGGEST HURDLE standing in the way of realizing the benefits of electric vehicles is the low rate of sales thus far. In the U.S., EVs have yet to take even a 1% share of annual sales. EV purchases actually fell year-over-year in 2015, as low gasoline prices (and relatively lower vehicle prices) helped conventional internal-combustion-engine (ICE) vehicles remain competitive. In 2015, a record 17.4 million passenger vehicles were sold in the U.S., but only 116,597, or 0.7%, were EVs.¹¹ Since arriving on the market in 2010, a cumulative 407,136 EVs have sold, which is just 0.16% of the U.S. passenger vehicle fleet.¹²

As with any technology adoption curve, however, the first 1% of market share is the hardest to achieve, and then high growth rates tend to take over and change the outlook entirely. Electric vehicles look poised to enter the rapid-growth portion of the classic technology adoption “S-curve,” as consumers become more familiar with EVs, less prone to “range anxiety,” more impressed with the performance of EVs, and more aware of EVs’ low total cost of ownership (instead of just their high sticker prices).

FIGURE 2: COMPONENTS OF OWNERSHIP COSTS FOR SELECTED VEHICLE TYPES

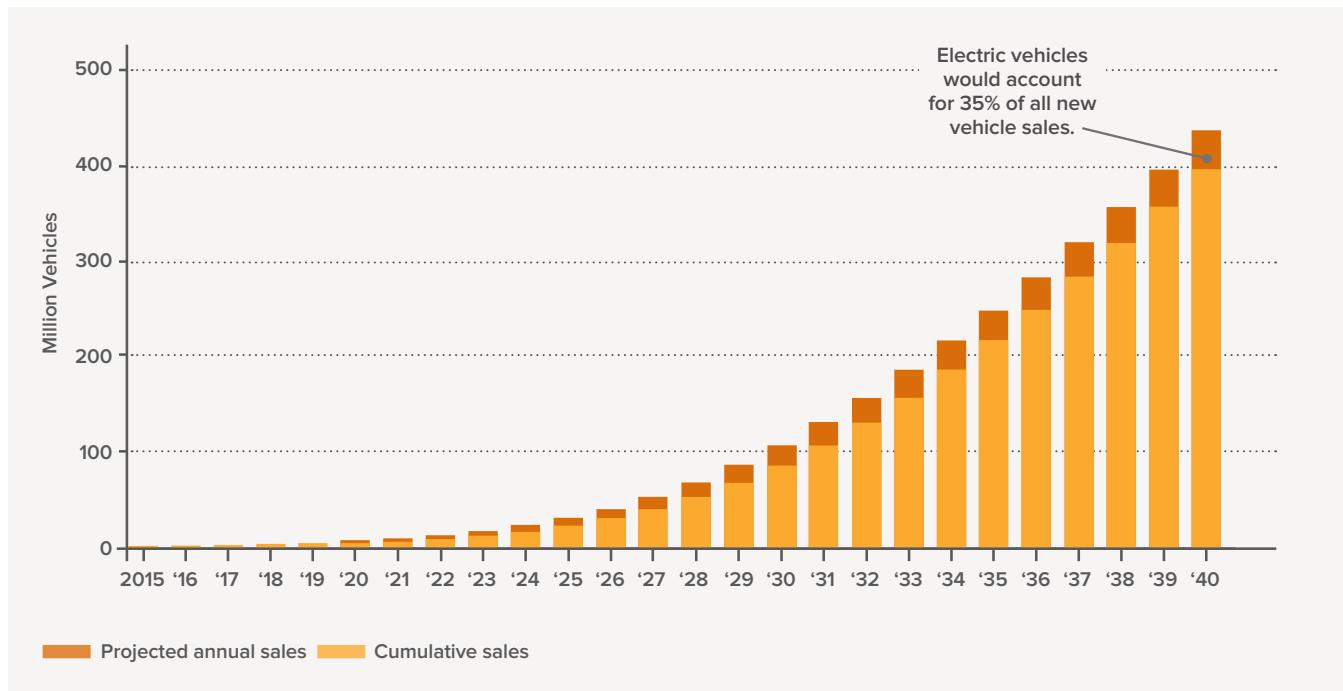


Source: RMI

FIGURE 3: AVERAGE FUEL COSTS AND EV COST SAVINGS PER MILE



Sources: EC, IEA, World Bank, MJB&A¹⁵

FIGURE 4: BNEF EV SALES PROJECTION¹⁷

Sources: Data compiled by Bloomberg New Energy Finance, Marklines

For example, an analysis done for the State of Maryland in 2014 found that the total cost of ownership for an all-electric Nissan Leaf could be less than that of a conventional Ford Focus, depending on assumptions about fuel prices and carbon prices.¹³ And a 2015 report by Cambridge Econometrics projects that by 2020, PHEVs will be cheaper to own over the life of the vehicle than conventional ICE vehicles, and that by 2025, BEVs will achieve cost parity with them.¹⁴

One driver of EV adoption now, which is sure to become even more significant in the future, is that they're cheaper to drive. The refueling cost of EVs is generally around one-third that of their ICE counterparts.

Although EVs are universally cheaper to drive and maintain than ICE vehicles, they have cost more to buy—long an impediment to adoption. However, that may cease to be the case in the near future: Tesla and Chevrolet plan to start selling electric cars with a range of more than 200 miles priced in the \$30,000–\$35,000 range by 2018 (before incentives). According to Bloomberg New Energy Finance (BNEF), battery prices are on track to make unsubsidized electric vehicles as affordable as their gasoline counterparts in the next six years, marking “the start of a real mass-market liftoff for electric cars.” By 2040, BNEF reckons, long-range electric cars will cost less than \$22,000, and 35% of all new cars worldwide will have a plug.¹⁶

State and municipal programs to encourage EVs at scale are beginning to emerge as well after years of pilot projects. For example, California's target is to have 1.5 million EVs on the road by 2025—a more than 600% increase over the roughly 200,000 EVs it has today. The City of Seattle has announced the Drive Clean Seattle program, which aims to increase EV adoption by 400% and get 15,000 EVs on the road in the city by 2025. As part of the program, the city intends to launch several projects that will triple the number of publicly available Level 3 chargers. Seattle City Light will also launch a pilot project to support residential charging stations through on-bill repayment and time-of-day pricing.¹⁸ And the City of Palo Alto has passed ordinances requiring all new multifamily developments, office buildings, hotels, and single-family homes to provide the needed circuitry for easy installation of car-charging equipment.¹⁹

Other incentives promise to help keep EV demand strong in the U.S.:

- At the federal level, at \$7,500 tax credit is available for buyers of pure BEVs, while the credit for PHEVs ranges from \$2,500 to \$7,500.ⁱⁱ Federal tax credits of up to \$1,000 are also available for installing residential charging systems.
- Some states offer as much as \$6,000 in additional credits.^{20,21}
- Various local incentive programs help drivers swap old vehicles for EVs and install charging stations at home. California alone has dozens of such local incentives.²²
- Incentive programs are also on offer to deploy charging stations at workplaces and other commercial locations, such as President Obama's EV Everywhere Workplace Charging Challenge, which aims to increase the number of workplaces with charging stations by 1,000% by 2018.²³
- Additional, nonmonetary incentives are available for EVs in various states, such as being allowed to drive in HOV lanes.

EVs have already enjoyed double-digit growth rates for the past five years, and that trend seems likely to continue. A November 2015 report from Goldman Sachs projects that EVs will have a 37% compound annual growth rate through 2025. Over the next five years, the firm expects battery costs to fall by more than 60%, battery range to increase by over 70%, and battery production capacity to triple.²⁴

So while the number of EVs on the road is still small both in absolute terms and as a percentage of the U.S. new vehicle market, their growth rate has been high and sustained, and is likely to remain so.

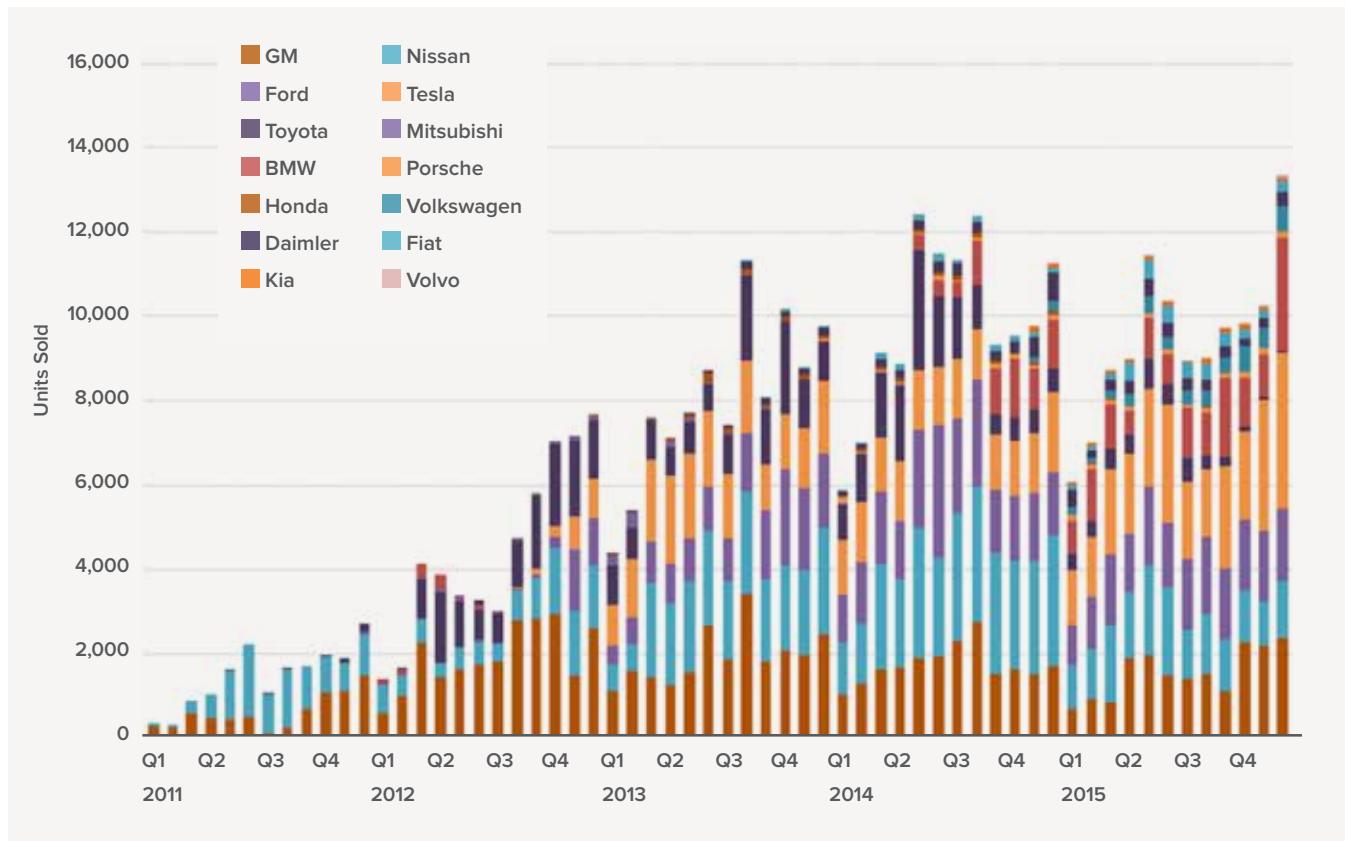
EV SALES SCENARIOS

Forecasts for EV adoption vary widely. ExxonMobil, for example, projects that EVs are likely to account for less than 10% of new car sales globally in 2040,²⁵ while BNEF projects they'll be 35% of sales by then.²⁶

Despite the recent oil price crash, global EV sales have continued to grow. Globally, EV sales grew 60% from 2014 to 2015. And although U.S. EV sales fell 5.2% from 2014 to 2015 as buying shifted back toward ICE vehicles in a year of unexpectedly low gasoline prices, EV sales have bounced back: In April 2016, EV sales were up 16.5% year-over-year, posting their sixth straight month of record sales. This suggests not only that electrified vehicles offer good value to consumers even when gasoline is cheap, but that consumers choose EVs for reasons other than their lower cost of refueling relative to ICE vehicles.

ⁱⁱFederal tax credits for plug-in vehicles are capped at 200,000 per manufacturer.



FIGURE 5: U.S. PLUG-IN ELECTRIC VEHICLE SALES BY MANUFACTURER, 2011-2015Source: SAFE²⁸

So despite EVs' very modest market share, and nearly two years of unexpectedly low oil prices, there are numerous reasons to believe that EV sales will remain strong. First, sharp cuts in capital investment across the oil sector during this low-price era increase the likelihood of sharp price increases in the coming years.²⁹ Second, EVs' continuing price declines and range increases, combined with ongoing policy support, should drive EV adoption to higher rates within the next few years. Third, an intensifying focus on decarbonizing transportation to help the U.S. meet its COP21 climate change abatement target (cutting its greenhouse gas emissions at least 26% below 2005 levels by 2025) will naturally lead to greater vehicle electrification. Over the typical 11-year life of a vehicle, all of these trends could easily become more pronounced.

Utilities are giving more attention to this opportunity, and many are developing their own forecasts, but utilities' expertise and focus on EV adoption vary widely. Not unexpectedly, utilities in states where EV adoption is expected to be high are contemplating the increased energy demand of EVs in their integrated resource plans, while other states have yet to begin serious load forecasting and load management planning.³⁰

MOBILITY AS A SERVICE

In addition to individual drivers adopting EVs for their own personal reasons, an even bigger demand could come from fleet vehicles for use on military bases, university campuses, corporate facilities, delivery companies, and the like.

One of the most interesting cases of fleet vehicles will come from *mobility as a service* applications—a variety of new solutions where fleets of EVs may be shared between multiple people, none of whom own the vehicles. Vehicles that belong to such fleets are typically used to a much higher degree than personally owned vehicles.

For example, the largest municipal fleet of EVs in the nation was launched in 2014 by the City of Indianapolis, with 425 EV/PHEV vehicles. The project is expected to save the city \$8.7 million over ten years, primarily by reducing fuel costs.³¹

The Indianapolis project is supported by Evercar, a full-service enabler and accelerator of EV adoption for fleets. With its suite of technology, data analytics, financing, and operational support, Evercar helps to reduce the cost and accelerate the adoption of EVs for fleets.³²

Evercar is also providing the platform for an electric, on-demand car-sharing service. Aimed at entrepreneurial drivers like Uber and Lyft drivers, Evercar provides EVs and fast-charging services that drivers can use without actually owning the vehicles or being responsible for their maintenance and insurance. Drivers can drive three to eight hours on a charge (depending on the specific vehicle and driving circumstances), then stop for a brief recharge—included in the vehicle rental fee—at a Level 3 charging station,^{iv} then continue on.³³ In October 2015, one Uber driver using a Nissan Leaf rented from Evercar clocked 387 miles over 26 hours around Los Angeles, charging the vehicle eight times via Evercar's services, which use a publicly available Level 3 charging network.

^{iv}For descriptions of different types of charging stations, see “Types of Chargers” on p. 68.



This kind of car-sharing results in a much higher utilization rate than is normally assumed for EVs, and it could scale up quickly—radically changing the outlook for EV electricity demand. And because it's being driven by the private sector, outside the planning efforts of utilities and regulators, it must be regarded as something that could quite suddenly and unexpectedly increase EV charging demand beyond the growth rates typically seen in the residential sector.

Mobility-as-a-service fleets may also be enabled by self-driving cars. Google, Apple, Tesla, and a variety of other high-tech companies are making substantial investments in autonomous vehicle development, with traditional automakers following suit. While these efforts are still in demonstration or pilot project phases, we have every reason to believe that those efforts will bear fruit and result in sizable fleets of autonomous vehicles over the next decade.

For example, fleets of autonomous “robo-taxis” may become available to deliver the same mobility as conventional taxis or Uber and Lyft drivers, but without the cost of a driver. Once such services reach the commercial deployment stage, they could expand quickly.

RMI is working on one such pilot project in Austin, Texas, where tech giant Alphabet (Google’s parent company) is within a year or two of deploying its electric, fully autonomous vehicles to provide mobility service to the public. RMI is working with the City of Austin to site charging infrastructure strategically for this effort. Charging autonomous service vehicles presents different challenges and opportunities than human-driven personal vehicles: Who plugs them in? Or do we need wireless charging? Since the vehicles don’t park at offices or homes, can we site charging at a location that is optimal for both the grid and the mobility service (and if so, how many residential chargers do we really need)? What if the service is extremely popular and thousands of long-range EVs quickly join the grid? The answers to these and other more farsighted questions will begin to emerge in the next two to three years, but there are other EV applications that demand our immediate attention.

Mobility as a service using EVs could offer a particularly attractive opportunity for utilities. Utilities could develop “charging depots” for such fleets where it is most advantageous to locate them—much like bus depots—considering implications for the grid and charging convenience for drivers. If a utility can site an EV charging depot on a brownfield site where rents are low, which is also near a substation and a transit hub, it could serve a significant mobility load serving many commercial fleet vehicles and taxis at a competitively low cost.

Such charging depots are an excellent example of both the challenge and opportunity in managing EVs on the grid. Done proactively, managing the charging of a large number of EVs at a single location (and as a single customer) could be a significant and low-cost form of demand response. If addressed reactively, such charging could be an expensive load to accommodate.

ADDITIONAL EV BENEFITS

In addition to the benefits available to EV owners, EVs offer numerous other social benefits that will further push policy and customer preference in their favor.

Displacing petroleum

Electrifying vehicles is frequently cited as the most effective way to reduce the consumption of petroleum, since transportation accounts for nearly three-quarters of it.³⁴ One study estimated that, of 18 different ways to reduce oil demand or increase domestic supply, electrification of vehicles is the single largest way to reduce oil use and move the U.S. toward oil independence.³⁵

Reducing electricity rates

More EVs on the road could mean higher total costs for generating, transmitting, and distributing power. But an E3 study for the California Electric Transportation Coalition that assessed the costs and benefits of California’s Zero Emission Vehicle Program found California’s utility customers are better off as a result of growing PEV use, because higher revenues to the utility can improve margins and be shared with customers as reduced electricity prices.³⁶ Effective management of EV charging loads to optimize the grid could also reduce electricity unit costs.

Enabling RE penetration

By virtue of being a flexible load, EVs can be used both to absorb renewable energy that might otherwise be curtailed during periods of high output and low demand, and to respond to real-time fluctuations in renewable output and system ramping needs, thus reducing the need for flexible gas generation.

For example, a 2013 National Renewable Energy Laboratory (NREL) study explored the potential for EVs to absorb excess solar photovoltaic (PV) generation.³⁷ Similarly, adding EV capacity to the grid can absorb excess production from wind and convert it to a dispatchable resource. According to a 2006 NREL study, “the deployment of PHEVs results in vastly increased use of wind.”³⁸

A 2012 study from Imperial College London showed that storage (including EVs) can more than halve the curtailment of renewable energy. The avoided curtailment not only saves energy; it actually improves the scheduling of generators and increases the value of wind energy.³⁹ And a 2015 study by Cambridge Econometrics, which cited the Imperial College London study, estimated that reduced curtailment alone could provide roughly twice the value in beneficial services to the grid that vehicle-to-grid (V2G) services could provide.⁴⁰

Reducing net emissions

About one-quarter of U.S. greenhouse gas emissions comes from transportation,⁴¹ so reducing petroleum usage for transportation could be a key pathway to reducing emissions.

The net effect of EV charging on emissions, both from the power grid and from fuel combustion in an ICE, vary by system or region based on several factors that primarily include the generation mix, how that mix varies over time, and the time of day that vehicles recharge, according to a 2016 study by NREL.⁴² The type of EV can also play a role.

Despite this complexity, a 2015 study by the Union of Concerned Scientists found that driving an average new EV produces fewer emissions than driving an average new gasoline car in all regions of the U.S., and that in states with the cleanest grid power, driving an electric car is equivalent to getting 85 miles per gallon.⁴³ A 2015 study by the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) produced similar findings, stating flatly that “PEVs pollute less than today’s conventional petroleum-fueled vehicles in the United States,” even after accounting for the emissions resulting from electricity generation.⁴⁴ Another 2007 NREL study found that total emissions from driving EVs are generally lower than from driving conventional vehicles, even on grids with high CO₂ intensity. According to the study, the best policy for reducing emissions is to increase the share of renewable energy on the grid while deploying battery-electric vehicles and workplace charging stations, preferably charging stations with colocated solar generation.^{v45} Total emissions associated with EVs depend more on the carbon intensity of the electricity grid than on the charging scenario.

^v “BEVs result in more electric miles overall than the PHEVs, but the efficiency of the conventional vehicle used by BEV owners is only 40.8 m/gallon, compared to a PHEV efficiency of 66.8 mpg in gasoline mode. The carbon intensity of the BEV non-electric miles is 0.48 lb CO₂/mile, while the carbon intensity of the PHEV non-electric miles is 0.29 lb CO₂/mile.”



