Chief Clerk  
Illinois Commerce Commission  
537 East Capitol Ave  
Springfield, IL 62701  

Re: Comments of the Union of Concerned Scientists on the Illinois Commerce Commission  
Notice of Inquiry Regarding Electric Vehicles (18-NOI-01)  

To the Chief Clerk of the Illinois Commerce Commission:  

The Union of Concerned Scientists thanks you for the opportunity to comment on the  
Commission’s Notice of Inquiry Regarding Electric Vehicles. Please find our responses to select  
Inquiry questions attached to this message.  

We have appended several of our reports that are referenced in our remarks: *Principles for  
Utility Investment in Electric Vehicles* (Appendix A), *Charging Smart* (Appendix B), and *Going  
from Pump to Plug* (Appendix C).  

In addition, we have appended two entries from the Union of Concerned Scientists blog: “New  
Data Show Electric Vehicles Continue to Get Cleaner” (Appendix D) and “Electric vs. Diesel vs.  
Natural Gas: Which Bus is Best for the Climate?” (Appendix E).  

Our comments and the appendices have been submitted via email to ICC.EVNOI@Illinois.gov,  
and hard copies have been sent by overnight mail. Please contact me at 202-331-5459 or  
shouston@ucsusa.org with any questions.  

Sincerely,  

// Samantha Houston  
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Comments of the Union of Concerned Scientists

Introduction

The Union of Concerned Scientists (“UCS”) is pleased to have the opportunity to comment on the Commission’s Inquiry into electric vehicle charging infrastructure (18-NOI-01). As the Commission describes in the Notice of Inquiry, electric vehicles (“EVs”) are expected to constitute an increasing fraction of the vehicle fleet. The impacts of increasing load of EV charging may be beneficial or detrimental to the electric grid, ratepayers, and society depending on whether the EV charging load is well managed and whether transmission and distribution systems are upgraded as needed.

Utilities have an important role to play in the development of EV charging infrastructure. Under the “business-as-usual” model of utility investment, utilities traditionally invest in many components of EV charging infrastructure from transformers to service connections and up to the customer meter. Beyond the traditional model of investment, utilities are well positioned to contribute to investment in EV charging infrastructure for a number of reasons. First, utilities have the core competencies required for such investments. They are skilled in designing and deploying physical electricity infrastructure. In addition, utilities have expertise designing rates, demand response programs, and other charging management strategies that are critical to realizing the benefits of transportation electrification. Second, utilities have the scale and access to debt and capital to undertake programs that will contribute substantially to infrastructure needed to support and promote electric transportation. Third, utilities have the relationships with customers they can leverage to promote their programs.

In this comment, we address a subset of the Commission’s questions in the Notice of Inquiry. We begin by discussing the potential benefits of transportation electrification, including grid reliability, financial net benefits, environmental and public health benefits, and energy efficiency. Next, we turn to questions regarding barriers to transportation electrification, EV charging infrastructure needs, and ratemaking. In addition to the discussion contained in the body of our comments, UCS has included our Principles for Utility Investments in Electric Vehicles in Appendix A. Our Principles speak to many of the questions posed by the Commission as well as additional items we present for the Commission’s consideration.

Benefits of Transportation Electrification

The Commission has identified many challenges in the electricity sector that will benefit from transportation electrification. Proactively developing an EV regulatory framework, as the Commission is embarking upon with this Inquiry, and expeditiously soliciting and evaluating EV program proposals are critical to realizing the benefits of electric vehicles described in this section.

1 As detailed by Phil Jones of the Alliance for Transportation Electrification in his remarks to the Maryland Public Service Commission, September 7, 2018.
Grid Reliability and Other Grid Services

Transportation electrification may enhance grid reliability and provide other grid services. Even without vehicle-to-grid integration, the flexibility of EV charging load can be managed in a way that smooths power generation ramping, reduces extreme peaks in load, and better incorporates renewable energy generation on the grid. These benefits can be achieved through a combination of price signals (like time of use rates), demand response programs, and other managed charging arrangements that encourage EVs are charged primarily at off-peak times. With vehicle-to-grid integration, EVs can serve as a distributed energy resource. The UCS report, Charging Smart (Appendix B), further details how smart charging schemes benefit the grid at the local and ISO level, particularly with regard to the incorporation of renewable energy generation.

Of course, while the EV charging load may offer the grid services discussed above, EV charging load may also reduce grid reliability if sensible accommodations are not made. Not making adjustments in advance of substantial electric vehicle adoption could result in the electric system and ratepayers facing increased peak loads, steeper generation ramps, and a stressed distribution system. UCS commends the Commission for taking steps through this NOI to ensure Illinois does not encounter these risks.

Financial Benefits

- Passenger Cars and Light Trucks

The UCS report, Going from Pump to Plug (Appendix C), shows how the fuel savings stacked up in 2015 for the average EV versus the average new gasoline in a selection of U.S. cities. In Chicago, ComEd customers stand to save $912 per year in fuel costs on the standard residential rate over the average new gasoline vehicle, even when considering the relatively low gas prices in 2015. Importantly, electricity prices are more stable than gasoline and diesel prices, so fueling with electricity insulates EV drivers from gasoline and diesel price spikes.

In addition to direct fuel cost savings which encourages EV adoption, a recent study commissioned by Charge Up Midwest and conducted by M.J. Bradley & Associates, Electric Vehicle Cost-Benefit Analysis: Illinois, details expected costs and benefits of electrifying passenger cars and light trucks in the State. The study quantifies the net benefits for utility customers and EV drivers attributable to EV adoption for two EV penetration scenarios: (1) MISO – McKinsey showing 18% EV penetration by 2050 and (2) Bloomberg New Energy Finance (“BNEF”) showing 56% penetration by 2050.

The benefits to utility customers are calculated by subtracting the cost of purchasing and distributing additional electricity for EV charging from the incremental revenue from EV charging. The authors note that ICC rules dictate that “net revenue from additional electricity sales general offset the allowable costs that can be passed on [to consumers] via higher rates.” Because of this fact, additional revenue from EV

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2 Going from Pump to Plug at 6
3 https://www.mjbradley.com/content/mjba-analyzes-state-wide-costs-and-benefits-plug-vehicles-illinois, see link at bottom for full report.
4 MJ Bradley report at 6
5 MJ Bradley report at 10
charging would put downward pressure on future rates, effectively saving ratepayers money over time. For off-peak charging in each EV penetration scenario, the net present value of ratepayer benefits is cumulatively positive at each decadal checkpoint through 2050.6

The annual savings for Illinois EV drivers is calculated by comparing average cost to vehicle owners for gasoline vehicles compared to EVs. Notably, the cost to EV owners includes the cost of the charger. Even so, EV owners realize substantial annual savings over gasoline vehicle owners each year in 2030, 2040, and 2050.7

- Medium- and Heavy-Duty Trucks

Medium- and heavy-duty vehicles including buses, heavy trucks, and off-road, port vehicles are ripe for electrification for a number of reasons, including the lifecycle cost of these trucks. As noted in the UCS report, *Delivering Opportunity*, the business case for medium- and heavy-duty electric vehicles is rapidly improving because the reduced fuel and maintenance costs for these vehicles can offset the incremental upfront cost of the vehicle.8 Because the operation of these trucks is so intensive, the incremental cost of an electric truck may pay back quickly.

Environmental and Public Health Benefits

*Greenhouse Gas Emissions Reduction*

The UCS report, *Cleaner Cars from Cradle to Grave*, details how EVs outperform gasoline cars in terms of global warming emissions on a lifecycle basis.9 The study concludes that from cradle to grave, electric vehicles on average “produce less than half of the global warming emissions of comparable gasoline powered vehicles, even when the higher emissions associated with [EV] manufacturing are taken into account.”10 This is because the incremental manufacturing emissions for EVs are rapidly offset by lower emissions to drive the EV.

To compare emissions from vehicle driving, the study calculates the greenhouse gas-equivalent miles per gallon (MPG-ghg) for EVs in order to compare EVs to gasoline vehicles. The MPG-ghg of the average EV conveys the MPG required of a gasoline vehicle to achieve the same level of greenhouse gas emissions. At the time the report was written, the EPA eGrid subregions covering Illinois had 36 MPG-ghg and 44 MPG-ghg for the SRMW and RFCW subregions, respectively, in 2012. As of 2016, eGrid data show these regions achieved 39 MPG-ghg and 50 MPG-ghg, respectively.11 In both 2012 and 2016, the MPG-ghg of an average EV surpassed that of an equivalent gasoline vehicle.