DEPLOYING CHARGING INFRASTRUCTURE

03



DEPLOYING CHARGING INFRASTRUCTURE

TO REALIZE THE potential of EVs will not only require many more EVs on the road, as discussed above; it will simultaneously require a significantly expanded network of charging systems. (For an overview of charging systems, see “Types of Chargers” on p. 68.)

For example, California aims to have 1.5 million EVs on the road by 2025—a more than 600% increase over the roughly 200,000 EVs it has today.⁴⁶ Supporting that many vehicles will require a significant and relatively rapid expansion of charging infrastructure: between 150,000 and 750,000 nonhome charging stations (assuming 10 and 2 EVs per station, respectively).⁴⁷

For that load to have a positive, as opposed to negative, effect on the grid, those chargers need to be where vehicles can plug into them at the right time. In San Diego, for example, where solar is a major contributor to grid power, that will mean more chargers are needed at the workplace, so that vehicles can charge during the midday peak of solar output.

Generally speaking, many regulators and EV advocates have preferred EV charging infrastructure be deployed and owned by third-party companies specializing in charging systems, due to a fundamental belief that charging should be a competitive market activity.⁴⁸ However, these markets have been slow to develop and some early entrants have gone bankrupt,^{49,50} largely because charging infrastructure is extremely costly: installed Level 3 chargers can cost \$19,000 to \$120,000 each in the U.S., compared with \$1,000 to \$1,250 for a commercial (nonresidential) Level 1 charger, and \$3,000 to \$11,000 for a commercial Level 2 charger.⁵¹ For charging companies, paying off a DC-fast charger installation in a reasonable time—particularly where EV deployment and charger utilization is low—can require user fees equal to or greater than the per-mile cost of gasoline (as high as \$2/kWh), which is enough to wipe out the economic advantage of driving an EV.⁵²

Accordingly, some regulators are beginning to reconsider the advantages of utility-owned charging infrastructure, and are considering performance-based incentives for utilities to support and enable the deployment, if not also the ownership, of charging stations. (For a review of some recent and proposed programs for utility-owned charging stations, see the Appendix on p. 68.)

Charging station deployment at workplaces and retail shopping locations could accelerate along with EV adoption, as availability of charging stations would be seen as a desirable feature, and their high utilization rates would considerably improve the economics of installing and operating them.

Streamlining permitting and removing roadblocks to installation can also speed charger deployment. For example, California has implemented a suite of laws to protect an owner’s right to install a charger at his or her parking space; to allow tenants to install charging stations; to set standards for charging infrastructure installation at multiunit dwellings and commercial buildings; to restrict subscription fees and membership requirements for use of charging stations; to require cities and counties to issue building permits for charging stations in an expedited and streamlined fashion, without demanding a use permit, except in rare circumstances; and to allow electronic filing for permits.⁵³

JURISDICTION ISSUES

A related issue, also being confronted in California, is how regulations regard charging stations and their owners as market actors, inasmuch as they are electricity resellers. For example, the New Hampshire Public Utilities Commission is exploring whether charging station operators should be regarded as public utilities or as competitive electric power suppliers.^{54,55} How this issue is resolved could have implications for how quickly charging infrastructure can be deployed.

How charging infrastructure gets deployed remains to be seen. The regulatory framework will likely vary from state to state, and this remains an important question that regulators must address. If both utilities and third parties can own charging facilities, but the third party ownership is regulated differently or not at all, this could create a competitive bias, a significant aspect of the dilemma facing state utility regulators. It may be that legislatures will have to step in for clarity.

COST RECOVERY ISSUES

Recognizing the potential benefit for nonparticipants, Western state regulators have initiated proceedings to consider whether a portion of the cost of extending EV charging service should be funded by utilities out of public purpose (conservation and renewable energy) funding, or directly absorbed in the allocation of costs to nonparticipants.⁵⁶

California has led this process. In October, California enacted SB 350, which directs utilities to plan for transportation electrification in their Integrated Resource Plans (IRPs). Further, it requires utility and air quality regulators to accept applications by electric utilities for programs and investments that encourage electrification of vehicles, vessels, trains, boats, and other equipment. It also directs regulators to approve those applications and allow cost recovery if they satisfy ratepayer interest tests.

Washington State law explicitly allows utilities to provide and subsidize EV charging service, up to a maximum impact on nonparticipants of a 0.25% increase in electricity prices.⁵⁷

Utilities in various states have proposed providing rebates for EV charging equipment, or attractive rates for providing EV charging services, arguing that the incremental revenue will more than cover the incremental costs, even at lower-than-average rates. This is analogous to the so-called “economic development rates” offered in some states to new or expanded industrial sites.

For example, EV charging is likely to be deployed in locations where other economic activity is already taking place—homes, shopping centers, and workplaces. Controlled EV charging can enable additional sales at these locations while potentially providing ancillary service benefits to the grid, but without needing additional distribution equipment to support the chargers. In such a scenario, the incremental cost of service for controlled EV charging will be significantly below a typical “fully allocated” cost of service. Regulators will need to use judgment in determining if controlled charging should bear a smaller share of joint and common costs than other services with uncontrolled usage characteristics.

As utilities’ roles in building charging infrastructure increase, regulators may consider providing some kind of performance-based incentives to reward utilities for reducing the cost of installing charging stations (e.g., by siting them close to existing electricity infrastructure), and for choosing optimal locations where charging stations will be well-used.⁵⁸

THE IMPORTANCE OF LOAD MANAGEMENT

04

THE IMPORTANCE OF LOAD MANAGEMENT

EV INTEGRATION POSES both challenges—such as accommodating EV charging without increasing the system load peak, or without overloading distribution system equipment where EVs are clustered—and opportunities, such as managing EV loads to optimize grid assets and maintain grid power operational limits at minimal cost. Regulators and utilities need to consider how to tap the synergies between smart EV charging and the operational needs of the grid in ways that maximize the benefits for all customers and for society at large.

Charging EVs during off-peak hours isn't only good for grid management. Encouraging off-peak charging can be profitable for utilities and, over time, reduce unit costs for customers.^{59,60}

VALUING V1G SERVICES

Managing the charging of EVs can deliver various services (often referred to as V1G services, as contrasted with the V2G services described below) at different levels of the electricity system, from bulk power markets to local distribution systems. In bulk power markets, well-managed EV charging loads can deliver system services such as demand response, voltage regulation, and certain other ancillary services, and help avoid investments in capacity. At the distribution system level, services will be more local, delivering operational savings and helping to avoid investments in capacity.

According to a 2015 technical report by NREL,⁶¹ managed EV charging can potentially provide numerous distinct services to the grid and customer benefits:

- Demand charge reduction
- Demand response
- Voltage support
- Frequency regulation
- Ramp rate reduction

These system benefits do not require a smart grid. For example, RMI's chief scientist, Amory Lovins, uses a Level 2 charger at his home, the experimental circuit of which measures grid frequency every second (within a ± 0.040 -Hz band) and instantaneously adjusts the charge rate between zero and seven kW according to whether the grid is short or long electricity—thus dispatching to the Western Interconnect seven kW of a valuable ancillary service called “fast grid regulation.” If he were paid what FERC says this is worth, he'd earn a few dollars every night just by charging his EV.

Integrating these diverse value streams across the various levels of the grid is one of the most challenging institutional obstacles to harvesting the full potential value of EV charging, because they may cross traditional boundaries between those levels.

A similar challenge exists in valuing stationary storage services on the grid. A recent RMI analysis, *The Economics of Battery Energy Storage*, showed that battery storage systems can provide to the grid up to thirteen distinct electricity services.⁶² But some of those services are effectively trapped behind the meter by regulatory barriers, unable to compete head-to-head with conventional investments in wires and generators. Although EVs are mobile, the same challenges exist for the V1G storage services they could provide to the grid.



AVOIDING CAPACITY INVESTMENTS

Integrating EV loads while maintaining acceptable reserve margins (installed capacity in excess of peak load), and while avoiding investments in new capacity, is a key part of the challenge for regulators and utilities. Capacity must be considered on multiple levels, from the bulk system level down to the distribution transformer level.

While most jurisdictions will not have large enough EV loads to affect their grids much in the short-to-medium term, where EVs are on track to obtain nonnegligible market share, the impact on peak load could be significant—particularly at the distribution-feeder level.

Bulk system level

The EV load is a function of the number of vehicles being charged at any given time, and the type of charging systems in use. (See “Types of Chargers” on p. 68 for a description of charging systems.)

A 2013 analysis prepared for the Regulatory Assistance Project (RAP) and the International Council on Clean Transportation (ICCT) found that in the U.S. and Europe, 5% of all vehicles charging at a four kW (Level 2) rate, or 1% of all vehicles charging at a 20 kW (Level 3) rate, would keep the EV charging load within 10% of the maximum potential peak load, which is within the typical reserve margin.⁶³

For example, if 7% of households in California had EVs (a total of 870,322 vehicles, which is below California’s target for 2020) charging at the same time, the EV charging load would range from 3.8% of the system’s baseline peak load with Level 1 charging, to 75.1% with Level 3 (40 kW) charging if all EVs were connected to the grid when the system demand reached its annual peak.⁶⁴

Substation level

A 2014 study by Xcel Energy concluded that the load on substation transformers would become significant when 5% of residential customers have an EV, at which point they would add no more than 2–4% to substation transformer peak load.⁶⁵

Distribution level

The distribution-system level is where EV charging is likely to need close monitoring and management first, long before it becomes an issue at the substation or system levels.

Because distribution transformers generally serve four to ten households, and an electric vehicle uses about one-third of one household’s annual energy, even a small number of vehicles charging at the same time on a distribution feeder could significantly increase peak-period transformer loading.⁶⁶

However, the need for distribution system upgrades can vary substantially within systems, so distribution system operators will need to carefully evaluate the particular needs of their systems down to the neighborhood level.

- A study by Xcel Energy concluded that if EVs charge during peak periods, as many as 4% of the distribution transformers on its system could be overloaded at local EV penetration rates of just 5%, even if EV adoption is geographically dispersed.⁶⁷
- In California, early experience with EV adoption has shown that the need for distribution system upgrades has been rare, at least in the earliest stages of EV adoption. Of the approximately 100,000 PEVs in investor-owned utility territory as of October 2014, only 126, or 0.1%, forced distribution system upgrades.⁶⁸ However, neighborhoods with clusters of EVs may have a higher risk of potential distribution system overloads than the statewide average indicates.



With better coordination or control, however, most EV charging can be spread out across off-peak periods to minimize these impacts, even as penetration reaches much higher levels, and avoid the need for investments in system reinforcements.

A recent 18-month pilot project in the UK called *My Electric Avenue* demonstrated the use of just such a control system to manage ten clusters of seven to twelve Nissan Leaf EVs, with 5% to 32% of properties in each cluster having EVs, and comprising more than 200 vehicles in total, on real distribution feeders using power line carrier signals. The project focused on demonstration of a management system that could be used to mitigate the potential impact of EV clusters in high-penetration neighborhoods. Up to three EVs were allowed to charge simultaneously within a residential cluster.

The project showed that if 40% to 70% of customers owned EVs, 32% of low-voltage feeders would require upgrading, assuming 3.5 kW charging. Newer EVs, which can charge at up to 20 kW rates, would require more upgrading and/or charging control. The study estimated that the use of its “Esprit” control technology could avoid more than \$3 billion in distribution system costs between now and 2050.⁶⁹

While the *My Electric Avenue* pilot suggests a solution based on control systems managed by the utility, this is only one of several options. Control systems could also be managed by an aggregator, or coordinated through autonomous peer-to-peer systems. To be most effective at the local level, however, EV charging control points may need to be able to either “see one another” or be seen by an aggregator or controller in order to prevent coincident start times and distribute load as widely and flexibly as possible. This could be an important consideration for regulators and utilities as they consider alternative pathways for EV charging control.

WHEN DO EV LOADS BECOME A PROBLEM?

Forecasting future electricity demand from EV charging on the grid is difficult, because many unknowns will ultimately affect the rate of EV sales: the availability of incentives, the price of vehicles, the prices of diesel and gasoline, and general economic health, to name just a few.

However, we can identify some bounds to this uncertain market.

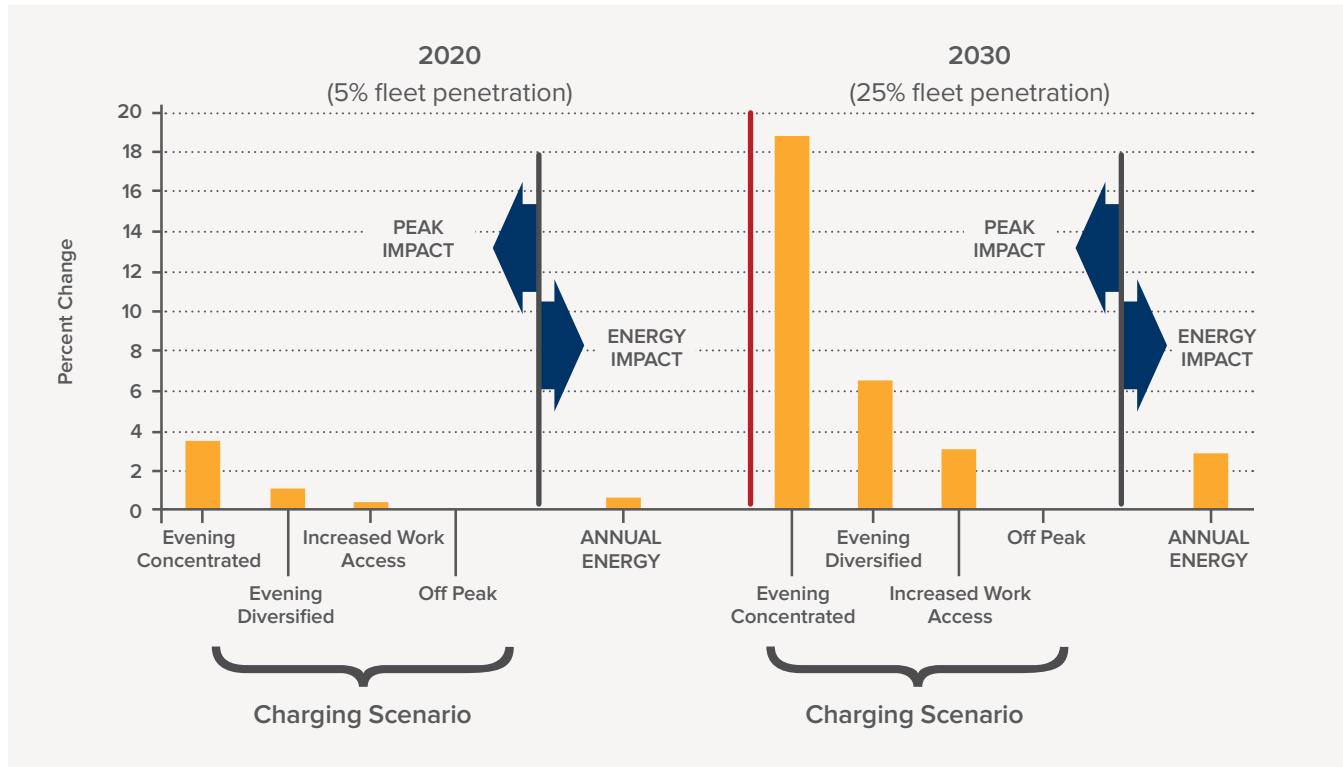
Most areas of the U.S. are still at the low end of the range of penetration, where EV charging demand amounts to less than 1% of total power demand—easily within the reserve margin of existing infrastructure. But what would be the high end of the estimate? If all light-duty vehicles in the U.S. were replaced with EVs, they would require about 1,000 TWh of additional electricity per year, or an increase of about one-quarter of our current electricity demand.⁷⁰ That would be more than enough to overload existing systems.

The important consideration for grid managers, particularly utilities, is to be alert to the possibility of rapidly increasing sales’ pushing EV charging out of the reserve margin comfort zone and suddenly becoming a significant load that they must anticipate and support. So how much EV capacity does the grid need to support, and when?

For an early clue, we can look to California, the leading U.S. state in EV penetration. According to charging control system operator eMotorWerks, the state’s EV fleet represents over 4 GWh of battery storage capacity and as much as 700 MW of peak shiftable load. Current EV sales of 3,000–5,000 units per month in the state add an estimated 70–120 MWh of storage capacity per month, and that rate is expected to increase dramatically this year as new, mainstream EVs with larger (e.g., 60 kWh) batteries and 200+ mile ranges hit the market.⁷¹ Such vehicles may create demand for less frequent recharging at faster (Level 3) chargers.

For another example, we can look at a model of the potential impact of EVs on the New England grid. Consider the two scenarios in Figure 6:

FIGURE 6: POTENTIAL IMPACT OF PLUG-IN HYBRIDS ON NEW ENGLAND SYSTEM DEMAND



Source: Vermont Energy Investment Corporation report^[2]

Notes: [1] 40 miles/day, 42 mpg (CS mode) and 200 Wh/mi (CD) mode for PHEV. [2] 200 million fleet size for the U.S. in 2020, and 5.2% fleet share for New England. [3] 2020 hourly system load based on DAYZER simulation inputs. [4] 2030 projections are based on 2020 hourly data, assuming an average 1.1%/year growth rate from 2020 to 2030.

As these models show, when 5% of vehicles on the New England grid are EVs, uncontrolled charging could increase peak demand by just 3.5—a hardly worrisome increase that would easily fit within the reserve margin of most grids. But if 25% of vehicles were EVs and they were charged in an uncontrolled fashion, they could increase peak demand by 19%, requiring a significant investment in new generation, transmission, and distribution capacity. However, if that same load were spread out over the evening hours, the increase in peak demand could be cut to between zero and 6%. And guiding charging to happen only at off-peak hours could avoid any increase at all in peak demand.

Clearly, it's important not only to understand the magnitude of the EV charging challenge, but also to be prepared to steer charging demand so that it has the lowest possible cost and impact on the grid, and the lowest emissions footprint.

The important consideration for grid managers, particularly utilities, is to be alert to the possibility of rapidly increasing sales pushing EV charging out of the reserve margin comfort zone and suddenly becoming a significant load that they must anticipate and support.

This is why we should not merely look at the low electricity demand of EVs today. Considering the long lead times that can be needed to build new generation capacity and implement new regulations and rate structures, each state and utility territory should be developing EV integration scenarios and preparing to implement tariffs that will be effective in shifting charging to the hours that are the most beneficial for all ratepayers. Following the California example articulated in SB 350, and directing utilities to plan for transportation electrification in their IRPs, is one way to ensure that appropriate planning is done.



TABLE 1: NUMBER OF VEHICLES MODELED FOR EACH STATE

STATE	CALIFORNIA	HAWAII	TEXAS	NEW YORK	MINNESOTA
Total Number of Cars	27,697,923	737,551	14,070,096	10,234,531	4,629,940
Electric Vehicles in 2015	170,000	3,050	9,925	11,278	2,775
Electric Vehicles at 23% Penetration	6,311,243	168,058	3,206,009	2,332,038	1,054,977

STATES IN FOCUS

As examples of how EV charging might affect state load profiles, we have selected five states for close examination. All of them have policies supporting renewable energy production; all of them either have or soon will have significant production of renewable energy; and most of them have incentives for EV deployment.

For each state, we show the EV charging load under a baseline scenario and a high-EV penetration scenario. Then we look at how the high-penetration scenario might affect the state's load profile when charging is uncontrolled versus when charging is optimized.

The baseline scenario, “Electric Vehicles in 2015,” shows charging demand for current EV penetrations and the current system load profile.

The high-EV penetration scenario, “Electric Vehicles at 23% penetration,” shows what the EV charging demand could look like in 2031 if EV charging were shifted to off-peak hours, assuming EV sales have a compound annual growth rate of 37% for the next 15 years, as forecast by Goldman Sachs.⁷³ At that rate of compounding, EVs would be 23% of the nationwide fleet in 2031, so we model the number of EVs in each state that would be 23% of the fleet in that state.

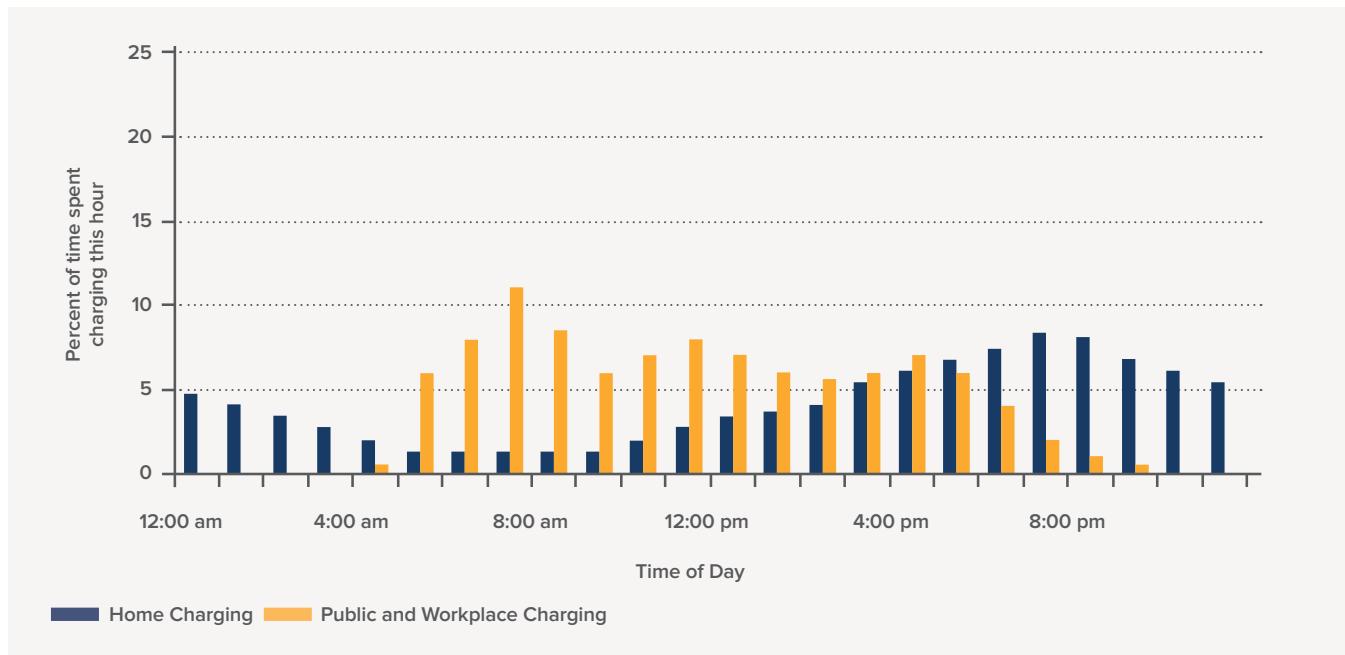
The resulting number of vehicles for each state is shown in the above table.

Charging profile methodology

We contrasted what charging loads would look like for these states under a standard, aggregate, uncontrolled EV charging demand profile versus an optimized charging profile for each state.

In the uncontrolled demand profile, shown in Figure 7, the dark blue bars represent hourly charging patterns for home charging,⁷⁴ and the orange bars represent typical charging patterns for workplace and publicly accessible chargers.⁷⁵ We then weighted the charging profiles based on available data to reflect the fraction of EV charging done at home (81%) and the fraction that is done at public or workplace stations (19%) to determine total hourly demand on the grid.⁷⁶



FIGURE 7: UNCONTROLLED, AGGREGATE EV CHARGING LOAD PROFILE

Source: RMI

For the optimized charging profile for each state, we manually shifted 90% of the EV charging load to the valleys in each state's load profile to represent an ideal optimization for the state.

In reality, the actual load profile for each state would be somewhere between the two extremes shown here, and would depend on the specific design of the EV tariffs.

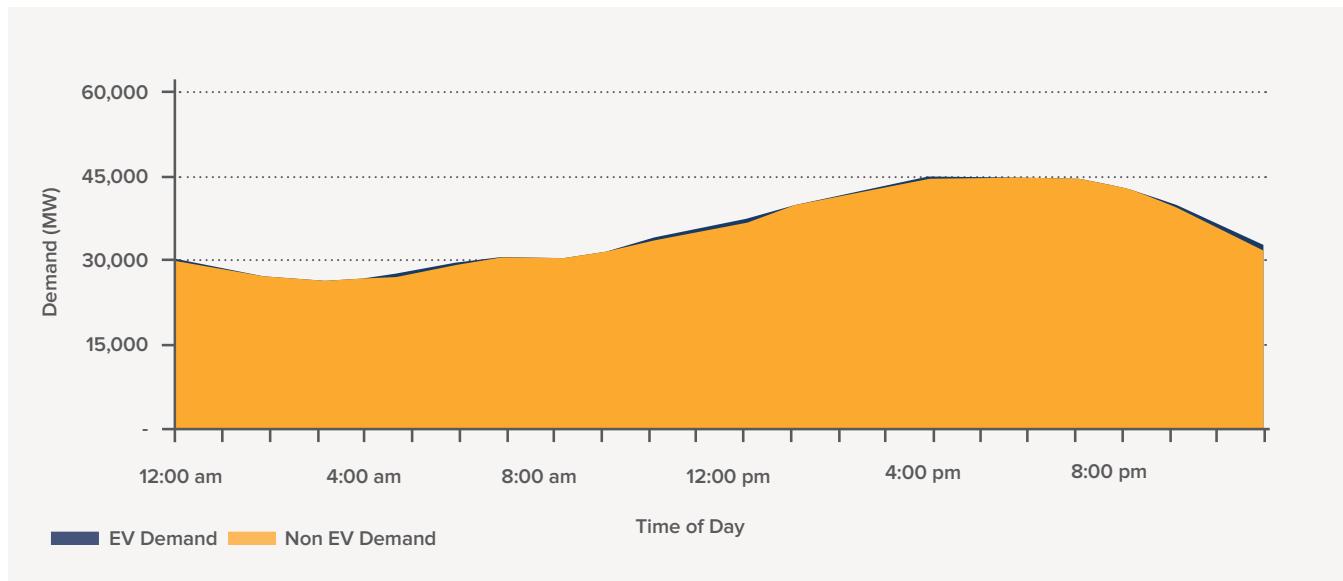
California

With roughly 200,000 EVs on the road today,⁷⁷ an official target of 1.5 million EVs by 2025, and several incentives for EVs, California is by far the most EV-oriented state in the nation. It also has the most solar production of any state, and the third-largest output of wind power (after Texas and Iowa),⁷⁸ so it will be one of the first states to test how EV charging can help avoid curtailment of wind and solar production. How California manages its EV load will offer many useful insights to other states.

To estimate the amount of PV and wind installed in 2031 for California in the high-penetration scenario, we assume a linear growth path toward its Renewable Portfolio Standard (50% renewable electricity by 2030).⁷⁹ We then subtract non-dispatchable wind and solar generation to show the effect of EV loads on the dispatchable demand profile to emphasize how controlling those loads can help smooth out the load profile.

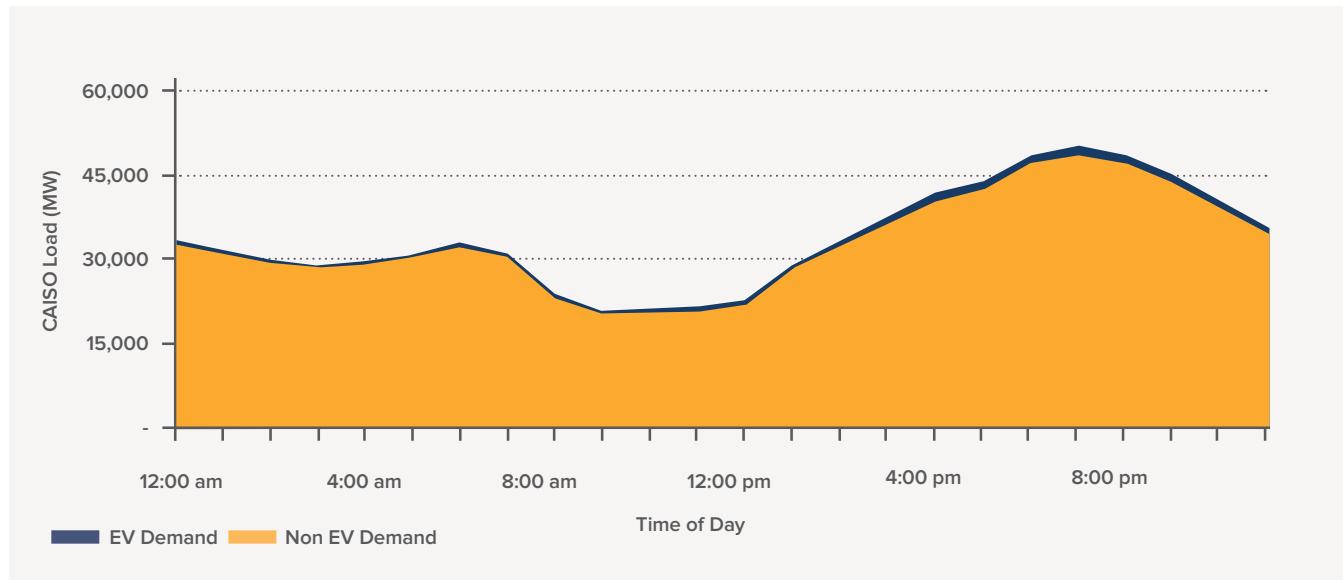
We show the EV charging loads in the context of the hourly system-load profile for the California Independent System Operator (CAISO) on September 10, the day of the 2015 CAISO system load peak.

FIGURE 8: ACTUAL CAISO DEMAND PROFILE ON SEPTEMBER 10, 2015



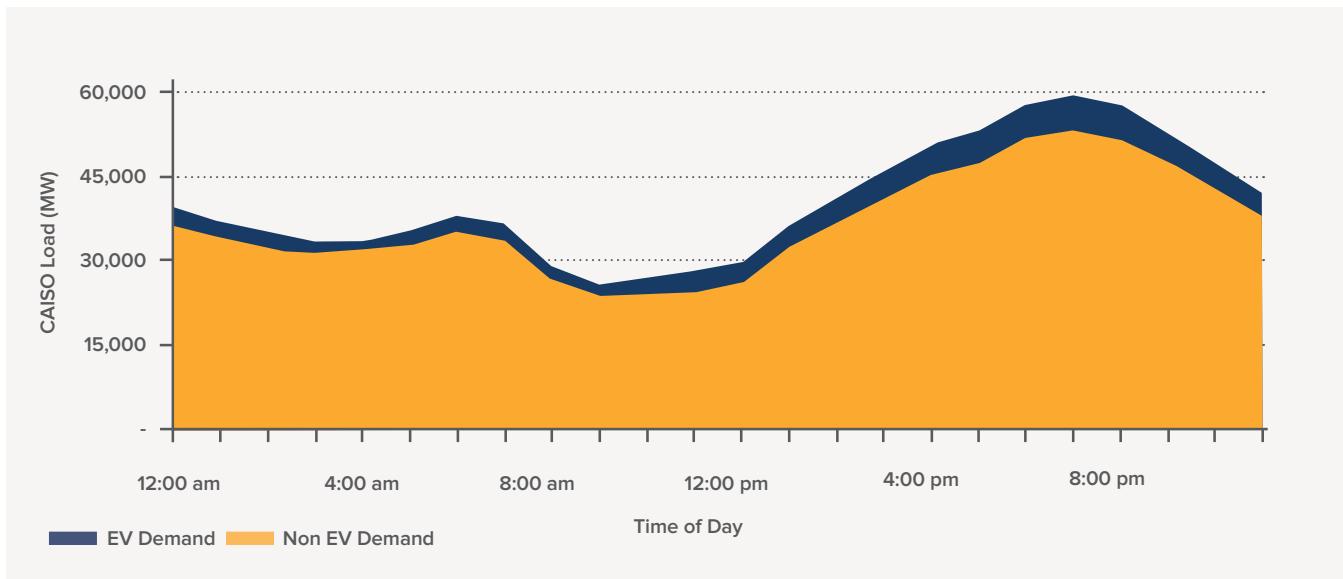
Source: RMI

FIGURE 9: PROJECTED CAISO DEMAND WITH 1.5 MILLION EVs AND 2031 RE PENETRATION GOALS WITH UNCONTROLLED CHARGING



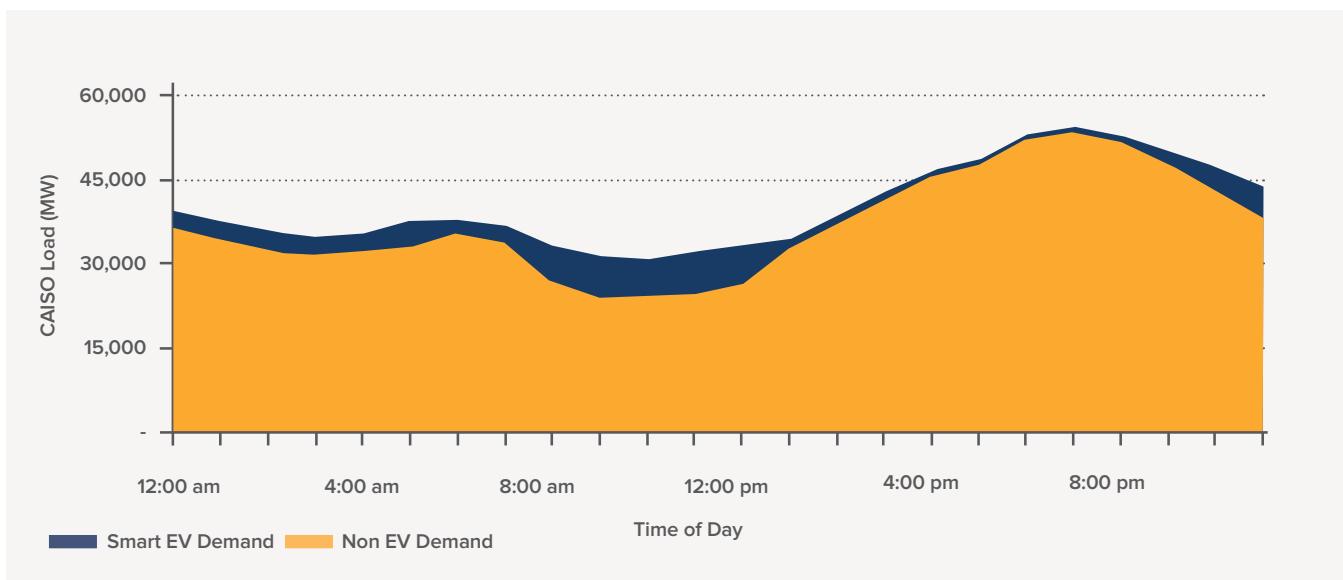
Source: RMI

FIGURE 10: PROJECTED CAISO DEMAND WITH 23% EV PENETRATION AND 2031 RE PENETRATION GOALS WITH UNCONTROLLED EV CHARGING



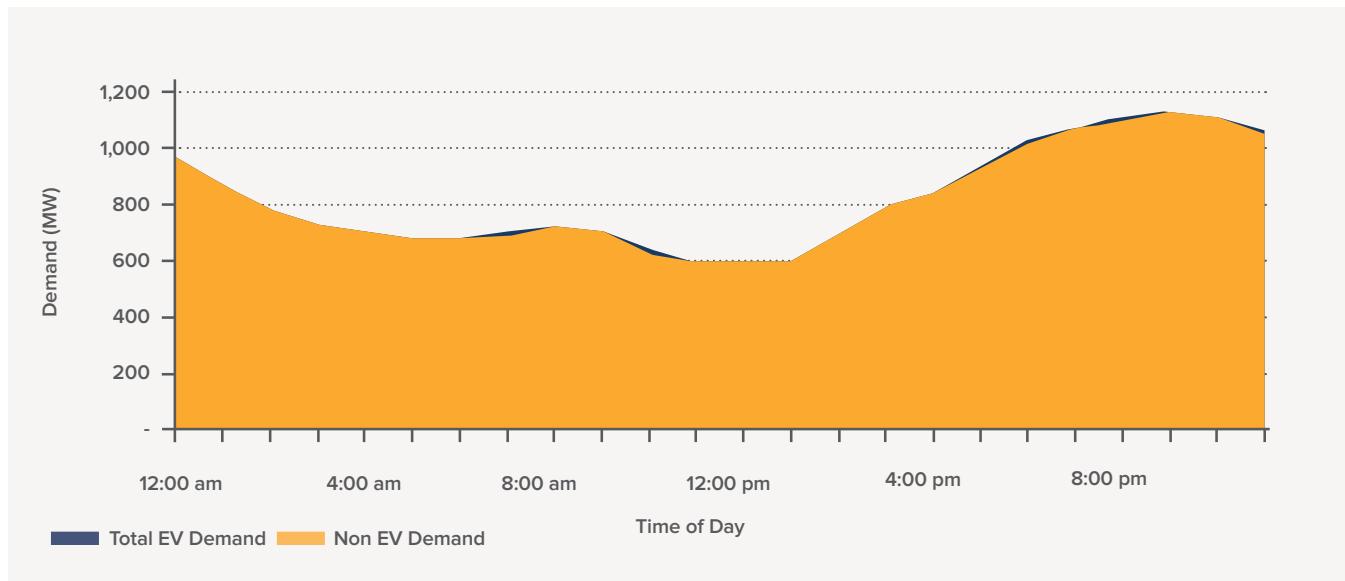
Source: RMI

FIGURE 11: CAISO DEMAND WITH 23% EV PENETRATION AND OPTIMIZED CHARGING



Source: RMI

Contrasting Figure 10 with Figure 11, it's clear that optimizing the charging of EVs can avoid increasing the state's system peak and substantially flatten its load profile.

FIGURE 12: ACTUAL HECO DEMAND PROFILE ON SEPTEMBER 22, 2014

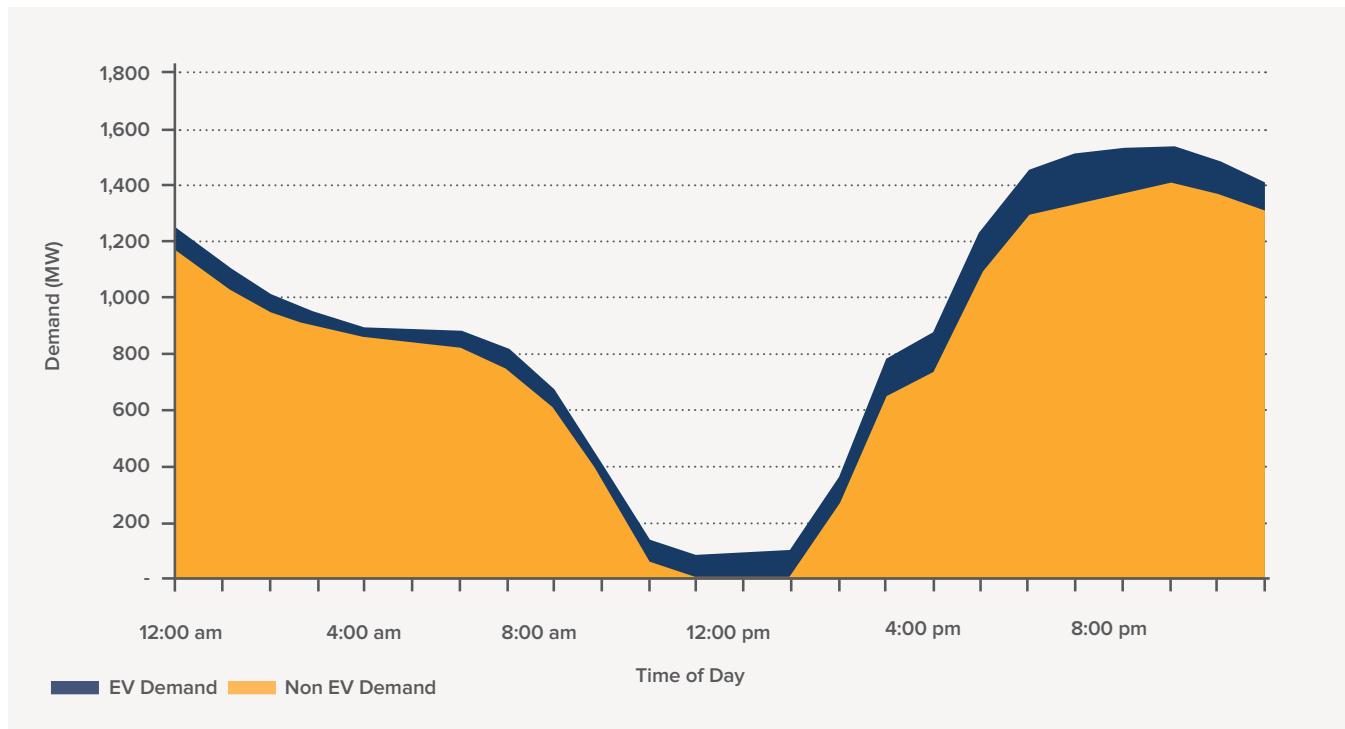
Source: RMI

Hawaii

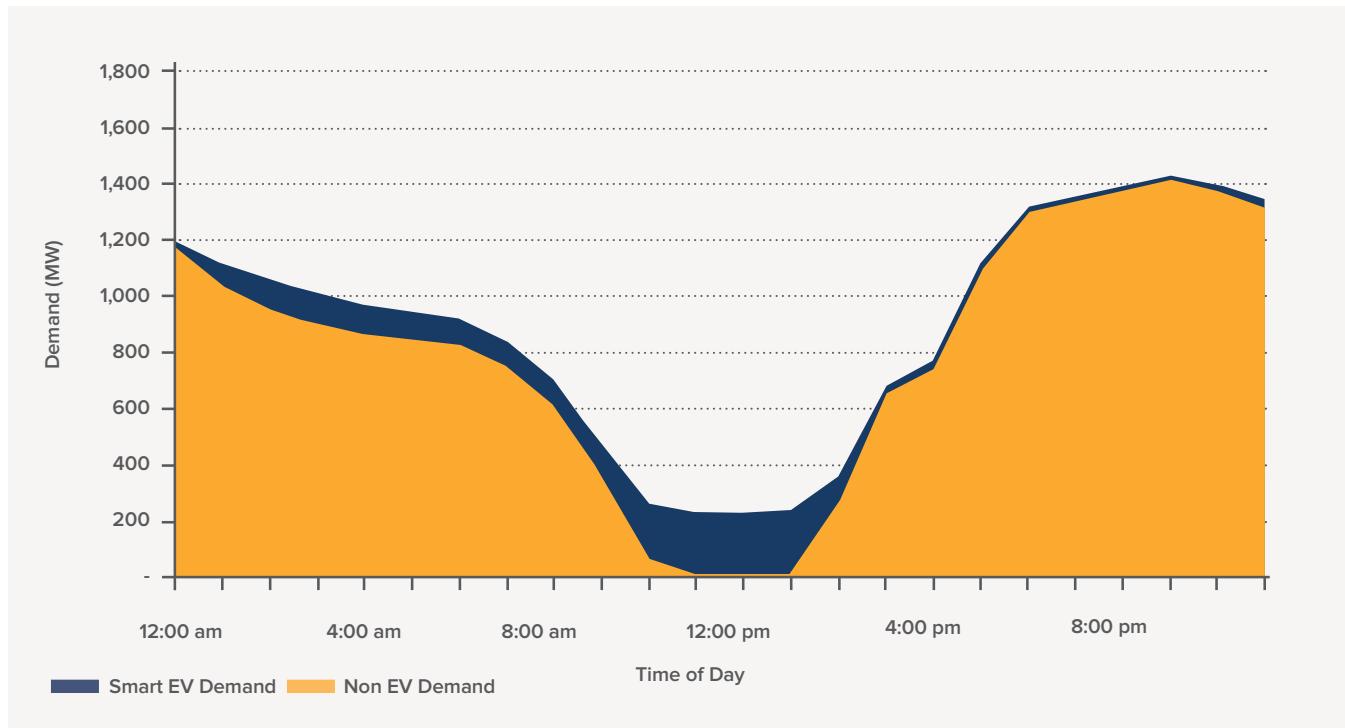
Hawaii has the second-largest percentage of EVs on the road, after California. It also has the highest percentage of solar systems, at 17% of households. As such, Hawaii has an opportunity to explore how solar production could be used to charge EVs during the midday peak without increasing total system costs. Optimized EV charging in Hawaii could potentially increase the capacity of distribution feeders to absorb solar power supply during peak periods while also helping to buffer the short-term effects of drops in solar output from cloud cover.