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6 MJ Bradley report at 9
7 MJ Bradley report at 12
10 *Cleaner Cars from Cradle to Grave* at 1
The aforementioned UCS report, *Delivering Opportunity*, shows vehicle-level greenhouse gas reductions per mile that electric buses can offer compared to diesel and compressed natural gas (“CNG”) buses when the electric bus is charged on California’s current electricity mix and on an aspiration 50% natural gas, 50% renewables grid. Even on today’s California grid, EVs emit 70% less than diesel. Although the mix of generation in Illinois is not quite as clean as the mix in California, UCS analysis indicates that the MPG-ghg in Illinois for buses is indeed substantially higher than diesel.\(^{12}\) These results indicate a great potential for reducing greenhouse gas emissions through heavy-duty vehicle electrification.

Moreover, greenhouse gas performance per mile driven of EVs in the vehicle fleet—whether cars, buses, trucks, or other vehicles—will continue to improve as grid emission factors improve through the incorporation of renewables and other low carbon electricity fuels are incorporated onto the grid. This means that an EV sold today will continue to help Illinois reduce its annual greenhouse gas emissions over time. On the other hand, a gasoline, diesel, or CNG vehicle will be stuck with roughly the same level of greenhouse gas emissions per mile over its lifetime. The continued improvement of EVs in the fleet is significant because vehicles reside, on average, for a long time. Cars spend over 11 years and full-sized buses spend over 8 years in the fleet, on average.\(^{13}\)

In addition to the ratepayer and EV driver benefits discussed in the Financial Benefits section above, the M.J. Bradley report quantifies expected greenhouse gas reductions attributable to EV penetration. By 2050, the report indicates that EV penetration can contribute to reducing greenhouse gas emissions from cars and light trucks by 53% and 64% below 2015 levels for the MISO and BNEF scenarios, respectively. These results underscore the role of utility programs for transportation electrification and support progress towards the 2007 Climate Change Advisory Group’s reduction targets for Illinois calling for reducing greenhouse gas emissions to 1990 levels by 2020 and to 60% below 1990 levels by 2050.\(^{14}\)

**Local Pollution Reduction**

Local air pollution from vehicle tailpipe emissions has serious health impacts. The main tailpipe pollutants of concern are fine particulate matter (“PM\(_{2.5}\)”), nitrogen oxides (“NO\(_x\)”), and ozone, the secondary pollutant formed by reactions between NO\(_x\) and volatile organic compounds. Transportation Electrification can reduce these local air pollutants and their consequential health impacts because electric vehicles have no tailpipe emissions.

The case for reducing local pollution the electrification of heavy-duty vehicles is particularly strong. As we point out in the UCS report, *Delivering Opportunity*, heavy vehicles emit a disproportionate amount of PM\(_{2.5}\) and NO\(_x\). Notably, heavy truck pollution affects some communities more than others. In *Delivering Opportunity*, we found that those most affected by heavy truck pollution in California are low income and communities of color. A similar trend may characterize areas in Illinois. Looking at the Chicago area on the EPA EJSCREEN tool, for example, you can see that low-income, minority communities coincide with areas of increased PM\(_{2.5}\), relative to other areas in the State (Figure 1).\(^{15}\) Thus, electrifying these vehicles

\(^{12}\) See Appendix E or https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate


\(^{14}\) http://www.epa.state.il.us/air/climatechange/documents/iccag-final-report.pdf

\(^{15}\) https://www.epa.gov/ejscreen
is a critically important step toward improving local air quality, particularly for communities that bear a disproportionate health burden of the heavy trucking.

Figure 1: Maps of the Chicago area showing each variable as compared to other areas in Illinois

Low Income Population

Minority Population

Particulate Matter Concentration

Energy Efficiency

Transportation electrification contributes to energy efficiency on an economy-wide basis. The main reason that switching from a fossil fuel vehicle to an EV offers efficiency gains has to do with engine efficiency. EVs use less energy to cover the same distance than comparable gas or diesel vehicles because electric engines are more efficient than internal combustion engine, even when accounting for transmission and distribution losses. This is because the EVs electric engine converts more of the energy it receives into power at the wheels than an internal combustion engine. According to the U.S. Department of Energy, an electric engine converts 54-62% of the electric energy it receives to power at the wheels of the vehicle.\(^{16}\) Conversely, Internal combustion engines convert only 17-21% of the energy stored in gasoline to power at the vehicle’s wheels.\(^{17}\)

Because EVs represent a substantial opportunity for economy-wide energy efficiency, UCS has supported transportation electrification as a complement to typical utility energy efficiency programs. That said, UCS recognizes that EV charging loads will be a new source of electricity demand. The Commission may need to consider and evaluate the additional EV charging on the grid and how it affects energy efficiency targets. In making such an evaluation, transportation electrification can complement energy efficiency programs while the intent and stringency of those programs is preserved.

Barriers to Transportation Electrification

Despite the many potential benefits, there are barriers that remain to increasing electrification of the transportation sector. On such barrier is passenger car and light truck drivers’ anxiety over public charging infrastructure coverage. This concern is especially acute for multi-unit dwelling residents and others without access to charging at home. Another barrier is the incremental up-front cost of EVs and EV chargers, which applies especially to medium- and heavy-duty vehicle drivers and fleet operators. Below, we present on-bill financing as one service utilities could offer to address up-front costs of electrification.

\(^{16}\) https://www.fueleconomy.gov/feg/evtech.shtml#end-notes

\(^{17}\) Ibid.
On-Bill Financing

Utilities have historically implemented on-bill financing for energy efficiency investments, and it could be applied equally effectively to transportation electrification infrastructure as well as to electric vehicles themselves. Through work UCS has undertaken with the Greenlining Institute and Clean Energy Works, we found that on-bill financing presents an effective way to address the incremental costs of electric vehicles, particularly for buses and other heavy-duty fleet vehicles. On-bill financing would complement other funding sources and could provide a long-term, sustainable way to address electric vehicle costs in order to reach a larger audience of vehicle owners and expand benefits to ratepayers.

EV Charging Infrastructure

Timely investment in EV charging infrastructure is critical to ensure that utilities are prepared for EV charging load as it grows. Investment in charging infrastructure is also important to promote additional electrification. Utilities need not undertake the full scale of investment required to support substantial electrification. Other programs, such as Electrify America, have already contributed to the build out of charging infrastructure. In addition, private investment will constitute an increasing share of investment as EV penetration into the fleet increases and improves the business case for public charging.

That said, utilities are uniquely well-positioned to be an early investor in EV charging infrastructure, and utilities are particularly important in investing in charging for customers in multi-unit dwellings and other areas where private incentives to invest are split or weak. In making investments at this critical, early stage, utilities jump-start a virtuous cycle of infrastructure investments that enable electric vehicle adoption that will eventually cultivate a robust and competitive market for electric vehicle charging.

The EV Infrastructure Projection Tool ("EVI-Pro") Lite tool from the U.S. Department of Energy Alternative Fuels Data Center can assist in determining the relative quantities of public (both DC fast charging and Level 2) and workplace charging needs for a state or city based on given total number of electric passenger cars and light trucks, mix of EV types, and fraction of drivers with access to home charging.18 This tool can be used when considering whether current infrastructure is adequate and when projecting future charging needs based on EV penetration forecasts. This tool highlights the fact that a portfolio of charging options, including home, work, and public, is necessary to support EVs.

In terms of technical standards for charging standards, UCS recommends utility infrastructure programs require an open software protocol and interoperability with all major EV platforms.

Ratemaking

Well-designed rates that are implemented in a timely manner are key components of achieving the benefits and avoiding the risks of EV charging loads. Furthermore, requiring utilities to offer time-of-use rates offers significant grid benefits and can be seen as a “no regrets” policy. Rate design should be co-developed as infrastructure proposals move forward. Utilities can avoid the danger of low subscription to time-of-use rates by requiring time-of-use rates as a condition of program participation. These points

18 https://www.afdc.energy.gov/evi-pro-lite
apply to rate design both for passenger cars and light trucks and for medium- and heavy-duty vehicles charging in the residential class or the commercial class.

**Conclusion**

UCS is encouraged by the step the Commission is taking to probe important questions about transportation electrification in Illinois. Utilities, as we have noted, are well-positioned to invest in electrification infrastructure at scale and to offer innovative rate design in an impactful way. We encourage the Commission to work with utilities proactively to implement transportation electrification programs that result in benefits for ratepayers and all Illinoisans.
FACT SHEET
HIGHLIGHTS
For more than a century, our cars and trucks have been fueled almost exclusively by oil. Today, electric vehicles give us the potential to power our vehicles with a diverse set of energy sources, including clean and renewable energy.

Working together, policymakers, regulators, communities, and utilities can help accelerate the transition to electric vehicles. With the right utility investments and policies, utilities will be able to serve new markets; electric vehicle drivers will have convenient charging options wherever they go; utility customers could benefit from lower rates and a more efficient grid; and all residents will benefit from cleaner air, a healthier community, and a more stable climate.