To estimate the amount of PV installed in 2031 for Hawaii in the high-penetration scenario, we assume a linear growth path toward the goal given in the Hawaiian Electric Preferred Plan RPS, which calls for 61% renewable electricity by 2030, including 19% rooftop solar and 10% utility PV.⁸⁰ We show the effect of EV loads on the dispatchable demand profile (after subtracting non-dispatchable solar generation) to emphasize the potential benefit of controllable loads to alleviate ramping-related issues. We show the EV charging loads in the context of the hourly system load profile for September 22, the day of the 2014 HECO system load peak.^{vi}

^{vi} Since Hawaii is a regulated state, it does not have an independent system operator/regional transmission organization (ISO/RTO) to provide state-level data. Data are taken from FERC Form 714.

FIGURE 13: PROJECTED HECO DEMAND WITH 23% EV PENETRATION WITH UNCONTROLLED EV CHARGING

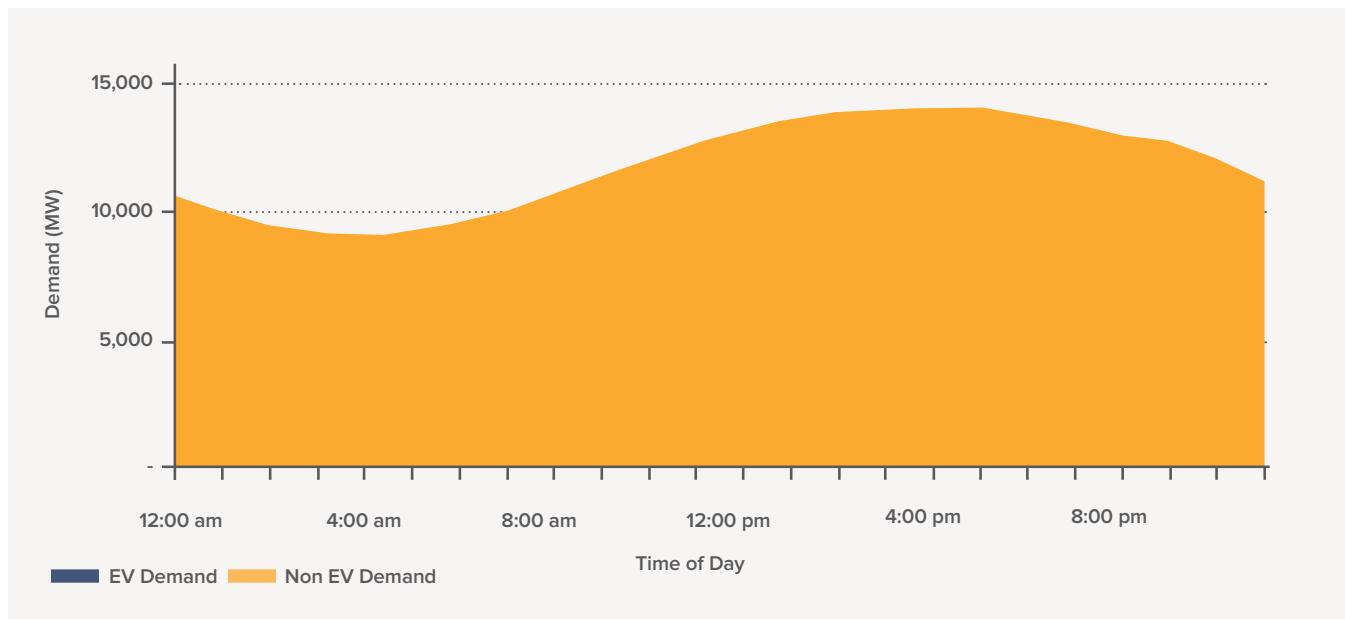
Source: RMI

FIGURE 14: PROJECTED HECO DEMAND WITH 23% EV PENETRATION AND OPTIMIZED CHARGING

Source: RMI



FIGURE 15: ACTUAL MISO DEMAND PROFILE ON JULY 10, 2015, SCALED TO REPRESENT MINNESOTA'S STATEWIDE ELECTRICITY DEMAND



Source: RMI

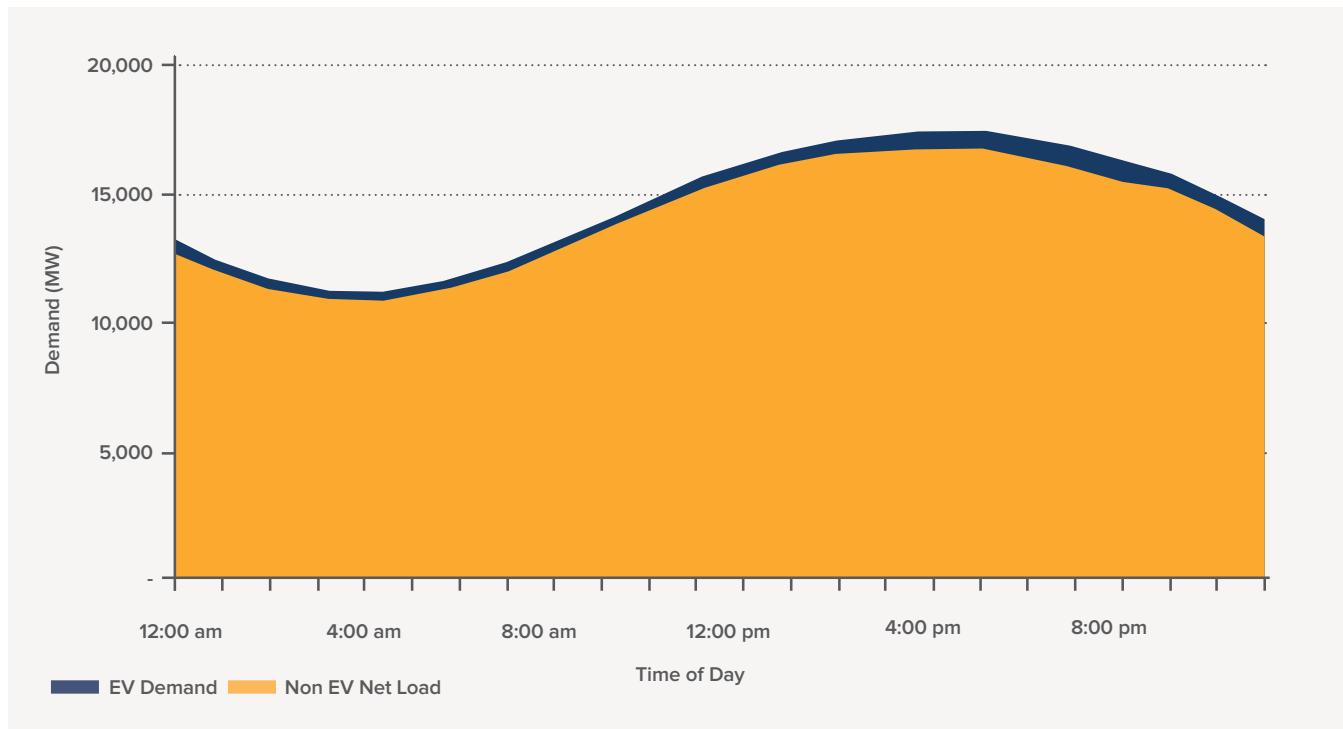
Minnesota

With 2,775 EVs on the road in 2014,⁸¹ Minnesota ranks 20th in the nation in EV registrations. However, it also has the nation's seventh-largest production of wind power in absolute terms, and the fifth-largest in percentage terms (2013 data).⁸² Minnesota therefore offers a good test case for charging at night, when wind production is generally highest and, in the long run, for using EVs as a way to absorb excess wind generation.

We show the EV charging loads in the context of the hourly system load profile for the Midcontinent Independent System Operator (MISO), scaled to represent Minnesota's statewide electricity demand, on July 10, the day of the 2015 MISO system load peak.^{vii}

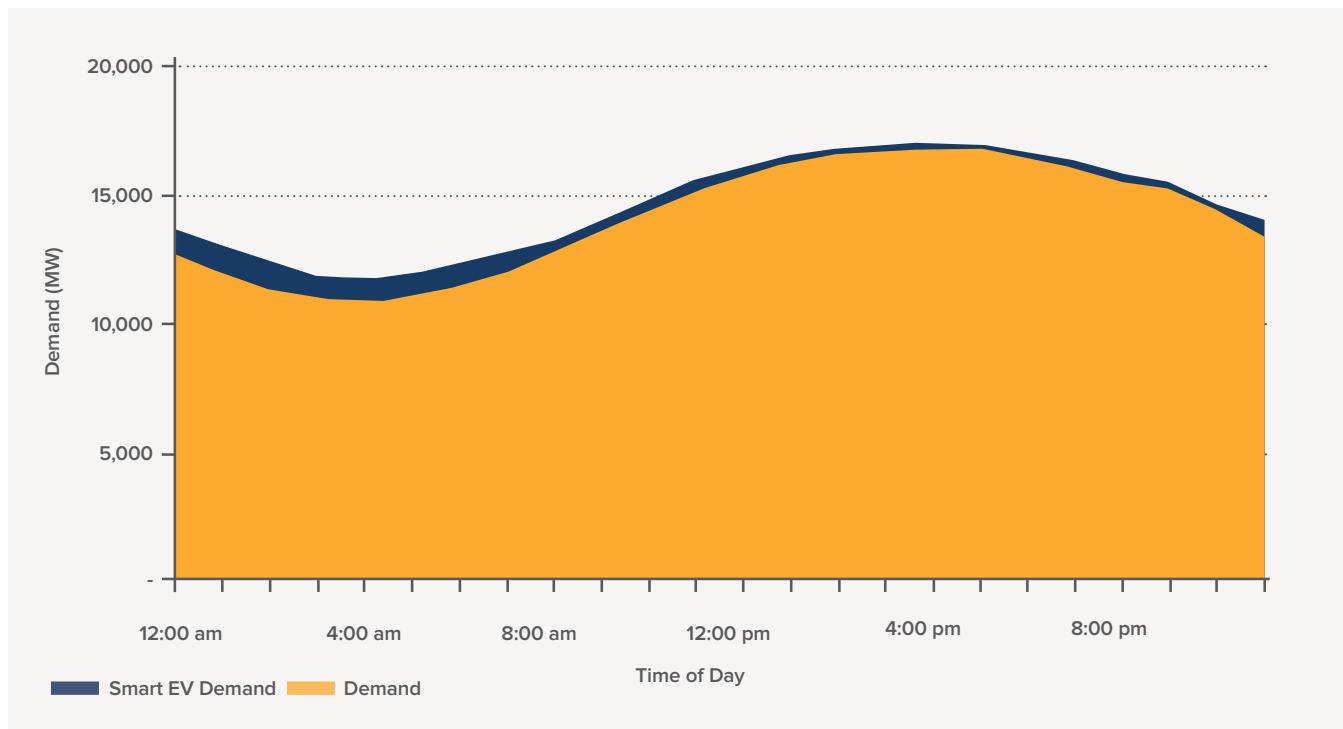
^{vii} Because state-level data are difficult to acquire for Minnesota, we estimate the state load by scaling the MISO actual hourly demand data by the ratio of the population of Minnesota to the population served in the MISO territory. MISO operates the transmission system and a centrally dispatched market in portions of 15 states in the Midwest and the South.