Electric vehicles (EVs) represent both an enormous opportunity and a significant challenge for our utilities. Converting our vehicle fleet to electricity could add as much as 1,000 terawatt-hours of demand onto our electric grid, an increase of about 25 percent of current levels (Fitzgerald and Nelder 2017). If managed correctly, this large and flexible load could significantly increase the efficiency of our electric system, which would benefit not only EV drivers but also all ratepayers, providing lower costs. In the long run, widespread deployment of EVs could also be a source of energy storage, filling a critical need as our electricity system moves away from fossil fuels toward intermittent sources of power, such as wind and solar. Without proper management of EV charging, however, the additional power needed to fuel EVs will require significant new capacity, reducing pollution benefits and imposing additional costs on ratepayers.

Building more EV infrastructure will help more people make the switch to an EV, saving money and reducing emissions. Consumer studies have consistently found that inadequate access to charging infrastructure remains one of the most pressing obstacles to EV adoption. We have had more than a hundred years to build the massive infrastructure necessary to support our gasoline and diesel vehicles, including more than 100,000 gas stations fed by million of miles of pipeline. Creating an EV charging network that can compete with our oil infrastructure will require tens of thousands of new charging stations.

Installing EV charging equipment at office buildings and retail centers can help expand EV ownership by giving more people access to convenient charging options. Workplace charging can also take advantage of high midday solar production.
Here are 10 key principles that should guide utilities as they consider how to invest in EV technology:

**Provide Chargers Where People Live and Work**

Most EV charging happens at home. An EV driver with access to home charging can begin each day with a full tank, and given current battery ranges, that is usually sufficient to serve their daily driving needs. Overnight charging is also ideal for the grid, taking advantage of relatively low electricity use at night. Providing universal access to home charging therefore stands as a top priority for infrastructure investments. Utilities should invest in infrastructure in apartment buildings and consider strategies to reduce the up-front cost of home charging installations, such as rebates and on-bill financing.

Providing charging at workplaces can be a valuable perk for employees and can help encourage EV purchases. An employee with access to workplace charging is six times more likely to purchase an EV than an average worker (DOE 2015). As we add more solar to the grid, workplace charging will also take advantage of high midday solar production.

**Create a Network of High-Speed Chargers along Highways**

Most days, overnight and workplace charging will be sufficient to provide EV drivers with the energy they need for their daily commutes. But consumers also want to be able to take their vehicles for long road trips, or for an emergency charge. A network of fast chargers along highways—capable of recharging an EV in 30 minutes or less—will be a critical component of our infrastructure.

**Maximize Benefits to Ratepayers and the Grid**

EVs can provide significant benefits to ratepayers and improve the efficiency of the electric grid if EV charging occurs during times of low electricity demand or high renewable energy production. Utilities can encourage drivers to charge their vehicles efficiently through time-of-use rates that provide additional savings for charging at night, or other times of low electricity use. Appropriate time-of-use pricing for EVs can deliver savings to ratepayers of more than $1,000 per vehicle, compared with gasoline costs over the life of the vehicle (Fitzgerald and Nelder 2017). In the long run, utilities should work with auto companies to advance vehicle-to-grid integration technologies that would allow EVs to act as a source of storage, improving the reliability and efficiency of the grid.

**Establish Fair Electricity Rates for EV Charging**

Creating a transparent and fair price structure will be important to making EV charging efficient. For example, high fixed or demand charges can make it difficult to create a viable business model for public fast-charging stations (Fitzgerald and Nelder 2017). Charging rates should ensure significant cost savings compared with diesel and gasoline equivalents. Installation of advanced metering infrastructure can help utilities establish a rate designed to promote efficient EV charging.

**Support Electrification of Trucks and Buses**

Heavy-duty vehicles such as trucks and buses are major contributors to global warming pollution as well as to local air pollution, such as nitrogen oxides and particulate matter that cause significant health problems (Chandler, Espino, and O’Dea 2016). Electric buses can reduce fuel costs and alleviate air pollution in congested urban areas. Investments in charging infrastructure and station equipment can help...
make these technologies cost effective for fleet managers and transit agencies.

**Support Electrification of New Mobility Services**

Ride-hailing services such as Uber and Lyft play an increasingly large role in our transportation system. As we look to the future, the rise of automated vehicles could make these “mobility service” companies cheaper and more popular. Transportation network companies (TNCs) currently report that inadequate access to fast-charging infrastructure in areas of high demand is one of the greatest barriers to EV use among their drivers (George and Zafar 2018). In addition, TNC drivers will require fast-charging rates that are cost competitive with gasoline. Utilities should work with TNCs to develop infrastructure proposals that meet the needs of TNC drivers and can speed electrification of this critical market.

**Ensure Low-Income Communities Benefit from Electrification**

Improving access to EVs in low-income communities remains a significant policy challenge that requires creative solutions. Integration of EVs into ride- and car-sharing networks, installation of more charging stations in apartment buildings, and electrification of transit and freight vehicles can help ensure that low-income residents benefit from the transition to electric transportation. Utilities should also work closely with state programs that provide increased rebates to low-income consumers and extend incentives to buy used EVs.

**Create an Open and Competitive Market for EV Charging**

The market for charging infrastructure is developing rapidly, with new technology and new business models being explored by auto companies, charging equipment providers, and utilities. Utility investments in EV infrastructure should support this robust and competitive marketplace. One option is for utilities to focus exclusively on “make-ready” infrastructure, while providing rebates for site hosts and other third parties to purchase and own the actual EV charger. Alternatively, utilities could procure charging equipment through a transparent and competitive process that provides site hosts with a range of charging equipment options. Either way, utilities should work with auto companies and charging equipment providers to ensure that the infrastructure investments we make today will account for continued improvement in EV charging technology.

Utilities should also take steps to ensure that charging stations are consistent and reliable. Charging infrastructure built with ratepayer funds should meet the highest national standards for interoperability, so drivers of all EVs can use all available charging equipment. Whether owned by the utility...
Electric vehicle charging infrastructure needs to be consistent, reliable, and well maintained. Utilities should work with auto companies and charging equipment providers to ensure that charging stations can stay up to date with the latest EV technology. Charging stations should also meet the highest national standards for interoperability, so EV drivers can use the charging equipment regardless of the EV model they own.

or by a third party, charging stations should be well maintained, so drivers can be confident that they will be able to charge their vehicles every time.

Engage Stakeholders in an Open and Transparent Process

Creating a strong market for EVs will require coordination among many stakeholders. Utilities should work closely with the auto industry, community groups, developers, state and local governments, and workplaces to determine how best to deploy EV infrastructure. It will be particularly important for utilities to reach out to low-income residents and communities that suffer disproportionately from vehicle pollution to ensure that the needs of these groups are well represented.

Educate the Public on Benefits of Electrification

Limited consumer awareness continues to be a major obstacle to widespread deployment of EVs. Less than half of consumers can name a single make and model of a plug-in vehicle, and 95 percent of consumers are not aware of consumer incentives for EVs (Jin and Slowik 2017). Utilities can leverage their existing relationships with consumers to help inform drivers of the potential benefits of electrification, including additional programs available to support drivers, charging rates, and incentives.

Daniel Gatti is a policy analyst in the Clean Vehicles Program at UCS.

REFERENCES

All URLs were accessed on [DATE.]


Appendix B

Charging Smart

Drivers and Utilities Can Both Benefit from Well-Integrated Electric Vehicles and Clean Energy

Pete O’Connor
Mike Jacobs

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Pete O'Connor is a Kendall Science Fellow at UCS. Mike Jacobs is a Senior Energy Analyst in the UCS Climate & Energy Program.

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet’s most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

More information about UCS is available on the UCS website: www.ucsusa.org.

This report is available online (in PDF format) at www.ucsusa.org/smartcharging.
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Introduction

Electric vehicles, with an electric motor and a battery, have been around since the earliest days of the automobile. Compared with gasoline-powered vehicles, they offer cleaner and quieter operation, greater energy efficiency, and, with fewer moving parts, potentially lower maintenance costs. Historically, their disadvantages have included limited range on each charge, slow charging, and higher initial costs, although performance has improved significantly on all those fronts in recent years.

Battery electric vehicles, ranging from scooters and small electric bikes to transit buses, are widely seen as a likely technology to enable deep cuts in global warming emissions (see Baumhefner, Hwang, and Bull 2016; Donohoo-Vallett 2016; Dutzik and Miller 2016; Ryan and Lavin 2015; Williams et al. 2015). The vehicles have no direct emissions, and the electricity used to charge the batteries can be clean. Even when the existing electricity grid and its mix of fuels powers their manufacture and charging, EVs are cleaner than typical vehicles with internal combustion engines throughout the United States, and they are cleaner than the best conventional vehicles in much of the nation (Nealer, Anair, and Reichmuth 2015).