FIGURE 16: PROJECTED MINNESOTA DEMAND WITH 23% EV PENETRATION AND UNCONTROLLED EV CHARGING



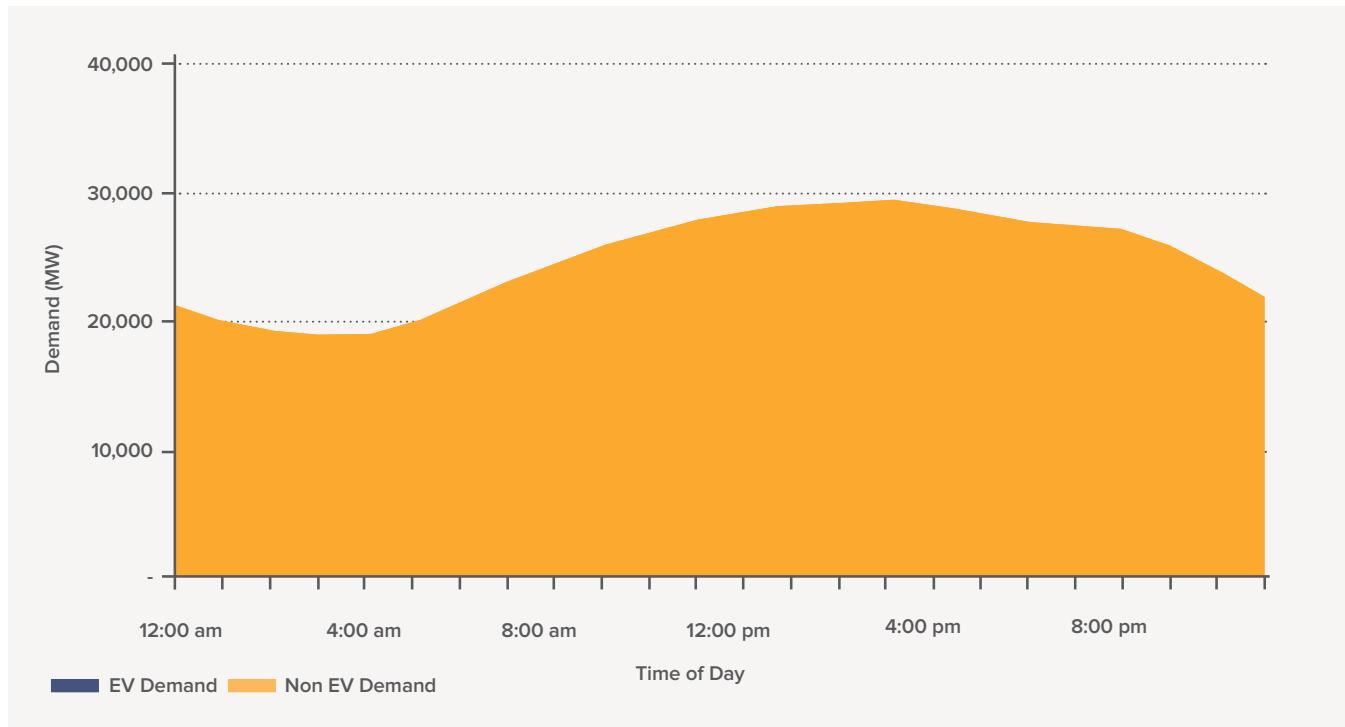
Source: RMI

FIGURE 17: PROJECTED MINNESOTA DEMAND WITH 23% EV PENETRATION AND OPTIMIZED CHARGING



Source: RMI



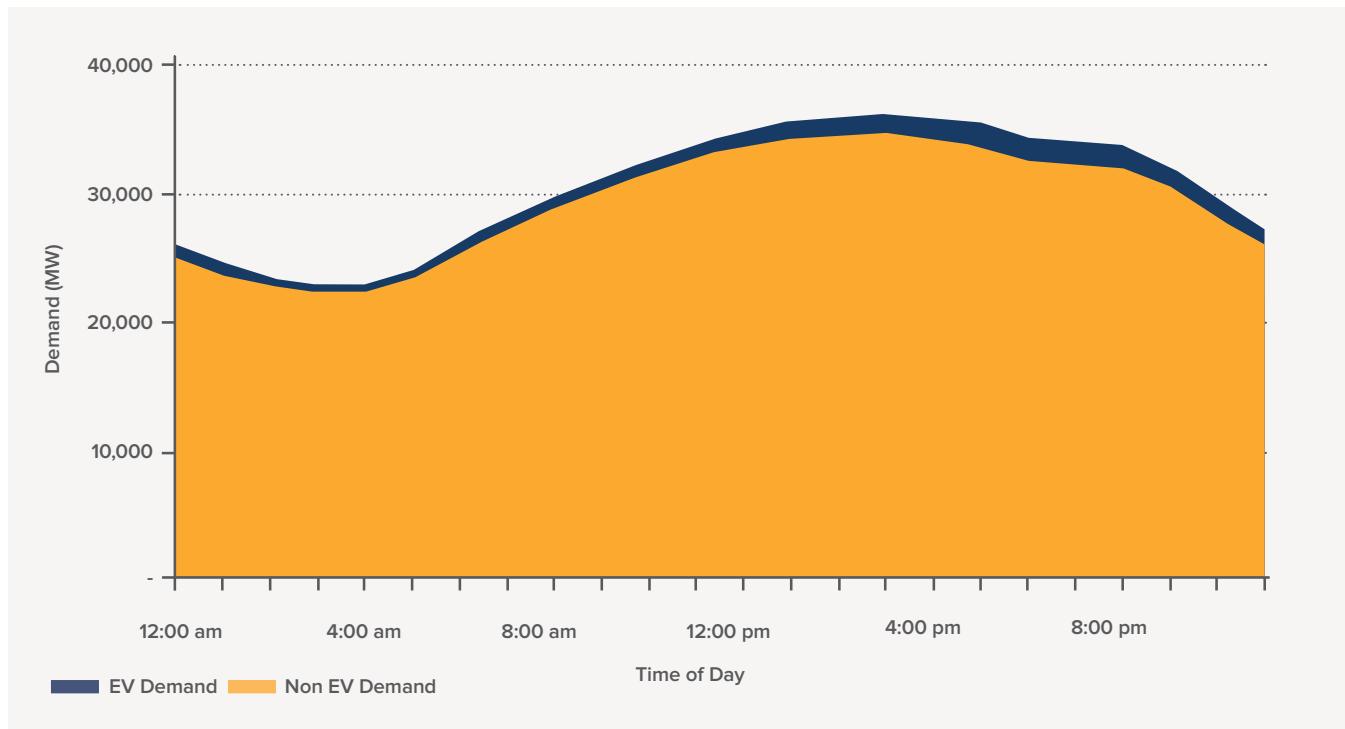
FIGURE 18: ACTUAL NYISO DEMAND PROFILE ON JULY 29, 2015

Source: RMI

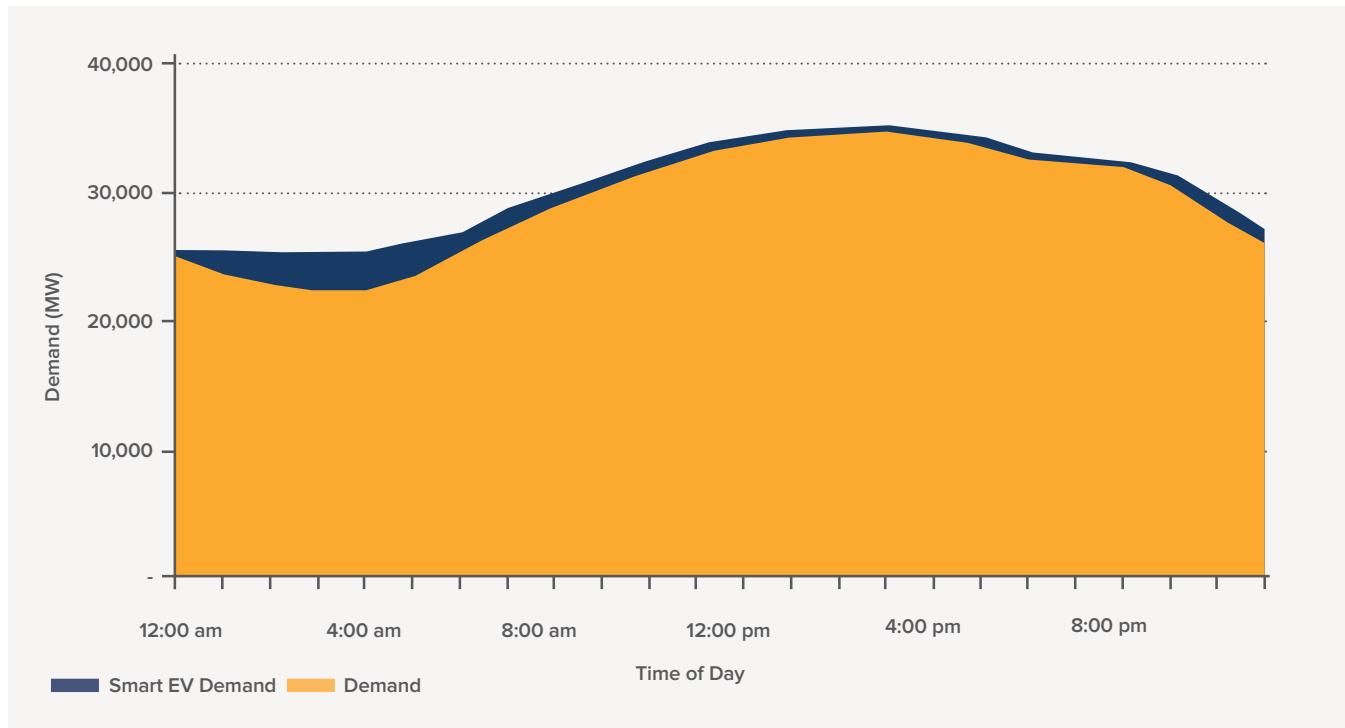
New York

New York has the fourth-largest fleet of EVs in the nation, the 13th-largest generation of wind and the 11th-largest generation of solar power (2013 data).⁸³ New York is one of eight northeastern states that have jointly committed to ensure the deployment of 3.3 million zero-emissions vehicles by 2025, together with adequate charging infrastructure to serve them. New York's share of this multistate goal is approximately 640,000 vehicles.⁸⁴ The state is in the process of comprehensively reorganizing its utility industry to encourage more efficiency, renewable generation, and demand flexibility and response through the Reforming the Energy Vision (REV) process. Through REV, New York may be positioned to integrate EVs at a very high level by using market mechanisms, and could potentially set a new standard for how that integration can be done.

We show the EV charging loads in the context of the hourly system load profile for the New York Independent System Operator (NYISO) on July 29, the day of the 2015 NYISO system load peak.

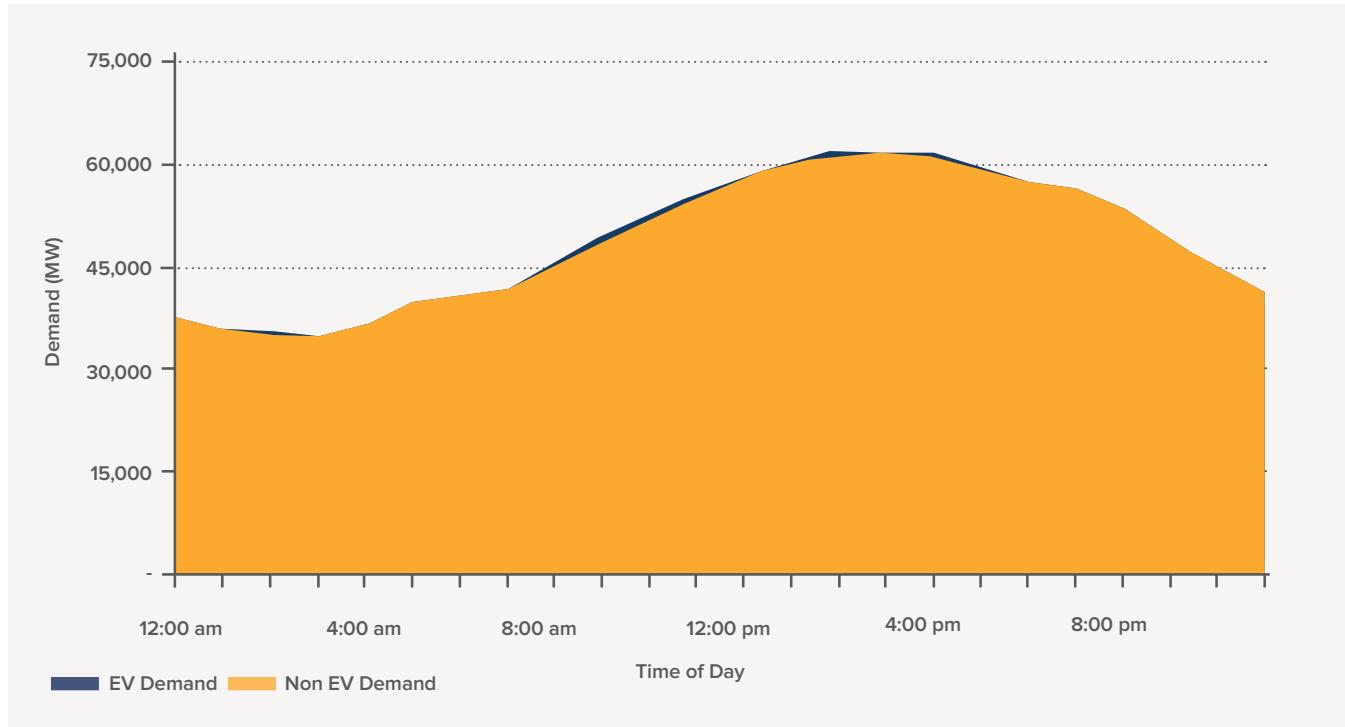
FIGURE 19: PROJECTED NYISO DEMAND WITH 23% EV PENETRATION AND UNCONTROLLED EV CHARGING

Source: RMI

FIGURE 20: PROJECTED NYISO DEMAND WITH 23% EV PENETRATION AND OPTIMIZED CHARGING

Source: RMI



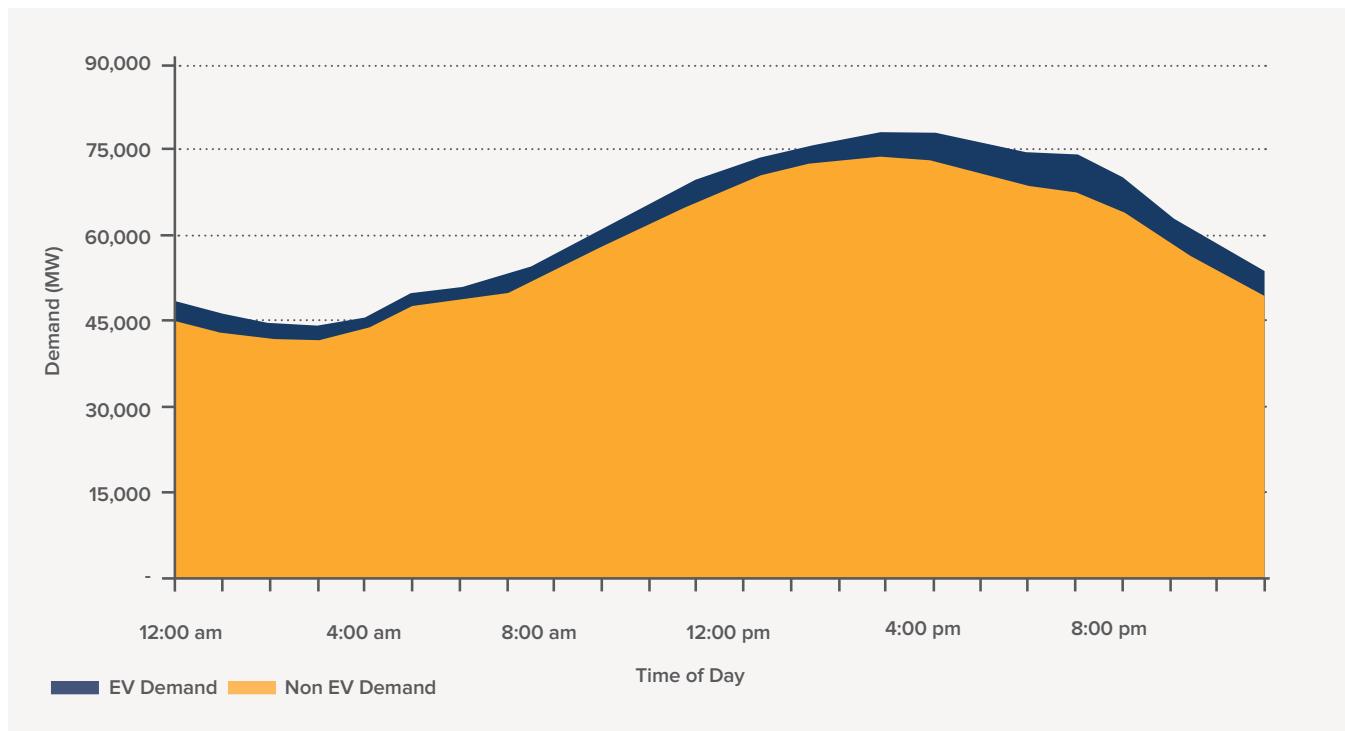
FIGURE 21: ACTUAL ERCOT DEMAND PROFILE ON AUGUST 25, 2015

Source: RMI

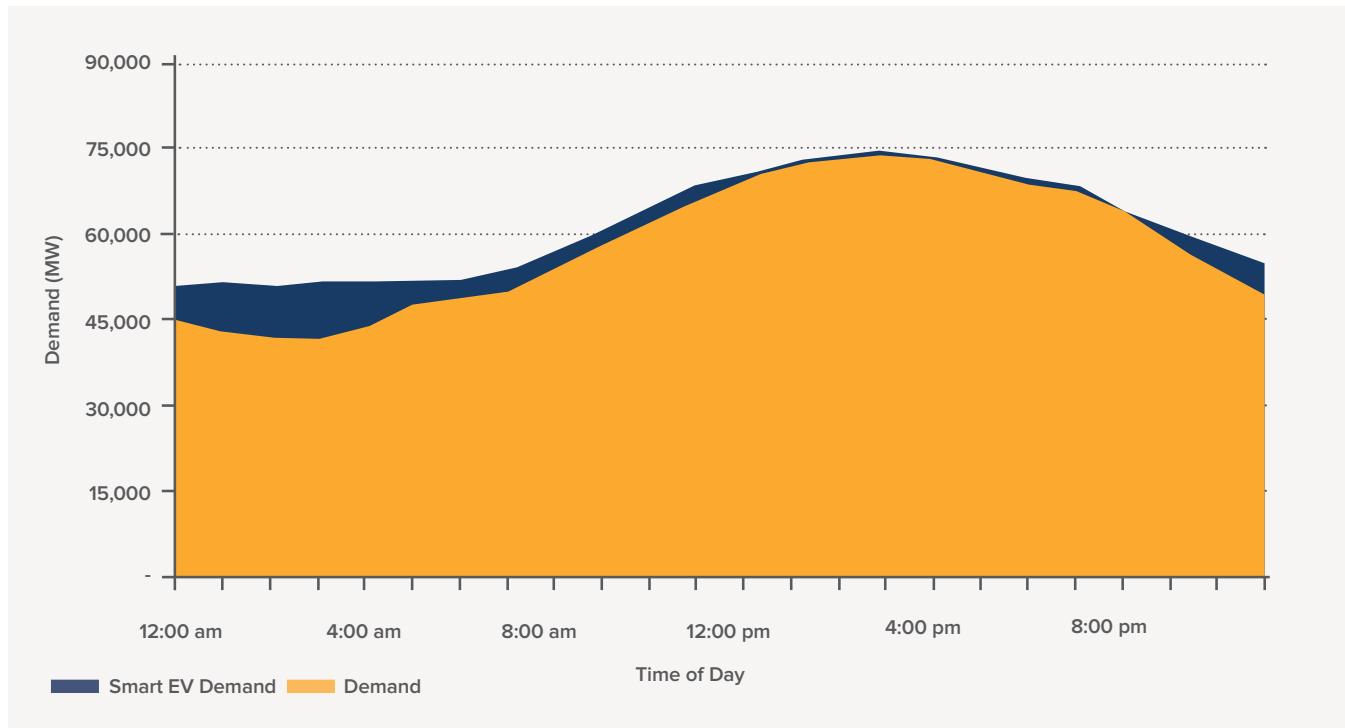
Texas

Texas leads the nation in wind generation, is the ninth-largest solar generator,⁸⁵ and has the sixth-largest fleet of EVs. Texas may find that it's best to match up EV charging with wind output at some times of the year and with solar output at other times.

We show the EV charging loads in the context of the hourly system load profile for ERCOT (Texas' ISO) on August 25, the day of the 2015 ERCOT system load peak.

FIGURE 22: PROJECTED ERCOT DEMAND WITH 23% EV PENETRATION AND UNCONTROLLED EV CHARGING

Source: RMI

FIGURE 23: PROJECTED ERCOT DEMAND WITH 23% EV PENETRATION AND OPTIMIZED CHARGING

Source: RMI



Results

As shown in the following summary table, shifting charging loads from peaks to valleys in our models can make a big difference. In Hawaii, for example, 23% of all vehicles doing uncontrolled charging would increase the peak load by 9%, but with optimized charging, it would increase the peak by only 1.34%. Shifting the EV load to fill the valleys and reduce peaks also creates a more uniform load profile across the entire system, with a higher load factor. This finding demonstrates that controlled charging can help optimize the use of grid resources, avoid having to invest in new peak generation capacity, and even integrate more wind and solar.

TABLE 2: RESULTS OF LOAD-SHIFTING FOR SELECTED STATES

STATE		CALIFORNIA	HAWAII	TEXAS	NEW YORK	MINNESOTA
Today	Share of grid power (%)	0.24%	0.13%	0.13%	0.02%	0.01%
	Peak contribution on peak day, uncontrolled	0.29%	0.14%	0.11%	0.02%	0.01%
	Peak contribution on peak day, optimized	0.13%	0.07%	0.02%	0.003%	0.004%
High EV penetration Scenario	Share of grid power (%)	8.90%	12%	5.96%	3.47%	3.03%
	Peak contribution on peak day, uncontrolled	11.14%	9%	4.94%	3.44%	3.05%
	Peak contribution on peak day, optimized	1.33%	1.34%	0.91%	0.56%	0.50%
	System load factor on peak day, uncontrolled charging ^{viii}	0.68	0.58	0.78	0.82	0.83
	System load factor on peak day, optimized charging	0.74	0.63	0.81	0.84	0.86
CA 1,500,000 EVs	Share of grid power (%)	1.90%				
	Peak contribution on peak day, uncontrolled	2.61%				
	Peak contribution on peak day, optimized	1.09%				

^{viii} Represents the average system-wide load on the day of the system-wide peak, divided by the peak system load on the day of the system-wide peak. A value of one would indicate that the average load was identical to the peak load (a perfect optimization). Lower values would mean some capacity was only used to meet peak load.



BENEFITS OF EVs AS GRID SUPPLY (V2G)

05



BENEFITS OF EVs AS GRID SUPPLY (V2G)

WITH APPROPRIATE VEHICLE-TO-GRID (V2G)

technology, EVs can function as grid supply—serving the same functions as power generators—as well as being grid loads. EVs could pump electricity back onto the grid at times of high demand and participate in the ancillary services markets, providing services like frequency and voltage regulation, reactive power for power factor correction, and reserve capacity.

Grid-power visionaries have imagined and promoted this sort of bidirectional role for EVs for many years. (RMI invented it in 1991.) However, we have elected to exclude EVs as supply from the scope of this paper, primarily because beyond a few small pilot projects, V2G has yet to become a reality. In the meantime, EVs as a demand-side (V1G) resource can provide nearly all of the same services.

Several significant hurdles remain to be overcome before V2G will be a viable market:

1. The auto industry needs to build V2G features into its vehicles. Currently, most manufacturers are not including onboard V2G capability in their vehicles (except for a few pilot programs and the newer Nissan Leaf models), and even where it is built-in, using it for V2G would void the vehicle warranty. It's a classic chicken-and-egg problem: Manufacturers aren't including V2G features because there isn't a market, and there isn't a market because there aren't enough vehicles with those features.
2. Manufacturers need to allow V2G use under their warranties. Currently, using an EV battery as grid supply would void warranties.
3. Regulatory frameworks and EV charging and delivery points are not designed for mobile resources, and appropriate tariffs that would pay EV owners for supplying power and other "unbundled" services to the grid are generally nonexistent.



4. Essential hardware and software infrastructure that would be needed from end to end to enable V2G is generally lacking, including real-time data exchange, advanced metering, cybersecurity layers, and standard interfaces between vehicle and grid.
5. Customer awareness of V2G potential is lacking, so customer demand is too.

In order to develop a true V2G market for EVs, several important questions need to be answered:

- 1.** What is the real, effective capacity that might participate in V2G markets? (It is generally believed that commercial vehicles and fleet vehicles would be more likely to participate in V2G than personal vehicles.)
- 2.** How, when, and where will sufficient numbers of participating EVs exist, such that aggregators can facilitate market development and deliver nontrivial capacity to grid markets? (Aggregated participation typically requires at least 300 vehicles to be aggregated into a single block of at least one MW.)
- 3.** How durable and reliable would V2G be as a supply resource? (If it's not as durable or reliable as firing up another generator, it would likely not succeed. In NYISO, a resource needs to bid at least one hour of service into a market, which would require several hundred vehicles to be parked and available to respond for at least one hour.)
- 4.** What is the total real potential economic value of V2G?
- 5.** How will that value be apportioned, and to whom? (Vehicle owners, utilities, V2G service aggregators, charging-station owners and operators, and other entities might all lay claim to some portion of that value.)
- 6.** Can utilities and vehicle manufacturers work together to develop a V2G regime that will address these issues and not void auto warranties? (New business models where automakers aggregate and resell V2G services in return for a discounted price to auto buyers could create a strong incentive to change this industry policy.)

Sorting out the answers to these questions, and developing appropriate infrastructure, business models, tariff regimes, and market designs, is probably more easily done in the stationary power storage market than in the EV market, because the former is so much simpler. Stationary power storage systems exist only to serve those functions, whereas for EVs, those functions would be secondary to their primary function as transportation.

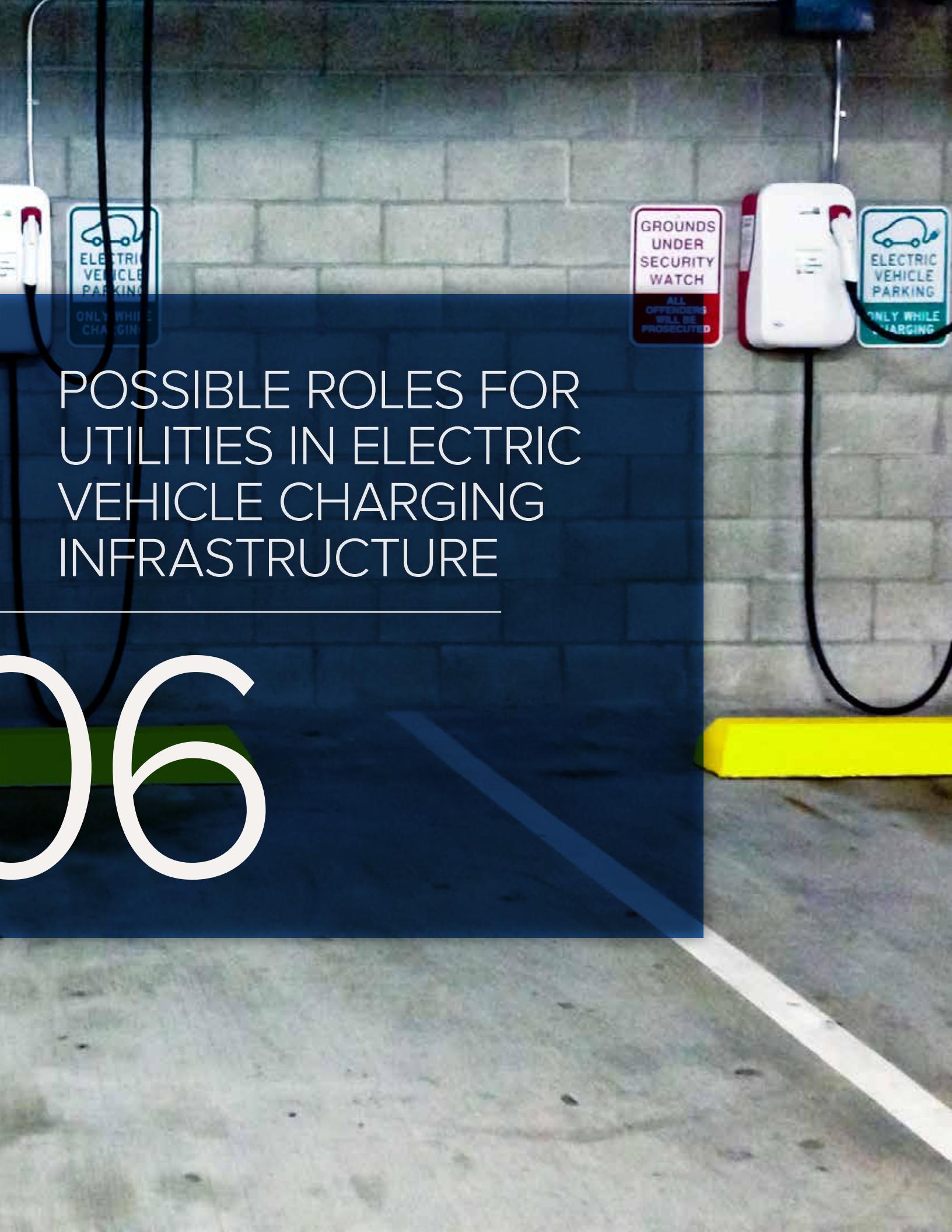
Stationary storage markets are themselves in a very nascent state, and are beyond the scope of this paper. Still, it is advisable to pay close attention to their development, particularly in California, and to be alert to insights that can be learned from them early on and applied to the V2G market if and when it emerges.

Although V2G is outside of the scope of this paper, its potential is indeed significant once the outstanding questions are resolved. A 2013 study by the U.S. Department of Defense found that frequency regulation alone could reduce the monthly lease price of a PEV sedan by roughly 72% in Southern California,⁸⁶ and a 2011 study by MIT found that a fleet of PHEVs in Boston feeding electricity to a building at peak times could save \$100/month per vehicle by reducing demand charges.⁸⁷ Capturing such substantial customer or business value could considerably speed EV adoption while reducing utility investment burdens.



POSSIBLE ROLES FOR UTILITIES IN ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

06



POSSIBLE ROLES FOR UTILITIES IN ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

UTILITIES AND THEIR regulators need to consider various options in determining the appropriate role for electric utilities in the electric vehicle charging market. We look at three different approaches and evaluate each by simple equity and efficiency criteria.

- **Utility as Facilitator:** The utility treats EV charging like other potential load, providing nondiscriminatory electric service when and where requested, but not engaging in the business of vehicle charging.
- **Utility as Manager:** In addition to delivering electric service to the location of the vehicle charger, the utility manages the charging operation to better integrate charging with grid capabilities and grid needs.
- **Utility as Provider:** The utility provides both the electric service to the charger and the charging equipment and charging service. It receives a cost-based payment for charging.
- **Utility as Exclusive Provider:** Vendors other than the utility are prohibited from providing charging service to the public, under laws precluding the resale of electric service.

In each case, the role of the regulator remains the same: to ensure that utility service and prices are fair, just, reasonable, and sufficient.

UTILITY AS FACILITATOR

In this arrangement, the utility simply provides electricity service to EV chargers, a meter, and a bill. The owner of the charger is responsible for the charging equipment and for the business relationship with the EV driver.

That relationship could vary from something as simple as a retailer providing free EV charging to its customers, to something as complex as a national charging-service provider installing point-of-payment equipment, with or without advanced charging control, in public parking areas or private facilities, such as multifamily housing garages. The owner of the charging station determines how to recover the cost of the service through charges paid by EV drivers.

Rate design in this arrangement would typically feature the following characteristics, which are shared by other small-scale services:⁸⁸

- No demand charge. The infrequent usage of a Level 3 charger's 20–90 kW load would be very expensive if demand charges were included. If a small commercial customer has no demand charge to begin with, offering an EV charging service should not change that. (Most utilities do not impose demand charges on residential customers or on commercial customers under 20 kW in recognition that their individual sporadic use is balanced by that of other customers, producing a predictable "group" load profile that can be priced equitably.)

TABLE 3: ROLES OF UTILITIES AND REGULATORS IN DIFFERENT FRAMEWORKS

FRAMEWORK	WHO OWNS CHARGING EQUIPMENT?	ROLE OF THE UTILITY	ROLE OF THE REGULATOR	PRICING OF CHARGING SERVICE	CONSUMER PROTECTION
Facilitator	Customer	Electric service only	Regulate tariff for electric service to location	Unregulated	Same as retail
Manager	Customer	Electric service plus dispatch	Lower tariff for electric service	Unregulated	Same as retail
Provider or Exclusive Provider	Utility	Electric service and charging service	Regulated tariff for charging service	Fully regulated	Through utility regulator



- A monthly service charge that recovers only customer-specific costs such as billing and collection.
- A time-varying energy charge to recover all distribution-system and power-supply costs.
- The owner of the charging equipment sets the price for charging service. In many cases the charging may be free or bundled into a parking fee, rather than being sold separately.

The role of the regulator is to ensure that an EV customer is not treated differently from other customers of similar size and annual usage characteristics, and that the tariff is neither prohibitive to the customer nor subsidized by other customers. The regulator should also ensure that fees for charging imposed by the owner of the equipment are transparent and evident before a transaction begins (particularly if other consumer codes do not provide equivalent protections), but should not otherwise regulate the price or service characteristics.

Where utility regulators have sought to impose price regulation on EV charging, or asserted that this is a regulated utility resale of electricity to the public, charging-service owners have worked around those regulations by providing free charging in a paid parking space, so there is no value to asserting a regulatory role over the ultimate pricing of the service.

UTILITY AS MANAGER

In this arrangement, the utility provides the electric distribution service to the charging station. The utility may also directly control chargers as a demand response resource, in order to better integrate charging loads with grid capabilities and needs. The charging equipment remains privately owned, and the business relationship with the EV driver remains with the owner of the charging facility. The utility-as-manager may also play the facilitator role, supplying electricity to others who offer charging service to the public.

This arrangement may be particularly desirable for retailers that want to provide free charging service without having to contract with a third party. Free charging stations of this kind could enlist as demand-response resources in order to obtain the lowest possible tariffs and minimize their costs.

UTILITY AS PROVIDER

In this arrangement, the utility owns the full supply chain, from the distribution grid through to the EV charging stations. It is responsible for maintenance of the equipment and for the business relationship with the customer (although it may use a third party for billing and payment settlement).

Here the regulator would be responsible for setting the retail tariff for EV charging service. The tariff would be designed to recover the power supply, electric distribution, and charging equipment costs. The regulator would also consider the effect the utility is having on the private market for charging, and may consider steps to remove bias. Options for the regulator include codes of conduct governing how the utility is able to use its status with customers to market charging equipment.

Allowing utilities and automakers to deploy and own EV charging infrastructure may be the most expedient way to get more charging stations deployed. Tesla is a leading example of this approach, and it makes sense because automakers can build the cost of deploying charging infrastructure into their broader cost structure over longer periods of time, and at a lower cost of capital.



For example, Tesla alone is deploying 105 charging stations in Manhattan; when that expansion is complete, there will be three times as many EV charging stations in Manhattan as there are gasoline filling stations, of which there are currently 40 (a number that is falling).⁸⁹

It can also be argued that EV charging networks can be built and operated more naturally as monopolies than as competitive marketplaces, for the same reasons that utilities are granted monopoly control of their market territories. As Brett Hauser, the CEO of Greenlots, a software provider for EV chargers, put it:

Utilities have to be the ones because it will take a longer time and cost more than a private company will give it.... Utilities can rate base the charging infrastructure upgrades and consider what is best for the community. Private sector financial concerns will focus the infrastructure on narrower, more affluent markets.⁹⁰

For a review of some recent and proposed programs for utility-owned charging stations, see the Appendix on p. 68.

In California, the nation's most developed EV market, the question of utility ownership of charging infrastructure has been hotly debated in its two alternative-fuel vehicle rulemakings and three utility applications to deploy charging infrastructure, with dozens of parties actively participating in proceedings at the California Public Utilities Commission (CPUC).⁹¹ The CPUC originally found that “the benefits of utility ownership of EVSE [vehicle chargers] did not outweigh the competitive limitation that may result from utility ownership,” then removed the blanket prohibition on utility ownership of charging infrastructure in favor of an “interim approach” which uses a “balancing test that weighs the benefits of electric utility ownership of charging infrastructure against the potential competitive limitation...on a case-specific basis.”⁹² That decision will still permit third-party providers to offer charging products to the marketplace.

A SECOND LOOK AT PUBLIC CHARGING BENEFITS

Managing the load of typical home charging stations today, and fleets of EVs attached to charging hubs in the near future, is undoubtedly a core part of EV grid integration. But we should be aware that EVs are a very dynamic market, and that EV charging patterns may be quite different in the future. Vehicle ranges are increasing, use patterns are changing, charging systems are changing, mobility as a service is emerging, and charging aggregators are just beginning to roll out services that have the potential to significantly alter EV ownership and use trends.

In particular, if public charging stations were to become widely available at public locations and workplaces, they would enable some new possibilities and challenges:

- Range anxiety would diminish or disappear entirely, removing a major obstacle to EV ownership.
- Longer-range EVs could reduce the need for Level 2 chargers at home, because high-speed Level 3 chargers at workplaces and public locations, combined with onboard Level 1 charging, would be sufficient for most users. Utilities could find that effective management of charging becomes more important in the daytime than at night.
- More of the charging loads would be served where sufficient electricity distribution infrastructure already exists to support high-speed Level 3 charging,^{ix} reducing the need for expensive installations of new heavy-duty conductors just to support Level 3 chargers.

^{ix} “For descriptions of different types of charging stations, see “Types of Chargers” on p. 68.

UTILITY AS EXCLUSIVE PROVIDER

In this arrangement, the utility owns the full supply chain, and entities other than the utility are precluded from offering charging service to the public for compensation. The regulator would set the price for service, ensure that the service is being offered when and where it is needed to meet public demand, and review any public policies regarding the availability of charging.

Where EV charging has been ruled a “resale of electric service” subject to regulation, most vendors get around this by providing free electricity as part of an hourly parking fee, if they charge such a fee at all.

Regulators should consider this option cautiously, as it may impose an anticompetitive bias and raise awkward legal and public-relations issues. In every state, utilities provide service to recreational-vehicle parks, master-metered office and residential buildings, and marinas, all of which pass the cost of electric service on to end-users.

- Even though Level 3 chargers are considerably more expensive to install, they could be a cheaper and faster way of providing ubiquitous charging infrastructure than installing Level 2 chargers in millions of homes and multiunit dwellings.
- Utilities would find it easier to manage daytime Level 3 chargers for the greatest grid benefit, particularly in areas where daytime charging could soak up excess solar production and minimize the need for nighttime baseload generators.
- It would reduce the likelihood of EV charging as soon as drivers get home from work, which exacerbates the “duck curve.”
- It would reduce the risk of overloading where clusters of EVs exist on the distribution grid.
- Charging stations would have higher utilization rates and their operators would be more profitable. This would support greater deployment and ensure that stations are properly maintained and kept in operation.





RECOMMENDED REGULATORY MECHANISMS AND RATE DESIGN

07

ON

RECOMMENDED REGULATORY MECHANISMS AND RATE DESIGN

MAXIMIZING THE BENEFITS of EVs to shareholders and consumers will require ways to influence charging so that it happens when grid power costs are lowest. Charging at those times will help to maximize the utilization of grid assets, particularly renewable energy generators, limit the need for distribution system upgrades, and avoid having to invest in additional peak generation capacity.

MANAGING LOAD AS DEMAND RESPONSE

One way that EV charging demand can be used as a flexible load is by providing demand response services to utilities or grid managers. Because it makes EV charging loads partially dispatchable, this approach is the most responsive to system needs.

This type of demand response could be done through an aggregator that controls the charging of hundreds or thousands of vehicles, tapering off charging when the grid operator signals that demand is high, and paying customers for the right to manage their charging—while guaranteeing that vehicles will be adequately charged when they need it.⁹³

eMotorWerks is one such startup. Under California's first major initiative to deploy distributed energy resources to provide grid services—the Demand Response Auction Mechanism, or DRAM—eMotorWerks plans to control the charging load of more than 1,000 smart EV chargers to deliver demand response of 900 kilowatts for SCE, 300 kilowatts for SDG&E, and an undisclosed amount for PG&E. eMotorWerks CEO Valery Miftakhov called the program “the largest program to date that integrates electric vehicle charging as a grid resource.”

With appropriate hardware, software, and communications systems, demand response could also occur directly between a utility and a customer without an aggregator.

Other entities that could function as demand response aggregators include distribution utilities (which could sell the services to wholesale market operators), vehicle manufacturers, and large customers that operate garages and banks of charging stations.

MANAGING THE LOAD THROUGH RATE DESIGN

A more discrete and targeted approach to rate design for EVs is time-varying pricing, where electricity prices that vary over intervals of the day provide market signals that help to shift charging away from the system-peak periods and toward low-demand periods.

Time-of-use rates

The simplest form of time-varying pricing is a time-of-use (TOU) rate, which offers different prices for power consumed during set periods of the day: reduced prices when demand is typically low, and high prices when demand is typically high.

Several states have TOU rates designed for EVs. An overview of some of these programs by The EV Project indicates a wide range of pricing.⁹⁴ Typically, the wider the price differential between the on- and off-peak hours, the more effective the TOU rate is at shifting charging behavior (see “Residential charging” on p. 55 for a case study on this point).

Notable examples of effective TOU rate designs for EVs in the U.S. include California (see “Lessons learned from California’s EV experience” on p. 53) and Nevada. NV Energy, the major utility in Nevada, offers TOU EV rates featuring wide differentials for on- and off-peak power. For example, its summertime rate for northern Nevada varies from 40.7 cents/kWh for on-peak power (from 1 pm to 6 pm) to 5.53 cents/kWh for off-peak power (from 10 pm to 6 am).⁹⁵

Notable TOU rates in Europe include the off-peak discount offered by EDF in France;⁹⁶ a special EV TOU rate offered by RWE in Germany;⁹⁷ and a day/night tariff offered by E.ON in Germany.⁹⁸

Where TOU rates for EV charging exist, it is clear that they can change charging behavior.

A study by the California Public Utilities Commission found that throughout the state, TOU rates were successful in shifting EV charging times from the



evening hours (roughly 3 pm to 9 pm), when whole-house loads typically peak, to the off-peak hours (midnight to 2 am).⁹⁹

A pilot project conducted by the Pecan Street Research Institute in Austin, Texas, which covered a 30-home sample of EV drivers, found similar results. Weekday charging by the 15 drivers who participated in a TOU pricing trial mostly occurred between 11:45 pm and 2:30 am, and only 12% occurred during the 3 pm to 7 pm peak hours, whereas the 15 participants who did not have the option of the TOU rate charged during peak hours 22% of the time.¹⁰⁰

Dynamic pricing

While TOU rates are a good way to begin supporting EVs, achieving higher levels of EV penetration, or a high density of EVs on a single power circuit, will require more intelligent management of charging loads in order to prevent creating new demand peaks when the vehicles are charging, and to avoid localized impacts on neighborhood transformers, distribution line segments, or feeder transformers.

One such regulatory mechanism would be *dynamic pricing*, in which electricity prices can vary hourly (or even more frequently) to more accurately reflect the real-time cost of power generation and delivery than TOU rates do. With dynamic pricing, automated charging equipment (including smart meters and charge controllers) can see and respond to prices that reflect immediate grid conditions.

Experience with dynamic pricing arrangements for electric vehicle charging is still limited, and ongoing changes in technology, including the systems used to control charging, contribute to uncertainties about how dynamic pricing will affect charging behavior. San Diego Gas & Electric (SDG&E) is beginning a program that will post dynamic hourly rates for EV charging on a day-ahead basis. A prospective analysis of this approach concluded that it would benefit all utility customers if PEV owners were responsive to the price signals.¹⁰¹ But customers may not be comfortable with the complexity of dynamic pricing, in which case load aggregators may be needed to obtain the benefits of dynamic pricing. (For details on the SDG&E pilot program, see “VGI pilot for EV charger deployment” on p. 58.)

MANAGING THE LOAD THROUGH DIRECT CONTROL

Charging loads could be controlled directly—by grid operators or utilities or aggregators of charging infrastructure—with parameters set by the user. This approach will likely yield the best results of all: a true, real-time implementation could control the charging of individual vehicles on a distribution circuit to avoid overloading it, and could optimize all assets on the grid under a dynamic pricing regime. However, it will not be a reality until utilities, vehicles, and charging systems implement bidirectional communications systems to support it.

Advanced metering infrastructure (AMI) will also be needed to measure hourly or subhourly demand and to enable billing for dynamic pricing, but its deployment has been relatively slow. As of mid-2014, AMI deployment only covered about 43% of households. However, it seems inevitable that it will achieve nearly full deployment eventually, at which point direct, automated, and real-time control and billing strategies will be more feasible.

ADVANCED CHARGING CONTROL ARCHITECTURES

In the earliest days of EVs, charging was simple. You got home, you plugged your car straight into an outlet or into the charging station in your garage, and when the car was fully charged, the charger stopped.

Today, EV drivers can use their home charging station, an app, or the vehicle’s on-board systems to ensure that charging occurs during the off-peak hours of a TOU rate.

In the emerging era of broad EV adoption and managing EV charging as a distributed energy resource, advanced control systems will be needed to enable the vision of dynamic, real-time pricing and highly flexible charging. Several architectures are possible. Some already exist, while others are conceptual, but each one will determine how much control and what kinds of markets are possible with it.



LESSONS LEARNED FROM CALIFORNIA'S EV EXPERIENCE

08

LESSONS LEARNED FROM CALIFORNIA'S EV EXPERIENCE

CALIFORNIA'S EXPERIENCE WITH efforts to integrate EV charging into the grid is illustrative of the complexity of the California market. California has the largest EV market in the U.S. thanks to a suite of supportive policies, including a zero-emissions vehicle program, financial incentives to purchase EVs, supportive EV charging policies, and direct engagement with utilities. The Golden State also has the nation's most ambitious EV deployment target: 1.5 million zero-emission vehicles on California roads by 2025. According to SDG&E calculations, if that many EVs all charged during peak times, it could add almost 10,000 MW of new peak load to the approximately 64,000 MW California grid.^{103,x}

Under provisions of SB 350, which was passed into law in September 2015, the California Public Utilities Commission was also directed to order the electric utilities under its jurisdiction to "file applications for programs and investments to accelerate widespread transportation electrification to reduce dependence on petroleum, meet air quality standards, achieve the goals set forth in the Charge Ahead California Initiative, and reduce emissions of greenhouse gases."¹⁰⁴

California's utilities and regulators are crafting policies designed to achieve savings through improved capacity utilization. Charging EVs when non-dispatchable assets like solar and wind generators are producing more energy than the electricity system can absorb can reduce the occurrence of oversupply and curtailment; help flatten out the duck curve of demand; and reduce the extent to which supply must suddenly ramp up when the sun goes down and people come home from work.¹⁰⁵ (Flexible EV charging is one kind of demand flexibility, which can play a significant role in mitigating the duck curve. For more information, see the RMI report *The Economics of Demand Flexibility*.¹⁰⁶) All of these characteristics reduce system costs, benefit ratepayers, and improve the profitability of generators.

According to a study by the CPUC:

Coupling the unique usage attributes of PEVs with new business and operational strategies has the potential to mitigate system impacts resulting from the growth of electrified transportation, and in turn, accelerate PEV adoption and hasten benefits to air quality, reduced GHG emissions, and the development of the industry.¹⁰⁷

THE EV PROJECT

The largest deployment and evaluation project of electric drive and charging infrastructure to date is The EV Project. Conducted by the U.S. Department of Energy's Idaho National Laboratory (INL), the project gathered data from 2011 through 2013 covering 125 million miles of driving and 4 million charging events in 20 metropolitan areas across Arizona; California; Washington, D.C.; Georgia; Illinois; Oregon; Pennsylvania; Tennessee; Texas; and Washington State. Participants included Electric Transportation Engineering Corporation (ETEC), Nissan, General Motors, and more than 10,000 other city, regional, and state governments; electric utilities; other organizations; and members of the general public. Charging behavior was tested on over 12,000 AC Level 2 charging units and over 100 dual-port DC fast chargers. Vehicles enrolled in the test, with somewhat diverse technical characteristics, included roughly 8,300 Nissan Leafs, Chevrolet Volts, and Smart ForTwo Electric Drive vehicles.