If all US cars and light trucks were electric, it would add about 25 percent to the nation’s annual electricity demand of about 4 trillion kilowatt-hours (kWh) per year. Currently, US light-duty vehicles travel about three trillion miles per year, and electric vehicles get roughly 3 miles per kWh. Thus, it would take 1 trillion kWh per year to charge these vehicles (ELA 2017). That calculation assumes constant travel demands, but a transition to autonomous vehicles would likely increase the total vehicle miles. This would result from a lower perceived cost of travel, with time spent in transit devoted to other uses, such as work or entertainment. A recent study estimates an impact ranging from a decrease of 0.1 trillion vehicle miles to an increase of 6 trillion vehicle miles (Stephens et al. 2016).

Of course, we are a long way from a time when all vehicles are electric, but even a modest deployment of EVs can affect the network that transmits electricity from suppliers to consumers—the nation’s power grid—and that impact can be positive. Consider how the electricity system works. Traditionally, the power grid has operated under the assumption that electricity demand simply happens: when consumers turn on an appliance, supply must be ready to power it. The designs of electricity generators featured either greater capital cost but lower fuel cost or lower capital cost and higher fuel costs. This set of conditions required a system with several layers of operation for supplying electricity:

- “Baseload” plants, with high capital cost and low operating cost, run as often as possible.
- Flexible, “load-following” generators ramp up and down to match hourly swings in demand.
- “Peaking” units, cheap to build but expensive to operate, run for relatively few hours per year.

That system can tolerate minor short-term mismatches between supply and demand.

According to Cory Budischak and collaborators, “The operating principle of fossil generation is ‘burn when needed,’ a principle simple enough that it could be followed without computers, digital high-speed communications, or weather forecasting—precisely the conditions when today’s electric system was created, early in the 20th century” (Budischak et al. 2013). Now, though, we have computers, digital high-speed communications, and weather forecasting. We also have flexible loads—including air conditioners, electric water heaters, and electric vehicles chargers—alongside light bulbs, computers, and other equipment that basically need power on demand. The flexible loads can shift when they draw power by a few minutes (or even hours) without reducing the quality of energy services.

At the same time, some new electricity generation technologies cannot be dispatched on command even though they are cleaner than fossil fuels and competitive in cost. Federal tax credits, combined with state renewable energy standards, have been a key driver for recent growth and cost reductions in the US wind and solar industries. Since 2009, total US wind and solar capacity has nearly tripled, adding 86,000 megawatts of new capacity, while the costs of wind and solar projects have fallen by more than...
two-thirds. Wind accounted for about 5.6 percent of US electricity generation in 2016 and solar for about 1.4 percent (EIA 2017). Installed solar capacity is projected to triple over the next five years (SEIA 2017).

Hawaii, California, and other states are dealing with the fact that more clean power is available in the middle of the day, when demand is lower, than in the late afternoon and evening, when demand tends to peak. As a result, these regions need high “ramping capacity.” Power plants, sitting idle when solar power is producing, come online to generate when the sun goes down. To deal with the problem of too much clean electricity, the two most important options are storage and load flexibility for shifting demand.

Battery technology and other technologies for energy storage have improved greatly in recent decades. Storage is not only used to support renewable energy; some regions reliant on nuclear or coal power use pumped hydropower, a form of energy storage, to support their baseload power plants. The systems can use low-cost electricity to pump water uphill at night, when electricity demand is lower, and the water can flow downhill to generate electricity when needed, typically during the day when the cost of electricity is higher.

Utilities have long used flexible loads to enhance the grid’s balance between supply and demand on an hourly basis. For example, an electric water heater features thermal energy storage; although it cannot discharge electricity to the grid, it has considerable leeway in when it draws power from the grid. The rapid growth in the adoption of electric vehicles provides an opportunity to further harness the value of load flexibility, as long as that option has a high priority in deploying EV infrastructure.

Smart charging and vehicle-to-grid (V2G) configurations belong to a larger group of solutions called “vehicle-grid integration” or VGI. This can refer to scheduling, planning, or varying the charging of an electric vehicle to reduce its impact on the grid or even provide benefits to it. Smart charging involves changing the time and power of the charging activity, with power flowing from the grid to the vehicle. This does not lessen a battery’s lifetime, but it can extend the time needed to charge a vehicle battery. V2G allows power also to flow from the vehicle batteries into the grid. This, too, can provide benefits but also carries some costs in interconnection and battery degradation. In anticipation of lower cost to vehicle owners and higher value to grid operators and consumers, policies and structures meant to allow one-way smart charging to realize its value to the grid should not foreclose the possibility of two-way, vehicle-to-grid power flow.

The first goal of VGI is to limit the impact vehicles have on the grid. An EV charger may increase a consumer’s annual electricity demand by around 40 percent and double its peak demand. Because very few homes have EV chargers, the grid can accommodate their impact easily. As EVs become more prevalent, smart charging can limit impacts on the distribution system.

The second goal of VGI is to use the vehicles’ demand flexibility to help the grid address other issues. For example, smart charging may help the grid incorporate higher levels of variable renewable resources like wind and solar. Used in conjunction with other flexible loads, smart charging might also help address grid issues like congestion or problems in power quality.
CHAPTER 2

Literature Review and Expert Observations

To explore the ability of EVs to support the expanded use of renewable energy, UCS gathered information on EV-grid integration through reviewing the literature, interviewing experts, and convening two conferences. The conferences were held June 2–3, 2016 in Boston, Massachusetts, and November 9–11, 2016, in Braselton, Georgia. About 100 people took part in each event.

Almost two decades ago, Willet Kempton and Steven Letendre of the University of Delaware noted the potential of electric vehicles to support the grid, particularly by enabling wind and solar power to increase their penetration of the electricity market (Kempton and Letendre 1997). “Several major automobile manufacturers have announced near-term plans to produce and mass-market electric vehicles,” they wrote at a time when General Motors was producing the EV1 vehicle. “The electric-drive vehicle (EV) will increasingly be connected to electric utilities over the next decades.”

Kempton and Letendre suggested that EVs would be available as grid assets 96 percent of the time, comparable to power plants. Moreover, they noted, “to a first approximation, the passenger vehicle fleet has ten times more capacity than all the nation’s electrical generation equipment combined, it was purchased at one-tenth the cost per unit of power, and it is idle most of the time.” Earlier work on smart charging examined such possibilities as the use of EV charging during low-demand hours in a “valley filling” approach (Ford 1994). Kempton and Letendre went further, postulating that vehicles could provide power back to the grid at critical moments—vehicle-to-grid.

Since then, dozens of researchers have explained how smart charging and V2G can not only reduce the grid impacts of EV charging but serve many other useful purposes as well. While GM’s EV1 was never widely commercialized, a new generation of electric vehicles began entering the marketplace in the late 2000s and early 2010s. Today, the EV market, though still at an early stage, appears to have momentum.

The Grid of the Future

Smart charging is part of larger transformations affecting the electricity grid, and many recent initiatives have explored what the grid and utility of the future might look like. A few examples are California’s More than Smart initiative (De Martini 2014), the Smart Electric Power Alliance’s “51st State” (SEPA 2017), New York’s “Reforming the Energy Vision” proceedings (NYREV 2017), and the Electric Power Research Institute’s Integrated Grid efforts (EPRI 2014). Other relevant studies include the US Department of Energy’s Future of the Grid (Gridwise Alliance 2014), the Rocky Mountain Institute’s Reinventing Fire (Lovins and Rocky Mountain Institute 2011), the Advanced Energy Economy Institute’s Toward a 21st Century Electricity System in California (AEE 2015), MIT’s Future of the Electric Grid (Kassakian et al. 2011) and Utility of the Future (Pérez-Arriaga et al. 2016), the Pacific Northwest National Laboratory’s Smart Grid Demonstration Project (Hammerstrom et al. 2015), and the Pecan Street Project’s Smart Grid Demonstration Program (Pecan Street Inc. 2015), as well as many others.

The diverse visions explored by these initiatives and studies share several elements:

- **Increased prevalence of distributed energy resources (DERs).** Rooftop solar panels, energy storage systems at homes or businesses, and other DERs can provide fast-response, localized stability for the grid, with artificial intelligence and machine learning improving the ability to predict demand changes (Chhaya 2016). The growing prevalence of DERs requires identifying their value and reexamining the utilities’ business model.

- **Reduced carbon emissions from the electricity grid.** The scientific literature has clearly documented the deleterious impacts that unchecked carbon dioxide (CO₂) emissions will have on human well-being and the environment (Field et al. 2014). Reducing emissions provides a net economic benefit (Nordhaus 2010; Stern 2006).
• **Electrification of transportation and other energy end uses.** This can reduce carbon emissions and provide the utility industry with revenue for investing in grid upgrades.

• **Continued improvements in energy efficiency.** Efficiency improvements are among the most cost-effective means of reducing carbon emissions per unit of energy services delivered, but they pose a challenge for utilities that generate and deliver electricity. The utilities’ fixed costs would be spread over a smaller amount of energy sold, necessitating higher rates. This is offset to a degree by the electrification of additional energy end uses.

• **Greater use of information technology.** The many opportunities to connect consumer-owned equipment to utility data streams can provide data in real time and optimize many aspects of grid performance, but safe operation requires effective cybersecurity measures. Utilities have employed “bring your own device” programs for smart thermostats that can communicate with the utility’s systems. This experience can be built on for other devices.

• **Increased interactivity of supply and demand.** Price signals, automatic controls, distributed energy management systems, or other solutions may govern such interactions. “Transactive energy” refers to the use of real-time price signals to govern them.

These changes are occurring for many reasons: the 1990s restructuring of utility regulatory environments, global efforts to limit carbon emissions, vastly improved communication systems (e.g., the Internet), and improved renewable energy technologies. Wind power has a major role to play in the grid of the future, and existing systems can handle much more wind power than was originally thought (Parkinson 2015; Weiss and Tsuchida 2015).

The technological change that in effect creates a paradigm shift is the rise of solar power. With rapid cost declines, scalability, and potential for distributed generation, solar power can drive major changes in the power system. Already, it has led to electricity surpluses at certain times of the day. Solar also has spurred interest in energy storage and the design of electricity rate structures. And deployment is poised to continue. Research suggests that we will need to add energy storage to the grid to accommodate solar power when it reaches very high levels (Jacobson et al. 2015; Keith and Safaei 2015; Williams et al. 2015).

Additional solutions could support expanded use of solar power on the grid. Solar power benefits from a grid that can handle variability in supply. Information technology and transactive energy models can help incorporate solar power into the grid, as can flexible loads such as EVs. This benefit is noted by the Electric Power Research Institute (EPRI) (Chhaya 2014), the National Renewable Energy Laboratory (NREL) (Markel 2015), the California Public Utilities Commission (CPUC) (Langton and Crisostomo 2014), the Independent System Operator/Regional Transmission Operator Council (ISO/RTO Council 2010), and many others. As the Natural Resources Defense Council noted in comments on EV infrastructure proceedings in Massachusetts, “There is no other load of comparable magnitude that is flexible enough to be pushed to hours of the day when the system is underutilized or when there is over-generation of renewable resources” (Tonachel and Baumhefner 2014).

The value of flexibility will vary by the geography and time period considered. An analysis for California found that dynamic charging of EVs for renewables integration offered a net present value of $850 per vehicle (E3 2014). An analysis for several Northeastern states found EV benefits ranging from $107 to $265 per year per vehicle, taking into account benefits to other ratepayers and reductions in carbon emissions (Lowell, Jones, and Seamonds 2017).

Flexible loads can provide a range of grid services, as detailed by the Rocky Mountain Institute in *The Economics of Demand Flexibility* (Dyson et al. 2015), NREL researchers (Milligan and Kirby 2010), and many others. Sometimes, utilities pay end users for their willingness to reduce demand when needed; “demand response” is a well known and partially established practice in the electricity sector. There can even be value in increasing electricity demand at specific times. California is conducting the “Excess Supply Pilot,” enrolling end users in contracts to draw power from the grid when needed. Other flexible loads include electric water heaters and commercial air conditioners that incorporate ice storage (Hledik, Chang, and Lueken 2016).

The Brooklyn-Queens Demand Management Project is a standout example of adopting the principles of the grid of the future (Elcock 2016). This $200 million Con Edison project, which makes it possible to defer a $1 billion substation upgrade through approximately 2024, includes storage, demand reduction, and demand response. The project incorporates financial and regulatory innovation as well as new technology: Con Ed can receive a return on investment for all expenditures, including services, and it can obtain incentive returns up to an additional 1 percent.

Although the grid of the future is partly about new technologies, the most significant challenge and opportunity may be to get incentives and business structures right. New York’s Reforming the Energy Vision initiative is addressing this issue through the Brooklyn-Queens project’s incentives.
The importance of getting incentives right is illustrated by an observation of what can happen with the wrong incentives. The “utility death spiral” refers to a theoretical impact of distributed solar. If utility customers using solar power zero out their utility bills while still using the grid, the utility must charge its remaining customers more. This encourages even more customers to adopt solar, further raising rates on those who remain (Kind 2013). Utilities have responded by seeking to impose a variety of costs on customers that use solar. The “death spiral” has not occurred, but as battery costs decline, rate structures that overly penalize grid-connected solar power could lead consumers to leave the utility system entirely. Compared with an integrated grid solution, this approach will yield less-than-optimal economic outcomes unless rate structures and market rules encourage customers to use their DERs to benefit the grid rather than giving them reasons to disconnect.

The Impact of Renewables and Distributed Energy Resources on the Power System

Solar photovoltaic (PV) systems are key to the grid of the future. The costs of PV modules (solar panels) fell 99 percent between 1976 and 2015 and 80 percent just since 2008 (Liebreich 2016). This happened because the technology was deployed in niches where it was viable, including power for satellites and small electronics, as well as off-grid power and eventually grid-tied systems for early adopters (Geels 2002). Indeed, early adopters have driven the market, whether to reduce emissions of carbon and other key pollutants, contribute to national energy security, or express other personal values. State and national initiatives supported deployment in the 1990s and 2000s, and more adopters joined in, installing solar even when it was not the cheapest option for electricity (Leon 2013; Kimura and Suzuki 2006). Because of these policies and early adopters around the world, the market has continued to grow and costs to fall, to the point where new solar power is cost-competitive with fossil generation in some regions even without subsidies or a national price on carbon (Lazard 2016).

Considerable overlap exists between owners of electric vehicles and photovoltaic systems (CSE 2015; CSE 2014). Owners of one can install the other to reduce emissions even further. Smart chargers can mitigate certain negative impacts of PV or other variable resources in many locations and on many time scales. This may require the ability to communicate with various levels of the electricity infrastructure, although specialized services such as demand-response aggregators may eliminate the need for device-level communication with grid-scale entities.

While PV integration into the grid presents challenges, it is important not to overstate them. PV systems affect transmission, distribution, and generation (Gigliucci 2012), and the impacts occur at timescales from seconds to seasons. NREL and many others have evaluated the impacts on electricity generation and transmission (Denholm, Clark, and O’Con nell 2016) and on the distribution system (Palmintier et al. 2016). Although these analyses do not focus on vehicle-grid integration, they do suggest that “new controllable electricity uses, such as electric vehicles, may provide additional opportunities to improve the timing of demand to match the supply of solar energy” (Palmintier et al. 2016).

The economic cost of integrating solar power with the grid appears small for the near and medium term. Consequently, reducing the costs of PV integration is of relatively minor value at present. Smart charging is not solving an expensive problem. Utility integration costs for 14 percent PV energy (far higher than any utility in the country) were modeled to be under $4 per MWh, while the value of the electricity generated typically exceeds $30 per MWh (Luckow, Vitolo, and Daniel 2015; Mills et al. 2014). Other researchers have found a small net benefit from PV on distribution systems, due to capacity benefit, but they did not specify the cost of required ancillary services (Cohen, Kauzmann, and Callaway 2015). However, utilities traditionally spread integration costs for power plants across consumers through the rate structure or present-day regional grid operators (Lovins 2014), so reducing the integration cost of PV may not affect the economics of PV power directly.

This projection of solar integration costs conforms to experiences with wind power, which appears fairly easy to integrate into the grid. Wind and solar provided about 7 percent of electricity generation in 2016; while a tenfold increase from 2006 levels (EIA 2017), that level is still easily managed, and expectations of higher integration costs have not been borne out. Even where these renewable energy sources are more common, the operators of power systems have managed well, adjusting practices based on wind forecasts and based on enhanced visibility and control of wind-farm operations. The region covered by the Electric Reliability Council of Texas (ERCOT), an independent system operator that covers most of Texas and has very limited ability to import or export power that might reduce the impact of wind variability, generated 15 percent of its annual energy from wind power in 2016; it reached 50 percent wind power on at least one day in 2017 (ERCOT 2017).

If much higher levels of intermittent renewables pose a real economic cost, then market mechanisms such as demand response and frequency regulation will place a high value on flexible loads. EVs could then earn revenue by providing these
services, reduce the cost of renewables integration, and accelerate further PV deployment. On the other hand, if the economic impact of intermittency is minor, smart charging could still accelerate PV deployment by alleviating concerns about intermittency even in the absence of any market signals.