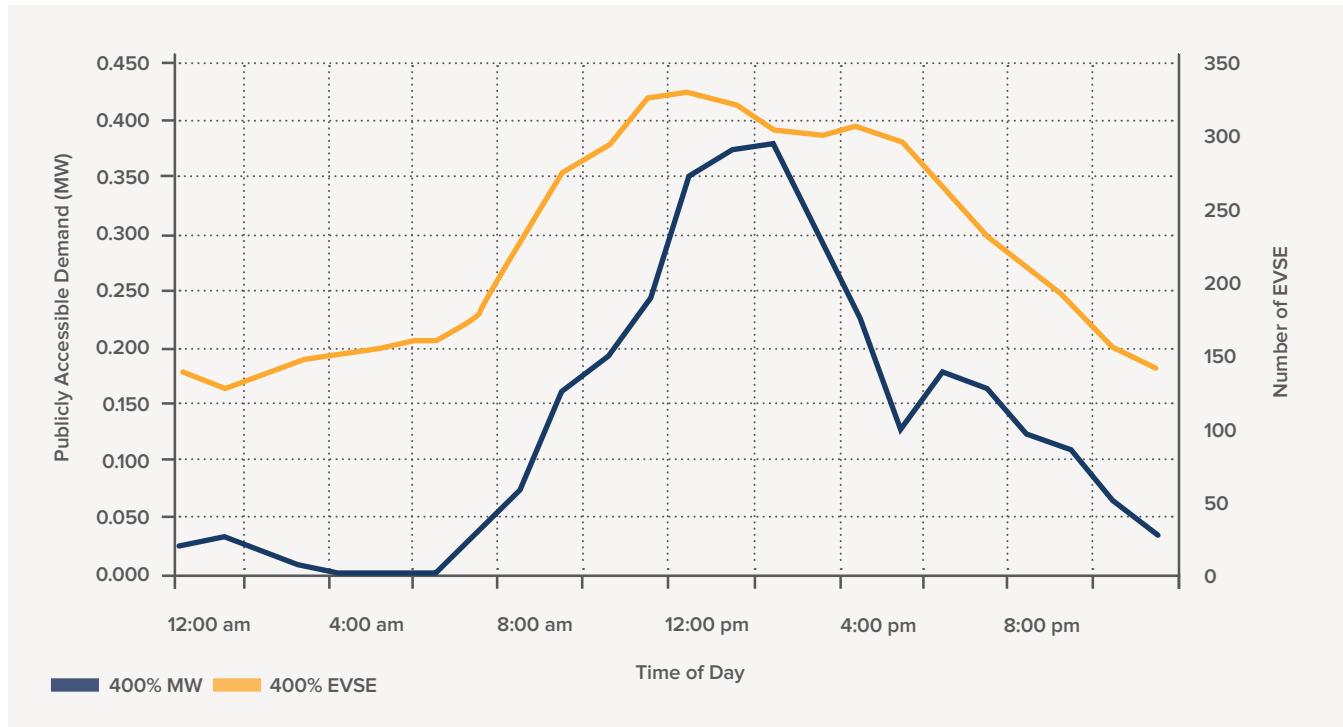
Commercial charging

Data gathered by The EV Project from 334 publicly accessible EV charging stations in the San Diego region in the third quarter of 2013 demonstrated that, if vehicles and charging stations were scaled up by a factor of four in order to exceed 100 kW of demand (the minimum aggregated demand to participate in demand response markets), and appropriate rate incentives and charge control systems were implemented, SDG&E could flexibly manage the load to provide valuable transition generation assistance and frequency- and voltage-control services, making the charging load mutually beneficial to the electric utility and to EV drivers.

^x In CAISO's summer 2015 resource adequacy planning convention, the ISO had a 63,822 MW total net supply.



FIGURE 24: EV CHARGING LOAD, SCALED UP BY A FACTOR OF 4, IN THE SAN DIEGO REGION, PLUS EVSE (CHARGING STATION) AVAILABILITY



Source: Idaho National Laboratory, The EV Project¹⁰⁹

However, until the publicly accessible charging stations are scaled to meet the 100 kW threshold, the study found that “direct utility control of nonresidential EVSE [charging systems] is not beneficial, whereas indirect control through rate incentives may be beneficial.”¹¹⁰

Residential charging

For residential charging, an experimental rate study performed by The EV Project and SDG&E found that rate design can substantially influence charging behavior.¹¹¹

Participants were required to own or lease a Nissan Leaf, install a second meter to separately monitor EV charging, and were randomly assigned to one of three experimental TOU rates.¹¹² All of the rates offered the lowest prices during the “super off-peak” hours of midnight to 5 am,^{xi} and were designed to test how much of a price difference would be needed to persuade participants to charge during those super off-peak times. The rates used three different ratios between the on-peak and super off-peak rates: approximately 2:1 for the EPEV-L schedule, 4:1 for the EPEV-M schedule, and 6:1 for the EPEV-H schedule. The EV Project installed a “Blink EVSE” charging system in the homes of participants with an intuitive touch-screen interface for scheduling charging.

^{xi}The periods were defined as follows. On-peak: noon to 8 pm. Off-peak: 8 pm to midnight and 5 am to noon. Super off-peak: midnight to 5 am. The periods did not vary by day of week and did not make exceptions for holidays or seasons.

The study showed that well-formed rate design works. The more money drivers could save by switching from undesirable to desirable charging times, the more drivers took advantage of it. The key findings from the study were:

- 1.** EV drivers typically connected their EVs to the chargers when returning home, but delayed charging until the cheapest, super off-peak period.
- 2.** Participants under the EPEV-H rate schedule (with the 6:1 ratio) generally charged their vehicles during the super off-peak hours throughout the study, while participants on the other two schedules gradually shifted toward the super off-peak hours, particularly during a learning phase in the first four months of the study. Therefore, it is clearly important to influence customers' charging behavior in the first few months of their EV ownership.
- 3.** The larger the price differential, the more shifting occurred. Compared with the EPEV-L rate, the EPEV-M rate increased the share of weekday charging during the super off-peak hours by four percentage points and reduced the share of peak period charging by two percentage points, and the EPEV-H rate increased the super off-peak charging share by about six percentage points and reduced the peak charging share by three percentage points.
- 4.** Study participants were more responsive to changes in peak and off-peak prices than to a change in the super off-peak price. Simulations suggest that a price ratio of 6:1 between peak and super off-peak periods is enough to shift 90% of charging to the super off-peak period, and that further price differentials would have minimal impact on charging behavior.

A follow-up report by Nexant on the SDG&E pilot confirmed these findings, and additionally observed that EV charging loads were very similar between customers with solar PV and those without. However, it found that PV customers were much less price sensitive in all rate periods, and appeared not to be influenced by the price in the off-peak period. This finding suggests that it may be more difficult to influence PV customers to shift their EV charging to off-peak hours.

However, the study notes, implementing such a system may require:

- Attractive rate structures
- Technology to set charge start times either at the residential charger or the PEV
- Technology to communicate billing information from the residential charger or the PEV to the utility
- A second electric utility meter (required by many utilities for their special PEV charging rates), the cost of which may be prohibitive to certain drivers

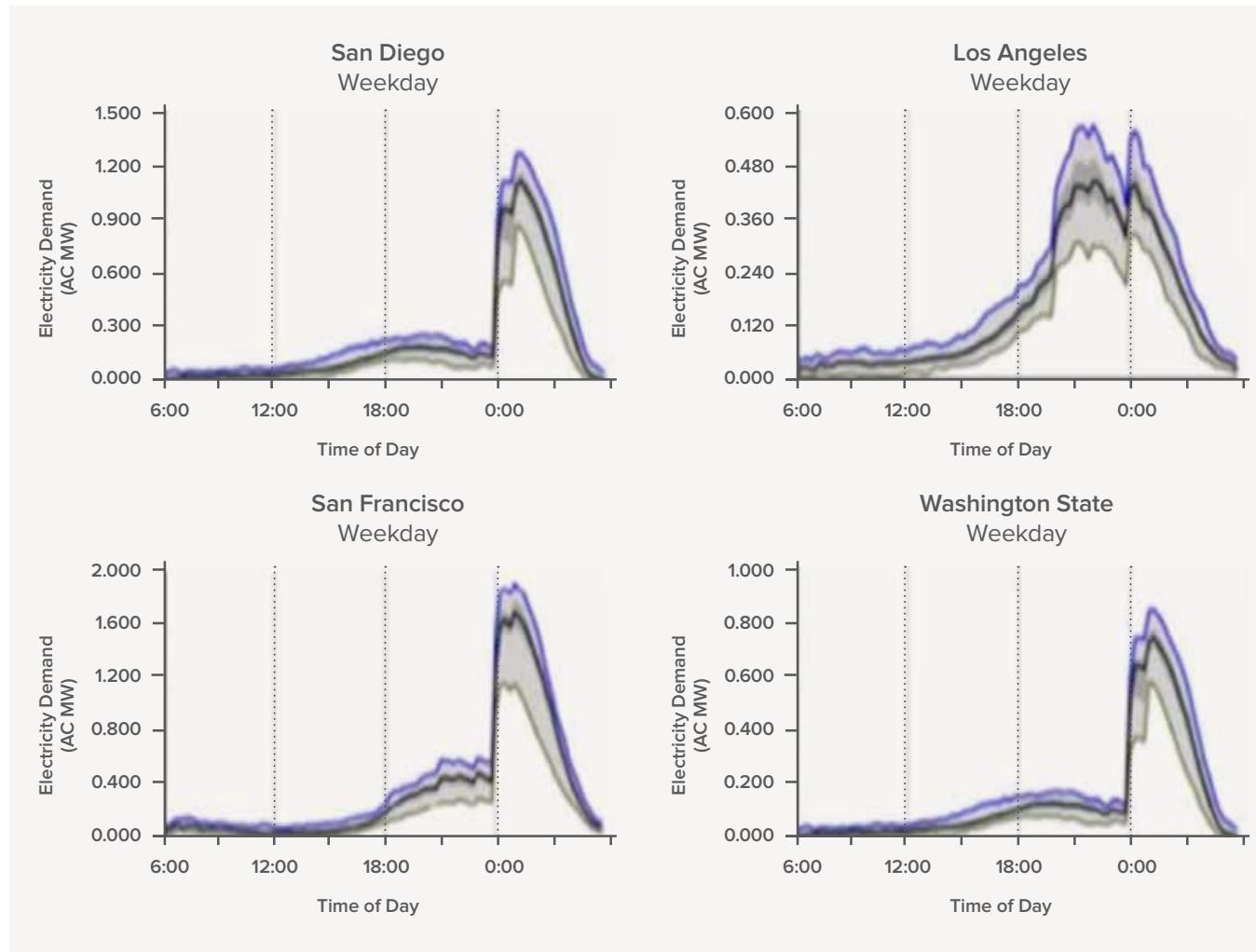
The EV Project demonstrated that where TOU rates were available, most EV charging occurred during the favorable, off-peak hours. Where TOU rates were not available, demand generally peaked when drivers came home from work, in the early evening.

In San Diego and San Francisco, where TOU rates offered low off-peak prices after midnight, drivers took advantage of them. In Los Angeles and Washington State, where such favorable off-peak pricing did not exist, drivers simply plugged in their vehicles when they got home from work, as shown in Figure 25.



FIGURE 25: EV PROJECT ELECTRIC VEHICLE CHARGING PATTERNS WITH AND WITHOUT TIME-OF-USE RATES

- Residential Level 2 Weekday EVSE 1st Quarter 2013
- TOU kWh rates in San Diego and San Francisco clearly impact when vehicle charging start times are set



Source: *The EV Project, 2013*

SAN DIEGO GAS & ELECTRIC

SDG&E is one of the U.S. utilities at the forefront of EV integration. The utility has run several pilot projects with EVs, including one that tested and developed new rates for charging EVs that was tested internally with EV-driving employees; one that aggregated demand from fleet vehicles in order to bid it as demand response into the CAISO; one that tested different rates for charging EVs with external customers; and a new program that will deploy EV charging infrastructure throughout its territory.

Fleet vehicle pilot

In this proof-of-concept pilot, two locations with stationary energy storage and three locations with small fleets of EVs (including delivery trucks), all connected to SDG&E's distribution grid, were aggregated together as a demand response resource from September 2014 to December 2015. SDG&E partnered with Shell International, which developed an optimization and control engine it could use to control charging remotely. The engine evaluated information about the state of charge of the storage systems and vehicles, future charging needs, grid conditions, and market prices, and then bid the storage systems and vehicles into the CAISO energy and ancillary service markets for the next day. In exchange for agreeing to curtail charging during certain hours, the aggregated resources were paid the locational marginal energy price in those hours, much as a conventional generator would be.¹¹⁴

VGI pilot for EV charger deployment

In April 2014, SDG&E proposed a vehicle grid integration (VGI) program that would be the most ambitious and progressive EV integration program in the nation to date to deploy charging stations. Far more stations are needed to meet the objectives that Governor Brown and the California Legislature have set, including deploying EV infrastructure able to support up to 1 million EVs in the state by 2020. San Diego has about 10% of California's automobiles, so meeting a proportional 10% of the state's 2020 target, or 100,000 vehicles, would require a rapid increase in charging infrastructure in SDG&E territory. There are currently only 20,000 EVs in the San Diego region.

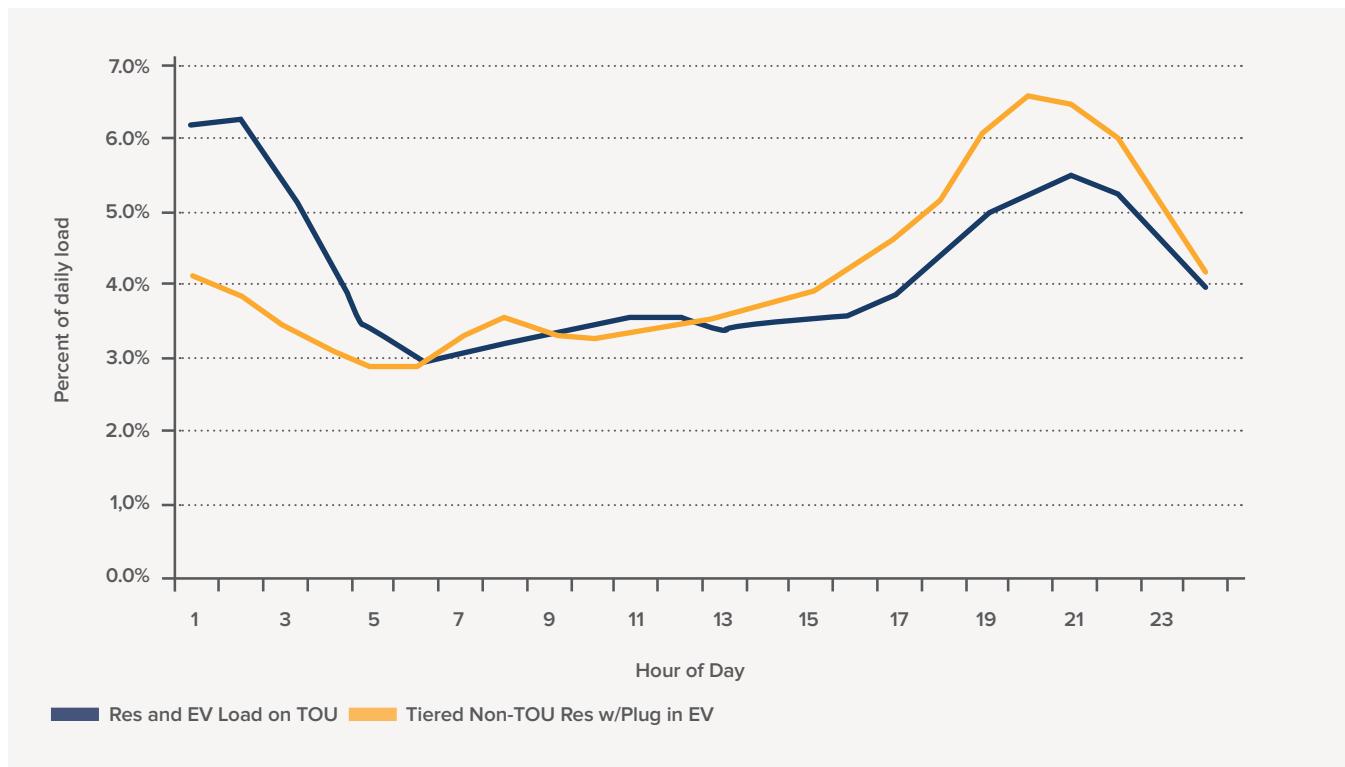
Nearly two years later, in January 2016, a scaled-down modification of the original proposal was approved by the CPUC. Under this 2016 VGI Pilot Program, SDG&E would be allowed to spend up to \$45 million to own and operate 3,500 Level 1 or Level 2 charging stations at 350 sites over the course of three years. At least 150 of the sites must be at multiunit dwellings, where half of SDG&E's customers live, and at least 35 of the charging sites will be located in disadvantaged communities.

"With rates encouraging off-peak charging," SDG&E's announcement said, "vehicles will be efficiently integrated onto the grid, helping to avoid on-peak charging that drives the need to build more power plants and other electric infrastructure." The company's press release explains that the program will help maximize the use of renewable energy and minimize the need for new fossil-fuel power plants.¹¹⁵ The new tariff may also offer discounted prices for EV charging when renewable energy is plentiful, although SDG&E is still working out those details.¹¹⁶

The CPUC estimates that the program would result in an increased cost to a typical SDG&E residential ratepayer of about 18 cents (about 0.02%) over the first year, and about \$2.75 a year if and when the full rollout is completed.¹¹⁷

The new EV tariff will feature hourly dynamic prices reflecting grid conditions. The prices will be published a day ahead and posted on a publicly available website, which will also include a database of the most recent hourly prices that reflect both system and circuit conditions, and include a circuit-level map of current hourly prices on all participating circuits. Customers will be able to use the website or a smartphone app to enter their preferences for charging durations and times, including the maximum price they're willing to pay. Then the app will match those preferences with the price information in order to provide the customer low-cost electric fuel based on their preferences and the hourly day-ahead prices. SDG&E developed the VGI pilot program based on a similar project in which its employees charged their EVs under dynamic pricing. The project showed that employees were able to keep 99.7% of their charging outside the highest-priced hours.



FIGURE 26: SDG&E RESIDENTIAL LOAD SHAPE FOR HOMES WITH EVS—TOU vs. NON-TOU TIERED RATES

Source: SDG&E

SDG&E EV RATES EXPERIENCE TO DATE

SDG&E is one of the few U.S. utilities with real-world experience in tracking and influencing customer EV charging behavior through rate design. Here is a brief overview of some of the findings from these experiments.

TOU vs. non-TOU rates for the whole house and EV

Recent SDG&E data shows that TOU rates are effective at incentivizing customers to shift their EV charging loads to off-peak periods. Most of the EVs come equipped with timers that enable customers to take advantage of the price incentives. The following chart shows the load shapes for a significant sample of customers for one year (September 2014 through August 2015) under two tariffs that pertain to the load of the entire house, including any EVs.

The “Res and EV load on TOU” load shape is for residential customers who have at least one EV and who are on a TOU rate (EVTOU-2). This tariff has a modest differential in the winter and a large (2.8x) differential in the summer between on-peak rates and the midnight to 5 am “super off-peak” rates. The “Tiered Non-TOU Res w/ Plug in EV” load shape is for residential customers who have at least one EV and who are on the standard DR or DR-LI residential rates. They have a similar load shape to the “Res and EV load on TOU” customers, but with less shifting to the super off-peak hours, and more of a ramp in the late afternoon, because there is no time-of-use advantage to shifting their loads to off-peak periods.