LOCAL IMPACTS: OVERVOLTAGE AND POWER QUALITY

Most studies of the cost of integrating renewables into the grid focus on the entire system. However, the near-term impacts of PV are greatest on the distribution level, with overvoltage and power quality among the most pressing concerns (Mather 2015; Steffel 2014). Overvoltage results when a distributed energy resource located close to regulation equipment adds more power locally than the system can accept (Steffel 2012).

The distribution system generally allows a 5 percent range of tolerance around the nominal voltage—so a 120-volt household service may actually vary from 114 volts to 126 volts. On a typical residential feeder circuit, homes closest to the utility substation will have voltages at the higher end of this range and voltage decreases with distance from the substation. If solar panels on the closer houses generate power during the daytime and use little power at that time, the voltage level on that section of the distribution line can increase above the permissible range. Other sorts of problems can also occur, whether caused by the solar panels or by loads on the circuit. “Power quality” encompasses not only voltage levels but numerous other potential problems with the electricity power supply (for example, “voltage flicker” and “harmonics” are two other aspects of power quality). The inverters that convert solar power from direct current into alternating current can be designed to improve power quality. Systems with such functionality are called “smart inverters.”

However, just adding a capability is not enough. For a time, smart inverters had their “smarts” switched off by utility-industry standards and expectations. New industry standards were needed to allow the capability to be used. Smart inverter measures include California’s “Rule 21” and IEEE Standard 1547a (Berdner 2015). These protocols allow inverters to help address various power-quality problems (Nelson et al. 2015). Also, the inverters can function as grid-edge sensors to offer utilities better insight into the operation of distribution grids (St. John 2015).

A report commissioned by the Florida Solar Energy Center provides an overview of using EV charging to address overvoltage events. “Besides arbitrary time constraints in communication protocols, no technical constraints have been identified,” it notes (Schwarzer and Ghorbani 2015). Much like solar power systems, EVs and their chargers also feature sophisticated power electronics that could, in principle, provide benefits to the grid beyond simply preventing negative impacts on power quality.

Without more awareness of vehicle use, it might appear that using smart charging to assist with distributed PV impacts is like trying to fit a square peg into a round hole. PV production peaks around noon, and most EVs are at workplaces during the day; this would mean that residential PV cannot charge EVs. In fact, about 57 percent of households have somebody at home nearly all the time (Pritoni et al. 2015), and 41 percent of cars are at home at noon on a typical weekday (Langton and Crisostomo 2014), although early data suggest that only around 10 percent of EVs are typically at home at that time (Schey, Scoffield, and Smart 2012). Distributed solar might charge other EVs on the same residential feeder. Other options to mitigate the impact of PV on distribution include stationary home storage (possibly integrated with an EV charger), a utility-scale battery at the transformer, and allowing backflow of power out of the feeder so the residential PV can support workplace charging.

ISO-SCALE: THE DUCK CURVE

The most significant potential impact of high levels of solar on the power system would be on generation and power prices at a regional level. The impact could reduce the economic viability of baseload power plants, increase the demand for flexible generation, and possibly threaten the revenue base of utilities.

The utility industry commonly cites the “duck curve” as a grid-scale danger of high levels of solar power (Figure 1). Solar panels generate power in the middle of the day, so other power plants could generate less at that time. Figure 1 shows net power demand on the California grid on a typical spring day, after considering solar power generation. In 2012, there was relatively little solar power. That is the baseline, the “back” of the duck. In each subsequent year, with increasing amounts of solar power, less and less power is needed from other sources from about 10 am to 4 pm. These lines form the deepening “belly” of the duck. In the late afternoon and early evening, peak power demand increases. Abundant on-demand generation needs to be kept in operating condition and ready to meet demand, although it will sit idle most of the day. With those power plants unable to earn any revenue
by operating in the middle of the day, the generators have to charge higher prices in the evening to recoup their costs.

Without addressing this effect, midday solar production eventually will push other generation off the grid. The need for flexibility to ramp up supply as the sun sets will exceed the flexibility available. When that happens, no more solar generation can be accepted, and any excess solar will be “curtailed” (will not feed power into the grid).

Flexible loads from EVs, water heaters, air conditioners, and other systems can play a significant role in resolving this problem (Lazar 2016a; Lewis 2014). By shifting load to the middle of day, they can flatten the curve and reduce the evening ramp-up that other supplies must meet. To enact this shift with more midday EV charging, commercial buildings could be encouraged to provide workplace charging. While demand charges could deter a workplace from doing this, improved rate design can achieve the desired outcome (Allison and Whited 2017; Lazar and Gonzalez 2015).

With V2G, EVs could actually move renewable energy supply from surplus periods to the evening peak. Today, there are too few EVs, even in California, to make a large impact on this load shape. In the future, when EVs reach a level of around 5 percent of overall electricity demand (i.e., if roughly 25 percent of all light-duty vehicles were electric), they could have a significant impact alongside other flexible loads.

The duck curve is generally considered a California problem, yet similar curves have been calculated for Hawaii, Italy, and Australia. Further, solar is starting to affect the load shapes in New England and may do so in New York by 2024 (Sedlacek 2016; Tarler 2015).

Increasingly, solar is considered along with wind for unexpected variations in output (Luckow, Vitolo, and Daniel 2015; Moore et al. 2015; Weiss and Tsuchida 2015; Mauch et al. 2013). Passing clouds may be short term and have local impacts (Figure 3), whereas a major storm system could limit power for days over a wide area. Flexible loads can mitigate the local effects of short-term intermittency, and they can provide ancillary services designed to address short-duration fluctuations in the overall supply-demand balance. This requires fairly short interruptions of demand, just long enough for other generators to respond to a loss of solar power output.

The duck curve also illustrates how solar power’s pattern of energy production creates economic pressures for the technology. The more solar is added to the grid, the less each new addition is worth, because new solar produces power at roughly the same time as the existing systems, adding to the oversupply (Perez 2015; Mills and Wiser 2014). Although the most immediate impacts of adding PV to the grid seem to be...
short term and limited to the scale of individual distribution lines, such as overvoltage, this peak value erosion is a longer-
term problem that is potentially much larger. Time-of-use pricing combined with workplace charging could benefit solar by providing more midday demand, thereby supporting the rates solar systems earn from selling power and benefitting EVs by providing low-cost clean electricity.

THE GRID IMPACTS OF ELECTRIC VEHICLES

Assuming the market share of EVs continues rising, their impact on the grid will depend on the charging infrastructure used. Figure 4 illustrates the relative abundance of each type of charger that will play a distinct role in the widespread adoption of EVs. Most charging happens at home. Presently, single-family homes with garages have the easiest time installing chargers, while multifamily homes remain a challenge. Home chargers may be Level 1 (an ordinary 120 V outlet, charging a vehicle at a rate of around 1.5 kW) or Level 2 (a 240 V outlet, usually providing around 7 kW). Workplace charging offers many benefits for extending range and raising awareness of EVs. Fleets of EVs could be significant providers of grid services, and networks of public fast chargers could alleviate range anxiety and possibly convince some vehicle buyers who are uncertain about the suitability of an EV for their needs. Public chargers are unlikely to account for a large fraction of vehicle charging.

Workplace charging, fleet charging, and home charging are most suitable for smart charging (Quattrini 2016). Applying smart charging to public charging stations likely yields small benefits compared with the costs and could impair the driver experience. These stations are typically meant for relatively fast charging, so taking action to slow or delay charging is not normally advisable.

For home charging, although clustering could cause local impacts, “PEV charging has had a negligible effect on the distribution-system components to date and is expected to have a negligible future effect at the anticipated rates of PEV adoption” (Committee on Overcoming Barriers to Electric-Vehicle Deployment et al. 2015). Utilities have raised the option of adjusting the price of power based on the specific circuit to signal the costs imposed by clusters of chargers (Bialek 2015).

To the extent there are costs, they tend to be driven by high-powered chargers leading to transformer upgrades. In Eversource territory in New England, EVs have driven upgrades on specific residential transformers only when customers have installed 20 kW Tesla chargers (Collins 2016). Its neighboring utility, National Grid, does not yet see enough
value in deploying smart charging communication infrastructure to defer the replacement of transformers. That distribution investment is not overly expensive and is projected to be fairly rare even at moderate levels of EV deployment (Valenzuela 2016).

Even if an EV charger is the “tipping point” that necessitates a transformer upgrade, the EV owner need not pay for that upgrade personally. “Asserting that a given EV ‘caused’ a transformer upgrade ignores all previously added loads which brought the transformer to the point of exceeding its capacity” (Tonachel and Baumhefner 2014).

An earlier concern about EVs was that a smoother load profile and more off-peak charging could hurt transformer lifetime by eliminating cool-down periods (EPRI 2012). However, research has found that not to be the case (Buchholz 2014). Smart charging algorithms can limit the extent of any impacts that might affect transformers (Hilshey et al. 2012).

 Appropriately designed incentives require the balancing of three interests: cost savings to utility customers, utility support for EV owners, and performance incentives to utility shareholders (Ryan and Lavin 2015). Utilities also need strategic direction to consider EVs in their integrated resource planning processes. Smart charging makes EVs more than just a demand on the grid, but a resource that can respond to grid needs and conditions and provide essential services.

**Engaging the Consumer**

If the flexibility of EVs can benefit the grid, what could encourage EV owners to provide this service?

First, consider what a “typical” charging practice might look like. Is the right model that of the gas station, where an EV owner charges once a week or so for a vehicle’s total range? An EV with a 200-mile range that drives 20 miles a day could charge once a week at work, where nine hours on a Level 2 charger would fill it up even with some modest fluctuations for grid services. Or is the right model closer to the smart phone, where the owner plugs it in every night and takes other opportunities to top off? These two models, which can be described as “gorging” and “grazing,” could also apply to electric buses, using a battery charged once for the entire day or employing en-route charging.

The driver’s greatest concern will be the possibility a vehicle is not charged when needed. Virtually every pilot project considers and addresses this situation, such as with an override button, an app that ensures a minimum charge by a specified time, or some other strategy. In practice, few consumers use overrides even when the option is available, suggesting that existing smart charging programs do well at avoiding any inconvenience to drivers.

Many experts observe that “set and forget” is a useful goal for smart technologies: the consumer is engaged at one time, and after that the system works without further intervention (Pecan Street Inc. 2015). Others note that the real hurdle is enrolling consumers in a program, such as a time-of-use plan; once enrolled, they are engaged, and even fairly small cost differentials will motivate them to shift their loads (Gross 2016). Still other experts note the potential for environmental factors to motivate decision-making (Lazar 2016b; McCready 2016).

If enrolling consumers is challenging (utilities have widely varying degrees of success at this), the best time is likely when a vehicle is purchased (Moskovitz 2014). The manufacturer could convey an up-front rebate offered by the utility if the buyer enrolls in the smart charging program. Enrolling might give the customer a smart-phone app with options for “fueling.” These could be “economy charge” (as low cost as possible to charge by a specified time), “urgent charge” (as fast as possible, at a higher rate), and “custom charge” (conforming to other specified criteria, perhaps to charge when the least-polluting power is available) (Lazar 2016b).

Receiving a rebate and enrolling in a smart charging program would also require letting the utility know exactly where a 6 to 20 kW power demand has been added. This is good: while current chargers are not an overwhelming load on the grid, utilities like to know when and where EV chargers are installed. Some have tried asking states to share motor vehicle registry information. Alternatively, the Salt River Project (an Arizona utility) gives EV owners a $50 Amazon gift card for joining their “EV Community.” This entails notifying the utility of the EV model, service address, and charging system. A number of conference participants agreed that EV early adopters tend to be engaged, knowledgeable, and willing to serve in an outreach capacity. Such activities might be promoting ride-and-drive events, raising awareness of utility EV programs, sharing information on forums with new EV owners, and participating in a smart charging pilot.
The Utility Role

In a number of ways, utilities could bring the benefits of EVs to the grid and promote beneficial charging practices. A wide range of utilities participated in UCS’s research for this report. Large and small municipal utilities attended the conferences we convened, as did vertically integrated, investor-owned utilities, restructured distribution companies, and other entities, such as the Tennessee Valley Authority.

Utilities in general support the goal of introducing more electric vehicles to the grid and interested in the concepts of smart charging and load management. Also, high EV penetration may lead to substantially increased electricity sales, directly benefitting vertically integrated utilities. Deregulated utilities would not benefit in this way, but if they can spread their prior fixed costs over more kilowatt-hours, without needing to invest heavily in new infrastructure, they can reduce costs per kWh for all customers—including those who do not own or operate EVs. Overall, utilities have emphasized the importance of safety, reliability, and value to ratepayers.

Utilities have a role to play in EV infrastructure, but the specifics are a topic of considerable discussion. Currently, some locations, such as many low- and moderate-income neighborhoods, are uneconomical for a third party to serve, so utility investment might serve an unmet need and achieve a social goal. These do not have to be rate-based investments: the Jacksonville Electric Authority has used air-quality funds to install EV chargers (King 2016). Independent charging providers and ratepayer advocates have fairness concerns about utility proposals to install charging systems and recoup the costs through billing all customers, including those who do not own EVs. However, the impact on non-EV owners of EV infrastructure can be positive, in reducing the need for future rate increases (Lowell, Jones, and Seamonds 2017). And it is not always a decision between utility investment and third-party investment; many approaches feature both.

The utility plays a key role as both holder of information and consumer of ancillary services. Charging providers such as ChargePoint, Greenlots, and EVGo recognize opportunities to work with utilities as partners. To avoid excessive costs for system upgrades, the utility’s knowledge of the distribution system is essential when siting new chargers. Also, if there is value in providing grid services (such as demand response or frequency regulation), these services could be sold to the utility rather than an ISO in many parts of the country.

The trend in the EV supply equipment sector is toward faster charging speeds, thus increasing the power demand from each vehicle charger. At the UCS conferences, many utility stakeholders expressed interest in finding ways to accommodate higher-powered chargers without incurring exorbitant demand charges or unduly straining the grid. Integration of storage into chargers is a possibility, especially if the utility can operate the battery to provide other revenue streams and defer other costs. Several representatives of utilities noted that high-powered charging can significantly affect their systems, and they were interested in the speed with which higher-powered fast charging would become the standard. With batteries of 60 kWh or more becoming widespread in the Chevy Bolt and the Tesla Model 3, the typical 50 kW fast charger would no longer be considered “fast,” taking over an hour to fully charge a battery. Would 150 kW become the new standard? Automakers noted that EVs with smaller batteries could not handle that sort of power input; 150 kW chargers as they emerge will coexist with 50 kW stations. Electric bus manufacturers noted that some of their systems would charge at 350 kW. Utilities can be valuable partners in siting charging depots for such systems.

Utility representatives reiterated the importance of knowing where on the grid the EV chargers were being installed, including the specific feeder. Engaging with EV owners, as the Salt River Project does, seems the best way to achieve this outcome.

Some experts suggest that vehicles should contain the communication and control capabilities, while others think that a stationary charger is a better option. From the utility point of view, locating the intelligence in the charger seems to offer more benefits. If the charger includes GPS and time references, it can offer a grid operator highly accurate measurements even when no vehicle is charging; this can be an important reliability service. Placing the intelligence in stationary chargers would also help in using smart charging to deal with local issues such as load levels and power quality on the distribution line, where an accurate GPS location may not be enough to identify the specific circuit a vehicle is charging on.

Some utilities have other reasons to support smart charging. Austin Energy determines its contribution to ERCOT transmission expenses based on its share of the system’s load at peak hours from June to September. This gives it an incentive to employ demand response to reduce load during those times. EV charging would normally increase the peak load, but it need not do so if deployed with demand response capability. Additionally, ERCOT is an energy-only market that relies on scarcity pricing to ensure adequate reserves. Demand response can provide a significant benefit because the price of electricity during critical peak
periods can be very high. Accordingly, Austin Energy is seeking to deploy automated, intelligent EV charging, with a focus first on demand response.

**ISO Markets and Grid-Scale Services**

Keeping all of the possible uses and values for smart charging in perspective requires considering the nation’s larger regional grids and the diversity of electricity users and suppliers. In much of the United States, independent system operators (ISOs) administer markets that are open to many types of participant. In such environments, EV smart charging must prove its worth for wholesale-level functions and benefits.

Flexible loads represent one set of options for helping the grid align supply and demand. These loads will compete against one another (perhaps EVs against water heaters and ice chilling systems), and against other options such as flexible generation or dedicated grid storage batteries. Storage pilots or demonstration projects might be warranted for research purposes, but mandating batteries as the sole solution for integrating renewables could prove overly expensive.

The enthusiasm of technology providers for their products can lead them to be insufficiently clear on the technology’s features and benefits. At the 2015 conference of the Energy Storage Association, Jigar Shah, a consultant on profitable solutions to combating climate change, stressed the importance of specifying which services a storage technology will provide, rather than just saying it will support solar power. In an online comment, Shah noted 18 potential applications for storage, including nine types of ISO grid services and four types of local utility grid services (Lacey 2015).

Similarly, providers of smart charging and flexible loads need to be clear about which services they will seek to provide. As both a form of storage and a competitor to dedicated grid batteries, smart charging can offer many of the same types of services (such as frequency regulation), although some are not possible (such as “black start capability” to restart a generator after an outage).