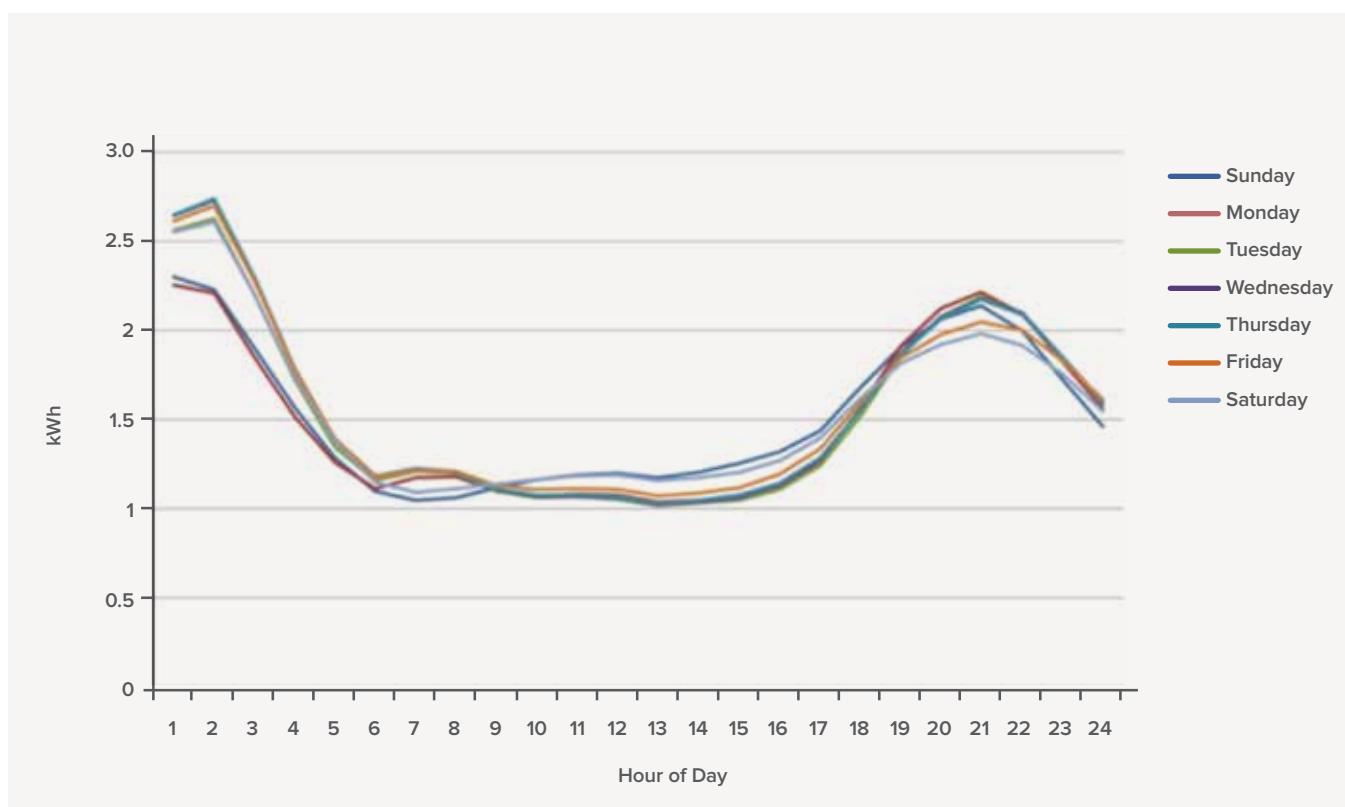


TABLE 4: SDG&E TOU RATE SCHEDULES FOR EVs SHOWN IN CHART

TARIFF		TIME OF DAY	CENTS/kWh			
			WINTER WEEKDAY	WINTER WEEKEND	SUMMER WEEKDAY	SUMMER WEEKEND
Schedule EVTOU	Super Off Peak On Peak Off Peak	Midnight to 5 am Noon to 8 pm All Other Hours	19.3 22.8 21.6	19.3 22.8 21.6	18 50.6 23	18 50.6 23
Schedule EVTOU-2	Super Off Peak On Peak Off Peak	Midnight to 5 am Noon to 6 pm All Other Hours	19.3 22.4 22	19.3 22.4 22	18 50.7 23.3	18 50.7 23.3

Whole house vs. separately metered EV on TOU rates

The load shapes shown in Figure 26 still show a fairly significant afternoon ramp, because they show the load profile for the entire house plus any EVs. The large spike in the super off-peak hours owes to EV charging under a TOU rate. Figure 27 shows these loads on each day of the week.

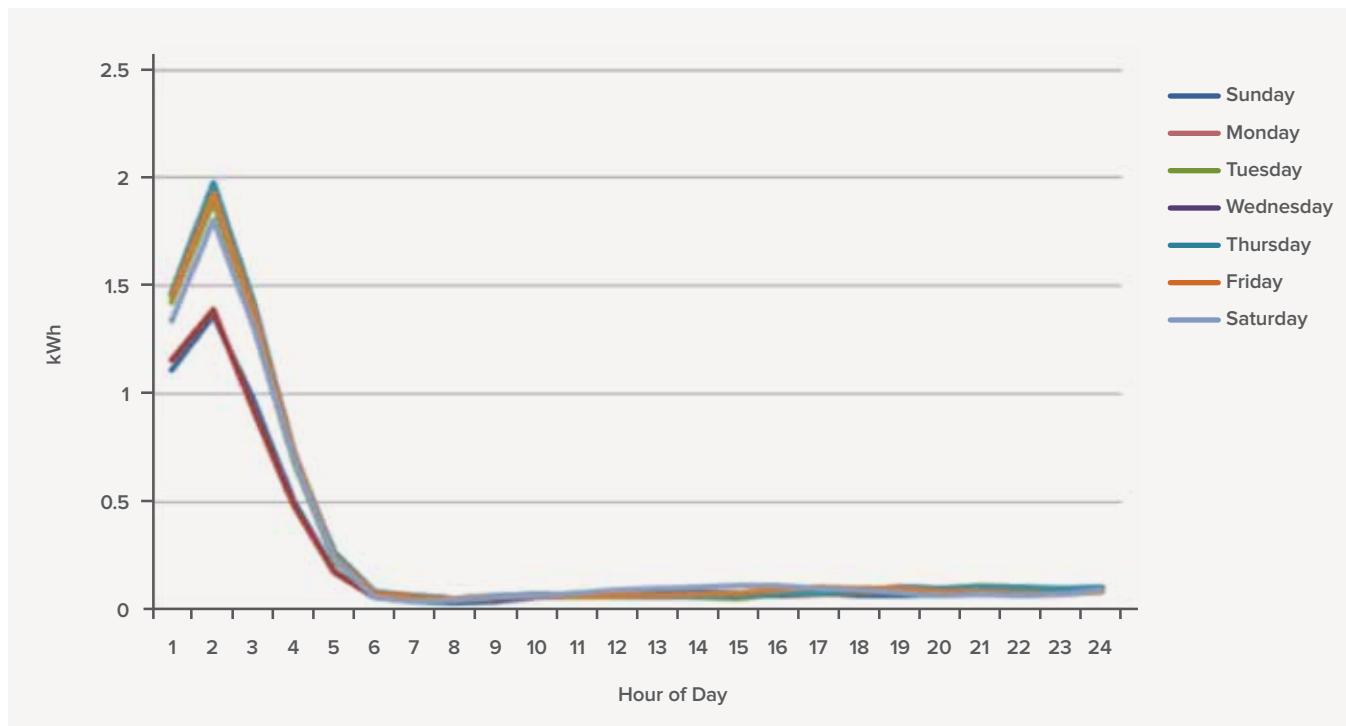
FIGURE 27: SDG&E AVERAGE LOAD PROFILE FOR SINGLE-METER CUSTOMERS BY DAY OF THE WEEK ¹¹⁹

Source: SDG&E



The charging load of vehicles through a separate meter apart from the rest of the house's loads, however, has a very different load profile from those who are on a single meter for the entire house and vehicles with a TOU rate, as shown in Figure 28. It's clear that well-designed TOU rates are very effective at influencing customers to recharge during the super off-peak periods.

FIGURE 28: SDG&E AVERAGE LOAD PROFILE FOR SEPARATE-METER (EV ONLY) CUSTOMERS BY DAY OF THE WEEK



Source: SDG&E

SOUTHERN CALIFORNIA EDISON

The CPUC has approved a two-phase plan by Southern California Edison (SCE) to install charging stations in its territory. The first phase will permit the utility to spend up to \$22 million to install up to 1,500 Level 2 charging stations at workplaces, schools, and multiunit dwellings. SCE will locate, design, and build the infrastructure, but

customers will own, operate, and maintain the stations. If the CPUC judges the first phase to be a success, then the utility would be allowed to deploy an additional 30,000 charging stations in a \$333 million Phase 2 that would run through 2020. SCE estimates the total cost of both phases would cause a rate increase of \$0.001/kWh, or 0.1% to 0.3% of the average bill.¹²⁰

RECOMMENDATIONS

09

RECOMMENDATIONS

MAXIMIZING THE BENEFITS of using EV charging as a distributed energy resource will require the active support of a wide and unusually diverse range of stakeholders: regulators, transmission system operators, distribution system operators, utilities, customers, aggregators, vehicle manufacturers, commercial building owners, elected officials, and others. And realizing those benefits will be a complex task, because doing so may require policies and mechanisms that cut across conventional boundaries, such as the ones between wholesale and retail markets, or between customers and generators. This underscores the importance of including vehicle electrification in integrated resource plans.

It is essential to have policies, programs, and appropriate tariffs in place to support EVs and shape their charging before EV adoption ramps up to significant levels, because all of those things take time, and because utilities' experience indicates that customer charging behavior can be effectively influenced during the first few months after a customer acquires their first EV, but that it becomes much more difficult after that. All stakeholders would be wise to anticipate their respective challenges before they arrive, and take a long-term view toward their respective opportunities.

All participants in the EV ecosystem will have important roles to play. For example:

- **Regulators, utilities, and distribution system operators** need to offer well-formed TOU rates or other dynamic pricing to shift charging toward low-cost, off-peak hours; educate customers and vehicle dealers about the value proposition under these new rates; capture the potential value of EVs through controlled charging; anticipate and prevent overload conditions where clusters of EVs exist on the distribution grid; engage with aggregators to create effective partnerships; integrate EVs into distribution system planning; and bring insights back to policymakers and grid operators about customer behavior and how EV loads are influencing the grid.

- **Regulators** need to create incentives, tariffs, and market opportunities that will accelerate the deployment of EVs and charging infrastructure, pave the way for EVs to bid into wholesale markets as demand response, maximize the charging flexibility of EVs to balance renewable generation, increase the utilization of existing capacity, and limit the need for distribution upgrades. Regulatory uncertainty—about utility ownership of charging infrastructure, rules for cost recovery, and treatment of EV charging as DER—is often cited as a barrier to EV deployment.

- **Transmission system operators** need to accommodate aggregations of EVs as demand-response assets and reflect EV effects in system planning.

- **Utilities, regulators, and policymakers** need to support aggregators, remove barriers to their formation and growth, and enhance their value opportunity for deploying charging stations, especially Level 3 public chargers. Coordinated effort will be needed to ensure that daytime workplace and public chargers are available where solar production is high and/or at risk of curtailment.

- **Utilities, regulators, and aggregators** need to work together to ensure that there is widespread access to charging stations, particularly at workplaces and public locations, to relieve range anxiety.

- **Utilities and distribution system operators** need to develop better awareness of where and how EV charging will affect their systems, and strategically deploy AMI, telemetry systems, new tariff structures, and possibly control systems. They also need to help customers understand their rate options and how to use their EVs to save money.

- **Utilities, dealers, manufacturers, aggregators, and policymakers** need to educate customers about the lower cost of owning EVs, their options for installing charging equipment, when it's cheapest to charge their vehicles, and how to operate various charging control systems.



- **Aggregators** need to work with manufacturers of charging equipment and vehicles to further develop charging control and communications systems; coordinate with utilities to site charging depots for maximum benefit and lowest cost; and engage with regulators, utilities, and customers to convey the value proposition of aggregation.
- **Vehicle manufacturers and dealers** need to work with utilities to expand the EV market, encourage well-formed TOU rates, and develop charging-control system architectures to flexibly supply what the grid needs, possibly including implementing open-source hardware and software interfaces.
- **Building owners** need to work with utilities, aggregators, and customers to identify high-value sites for charging stations and enable their installation and maximum access for customers.
- **Elected officials** need to understand the importance of implementing the vision of EVs as a DER and help enable it by setting targets for growth, supporting regulatory and utility efforts, cutting red tape in building and planning departments, doing outreach and promotion, and looking for ways to cut the cost of charging-system installation.
- **Regulators and policymakers** need to be involved in these processes so that programs and policies are approved expeditiously.

Drawing upon the literature and pilot projects reviewed in this paper, we make the following recommendations.

INCREASE EV DEPLOYMENT

TABLE 5: RECOMMENDATIONS TO INCREASE EV DEPLOYMENT

OBJECTIVE	BEST PRACTICE	KEY ACTORS
Encourage EV sales	Establish incentives: rebates, HOV-lane access, preferential parking, etc.	Legislatures State and municipal officials
Increase public awareness	Publicize economics of EV ownership, advantages for EV owners (rate schedules, other incentives)	State and municipal officials Utilities Car dealerships
Build charging infrastructure	Forecast EV demand, identify needed locations for charging stations, clear path for deployment, develop incentives	Third-party charging companies State and municipal officials Utilities Regulators
Enable mobility as a service	Identify ideal locations and build charging depots for fleet vehicles	State and municipal officials Utilities Third-party charging companies Regulators

BUILD APPROPRIATE CHARGING INFRASTRUCTURE

TABLE 6: RECOMMENDATIONS TO BUILD APPROPRIATE CHARGING INFRASTRUCTURE

OBJECTIVE	BEST PRACTICE	KEY ACTORS
Build charging infrastructure faster	<p>Provide incentives for charging station construction (subject to technical and deployment standards), particularly for third-party charging companies</p> <p>Allow utilities to rate-base construction of charging infrastructure (and potentially own and operate it too)</p> <p>Streamline distribution-interconnection procedures to facilitate third-party development, ownership, and operation of charging infrastructure</p>	<p>Third-party charging companies</p> <p>Utilities</p> <p>Regulators</p>
Build charging infrastructure in the right places	<p>Identify when demand is low, and where vehicles are at those times</p> <p>Identify when renewable energy supply is likely to be curtailed/spilled now and in the future, and where vehicles are at those times (e.g., via integrated resource plans)</p>	<p>Utilities/ISOs</p> <p>Private charging companies</p>
Build charging infrastructure in the right places	<p>Make rules designating appropriate charging station types and locations based on demand and vehicle surveys</p> <p>Remove interconnection barriers to charging stations deployment by private charging companies</p> <p>Provide sliding-scale incentives for charging stations: The more a charger is used, the more its owner makes</p>	<p>Regulators</p> <p>Utilities</p> <p>Private charging companies</p>
Reduce costs of charging infrastructure	<p>Allow utilities to rate-base construction of charging infrastructure, if paired with performance-based incentive for utilities to reduce costs of charging stations</p> <p>Offer more attractive value propositions for private charging companies</p>	Regulators
Reduce costs and accelerate deployment of charging infrastructure	<p>Streamline permitting for infrastructure deployment and remove obstacles</p> <p>Integrate charging infrastructure with a wide variety of general public infrastructure planning to help meet climate change and other social goals</p>	<p>Regulators</p> <p>State legislatures</p> <p>State, county, and city officials</p> <p>Utilities</p> <p>Developers</p>
Build enabling infrastructure	Deploy AMI smart meters, and (where appropriate) separate meters for EV chargers	<p>Utilities</p> <p>Regulators</p>
Use EV chargers as DER for demand response	<p>Implement incentives for utilities to use EV chargers as DER instead of building new generation and distribution capacity</p> <p>Offer incentives for charging aggregators</p> <p>Give charging infrastructure access (via aggregators or other agents) to wholesale markets such as PJM and California's Demand Response Auction Mechanism (DRAM); expand service options for demand response to allow bidirectional dispatch and service regulation</p>	<p>Regulators</p> <p>Wholesale system operators</p>



OPTIMIZE CHARGING BEHAVIOR

TABLE 7: RECOMMENDATIONS TO OPTIMIZE CHARGING BEHAVIOR

OBJECTIVE	BEST PRACTICE	KEY ACTORS
Encourage charging at the best time for the grid (Beginning)	Design TOU rates for EV owners with large differentials between on- and off-peak rates	Utilities Regulators
Encourage charging at the best time for the grid (Advanced)	Identify at-risk feeders where EV charging demand might be high and overload equipment	Utilities Peer-to-peer networks Aggregators
Encourage charging at the best time for the grid (Advanced)	Design real-time variable rates for EV owners Watch SDG&E's 2016 VGI Pilot Program for lessons learned Revise rate design iteratively in response to actual results	Utilities Regulators Peer-to-peer networks Aggregators
Communicate real-time rate and EV charging-state information between utilities and EVs/EV owners	Build two-way, real-time telemetry (communications) systems	Auto manufacturers Utilities Software integrators
Encourage demand response	Test various demand-response incentives: payment for nonconsumption, EV demand response aggregator support, utility-driven charging control	Aggregators Utilities Regulators Independent system operators





GLOSSARY, APPENDIX, AND ENDNOTES

10

GLOSSARY

AEV: all-electric vehicles
 BEV: battery electric vehicles
 CPUC: California Public Utilities Commission
 DCFC: DC fast charging
 EVSE: electric vehicle supply equipment (charging equipment)
 GHG: greenhouse gas
 PEV: plug-in electric vehicles
 PHEV: plug-in hybrid electric vehicles
 VGI: vehicle grid integration
 V2G: vehicle-to-grid
 SEALS: shared electrified autonomous lightweight service vehicles

APPENDIX EV RANGE AND CAPACITY¹²²

TABLE 8: EV VEHICLE TYPES AND TYPICAL RANGES

VEHICLE TYPE	TYPICAL ELECTRIC RANGE
PHEV	10–35 miles
AEV	75–250 miles

Typical EV efficiency: 0.3–0.4 kWh/mile.

Example: At 0.34 kWh/mile, 5,000 AEVs each driving 10,650 miles per year would require an additional 18,105 MWh delivered annually. At a typical annual residential electricity usage of 11,280 kWh, this additional demand would amount to the equivalent of 1,605 of new homes being added to a service territory. In the case of a PHEV, 70% of annual vehicle miles traveled (VMT) being powered by electricity would result in an additional 12,670 MWh of electricity usage.

Several companies also offer wireless induction chargers for EVs, but they are generally in the prototype and demonstration stages at this point.¹²³

TABLE 9: TYPES OF CHARGERS

TYPE	VOLTAGE (V)	MAX CAPACITY (KW)	TIME TO CHARGE AN EV WITH A 60–80 MILE RANGE	MILES RANGE ADDED PER HOUR
Level 1	120	2	14–22 hours to full charge	2–5
Level 2	240	4	4–7 hours to full charge	10–20
Level 3 ^{xii}	480	20–90	30 minutes to 80% charge at 20 kW	60–80 at 20 kW

^{xii} Level 3 chargers include DC Fast Chargers (DCFC); CHAdeMO chargers, which have been popular in Asia and are increasingly being used in California and elsewhere; SAE Combined Charging Solution (a.k.a. SAE Combo or CCS); and the Tesla Supercharger format.



UTILITY-OWNED CHARGING STATION PROGRAMS

Table 10 gives a sense of the variety of utility-owned charging station programs.

TABLE 10: MAJOR UTILITY-OWNED CHARGING STATION PROGRAMS

STATE	UTILITY	CHARGING STATIONS	ALLOCATION	COST PER CHARGING STATION ^{xiii}	RATE OPTIONS
California	SDG&E ^{124, 125, 126, 127, 128}	3,500 stations (unspecified blend of Level 1 and Level 2)	350 sites, including 150 at multiunit dwellings and 35 in disadvantaged communities	\$12,857 (average cost per station for entire program across all types and locations)	"Site hosts will have the choice of two billing options: (1) the VGI rate offered directly to the EV driver (VGI Rate-to-Driver); or (2) the VGI rate offered to the site host (VGI Rate-to-Host)"
California	SCE	Level 2: 1,500	Installed in locations where people park their cars for extended periods of time: workplaces, campuses, recreational areas, and apartments and condos; at least 10% will be installed in disadvantaged communities	\$14,667 ^{xiv} (average cost of rebates across all charging station locations, types)	SCE provides a "make ready" location where a third-party charging company installs, owns, and operates chargers under a TOU rate with the utility, which could be different from the rate charged to the customer
California	PG&E Proposed program options only; not yet approved	Level 2 Option 1: 25,000 Option 2: 2,500 Option 3: 7,500	Option 1: \$26,000 Option 2: \$35,000 Option 3: \$29,000 (total program costs, including nondevice costs, divided by the number of chargers)	60–80 at 20 kW	Unknown
Georgia	Georgia Power ¹³¹	11 "charging islands" with a Level 3 and a Level 2 charger	Publicly available office parks	Unknown	At charging islands Level 3: \$4.95 activation fee (first 20 min.) Then 25 cents per each minute Level 2: \$1.00 per hour fee (first 3 hours) Then 10 cents per each minute
Washington	Avista ^{132, 133,}	Level 2: 265 Level 3:	Home: 120 Workplace: 100 Public: 52	Home: \$1,375 Workplace: \$3,500 Public: \$8,000 Level 3: \$125,000 (Total cost per EVSE port connection)	Selected utility EV charging-station programs

^{xiii} Cost figures are not strictly comparable, as they represent different types of program costs for the various utilities cited. Charger costs and types, program design assumptions, back-end systems, eligible customers, and more vary across the utilities and do not necessarily determine the cost of equipment.

^{xiv} SCE will "also offer rebates of between 25 and 100% of the base cost of the charging stations and their installation, depending on location and market segment."



ENDNOTES

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1820 Folsom Street, Boulder, CO 80302 USA

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