Large-scale grid needs generally fall along three timescales: regulation is minute to minute, load-following (dispatch) ranges from minutes to hours, and scheduling refers to day-ahead, unit-commitment decisions (Milligan et al. 2011). Some products operate at faster timescales, such as voltage control and reactive power management (seconds) or fast frequency response (sub-second). EVs can perform both of these (Mitchem 2015; Wu et al. 2012). Other grid needs have longer timescales, such as the seasonal variations in PV power output.

Short-term services like frequency regulation can be provided with only minor impact on charging speed, especially if many EVs are connected. Any actions to benefit the grid on the timescale of hours are unlikely to come from smart charging on an as-needed basis, but design of the system can induce shifts of hours on a more predictable basis (such as time-of-use rates or workplace charging).

Many markets allow flexible loads to provide grid services. This is a very fluid area and subject to change; prospective market participants can consult directly with their regional grid operators to learn about the latest developments. CAISO has several avenues for EVs to participate in grid markets, including demand response, frequency regulation, and spinning and non-spinning reserves. PJM features V2G participation in its frequency regulation market, and ISO New England allows controllable loads such as EVs to participate as alternative technology regulation resources. ERCOT has also demonstrated smart charging for grid services (fast frequency response).

The barriers to EV participation in ancillary services markets are those faced by distributed energy resources more generally, such as minimum resource size, restrictions on aggregators, telemetry requirements, and transaction costs. Some of these transaction costs are independent of the resource size, making them prohibitively expensive for small projects and incentivizing aggregation by firms with focused business models.

Some areas also have opportunities for flexible loads to provide value to the utilities, not just the markets administered by ISOs. For example, California’s “resource adequacy requirement” on utilities can provide an opportunity to earn revenue from technologies capable of reducing demand. In addition, interest is increasing in using EVs for “energy assurance.” This term, referring to resilience in emergency situations, would benefit from vehicle-to-building power supply. Nissan offers this option with “LEAF-to-Home” in Japan but not in the United States.

The administration of markets varies greatly across ISOs. The details of the services differ, as do market rules, so opportunities in one area may not apply in another. Federal policymakers could push ISOs to look at innovation and consider the ways in which DERs can help them operate their grids.
Distribution Capacity Deferral

Normally, when one residential customer increases demand, all ratepayers bear the cost of necessary upgrades to the distribution system. If smart charging can avoid the need for upgrades, that would be a reason to create economically defensible incentives for smart charging.

The Rocky Mountain Institute has noted the deferral of distribution capacity as one of the most significant values provided by energy storage (Fitzgerald et al. 2015). Performance-based incentives for the utilities, rather than relying solely on the regulated return on capital investments, could lead to greater utilization of smart solutions on the distribution side. Distribution restructuring initiatives in California, New York, Massachusetts, and other states are exploring ways to encourage consideration of alternatives.

An important consideration in distribution investments is to ensure that they are flexible and modular, making them as “future-proof” as possible. “Modularity would mitigate stranded cost risk and enable future optionality to benefit from unforeseen innovations such as was the case with modular smart meter designs developed before the iPhone was launched” (De Martini 2014). More broadly, it is possible to change the business models for electricity distribution, keeping in mind the goals of resiliency, reliability, social priorities, equity, and other aspects (Newcomb, Lacy, and Hansen 2013).

Even the existing utility regulatory structures offer possibilities for creative solutions. In North Carolina, Duke Energy faced local opposition when it sought to meet peak demand in Asheville by building new generating capacity. It is now working with the community to reduce demand enough to make the plant unnecessary.

Smart charging has the potential to defer distribution upgrades that could be required by unmanaged charging. Quantifying this value of deferring investments can be contentious. It requires data and transparency, as well as good information on what specifically imposes costs on utilities’ systems.

Rate Design and Implied Incentives

The design of utility rates can make a significant difference in the success of electric vehicles. For example, California’s inclining (tiered) rate blocks, intended to foster conservation, can make it difficult to add the electric load of an EV even when that vehicle reduces energy use and produces less pollution than the gasoline vehicle it replaces. In Massachusetts, an imprecise definition of peak period and resulting on-peak pricing creates a penalty; drivers may prefer to use grid power for “preconditioning” an EV on a cold day, warming up the interior of the vehicle while it is plugged in. Here, and likely in many places, the utility and state regulators have adopted time-of-use rates that start the “on-peak” period at 8 am, well before the system approaches its real peak. This raises the cost of warming up the vehicle, illustrating the unintended consequences of a time-of-use rate mismatched to peak demand hours. Another category of rate elements, demand charges for businesses, can deter the owner of a commercial property from installing workplace chargers.

The utility ratemaking process can also enable incentives for certain types of investments. Smart-charging incentives that subsidize EVs without reflecting actual value provided would not offer a long-term solution. On the other hand, compensation that reflects real benefits provided to the grid and to society would make incentives economically defensible. As noted, deferral of distribution capacity investments can be a significant benefit, and one that is typically not monetized. The dollar value of avoided emissions of carbon or other pollutants may be uncertain. However, “[t]o not incorporate externalities in prices is to implicitly assign a value of zero, a number that is demonstrably wrong” (Koomey and Krause 1997). Externalities have to be considered.

In recent years, most rate design discussions have addressed a different distributed energy resource: solar power. This has spurred many analyses, often seeking to address concerns about utility compensation in a high-DER future. Without making sweeping statements about the wide range of literature, in general these studies share several conclusions (Wood et al. 2016):

- Smart meters should make it easier for rate design to take into account the causes of cost increases or decreases.
- The combination of rate design and technology can help some customers modify some of their consumption patterns to reduce the costs they impose upon the grid.
- Rate design must also consider principles of simplicity and equity.
- Increasing fixed charges is unlikely to support the goals of reflecting cost causation (establishing rates that reflect the costs imposed on the grid), enhancing equity, or reducing externalities. High fixed charges adversely affect low-usage customers, who are often lower income.
FIXED CHARGES AND DEMAND CHARGES

Some households typically use less electricity than the residential average in nearly all regions of the United States: elder households; low-income households; and households headed by an African American, Latino, or Asian American. Increasing the role of fixed charges in tariffs would place a disproportionate burden on these groups. Fixed charges are a blunt instrument that fails to address cost causation appropriately.

Fixed charges also would be problematic for any customer trying out a time-of-use plan with a separate meter for the EV. The fixed charge would apply once to each meter, considerably increasing the cost (as well as the initial cost of installing the second meter).

General themes addressed in the UCS-convened conferences included simplicity, fairness, discrimination, and efficiency. Good rate design should reduce regressivity in the allocation of home energy costs and benefits and narrow the home energy burden gap among residential ratepayers. It should enhance the home energy security of low- and moderate-income ratepayers, reduce service disconnections, and increase access to affordable, reliable service (Howat 2016). In addition, utilities could improve opportunities for aggregators and other third parties by providing better information about the value of energy, capacity, and ancillary services (Trivedi 2016).

Workplace charging has the potential to mitigate “duck curve” effects. However, commercial rates typically feature demand charges, which are based on a building’s peak load at any one moment. If adding EV chargers increases a building’s peak load, the building will pay higher demand charges. In theory, this reflects the strain the building places on the grid. The actual relationship to grid costs can be quite different, especially if the building’s peak does not align with the system peak. Rate design should encourage workplace charging to take advantage of abundant solar, low wholesale power prices, and available system capacity. Demand charges that fail to take into account the timing of a building’s peak relative to the system peak do not achieve efficient economic outcomes (Allison and Whited 2017).

TIME OF USE RATES

Demand charges emerged before metering could record the time of highest user demand. Today’s smart meters can track energy use at 15-minute intervals, providing options for improving rate designs. Generally, shifting a greater portion of utility cost recovery from demand charges to hourly volumetric rates would better align demand with system needs. Time-of-use pricing is a way to do this; it is one of a broader set of options called time-varying pricing, along with real-time pricing, critical peak pricing, and other options (McNamara, Jacobs, and Wisland 2017).

Time-varying pricing raises some questions and concerns, given that price-responsiveness differs between groups of customers. A 3,000-customer pilot by the Sacramento Municipal Utility District included 1,000 low-income participants. The low-income participants could lower their electricity usage by about 11 percent during critical peak pricing events, while other customers could decrease their usage by about 20 percent. The primary reason for this difference was that the low-income customers had lower air conditioning loads to begin with (Lazar 2016b).

Smart grid technologies present additional benefits that should be considered, including improved information about grid and energy consumption patterns, but it is essential to allocate risk appropriately. The introduction of time-varying pricing can be a managed, gradual process for broader consumers with “shadow billing” and “hold harmless” provisions. A utility might employ both of these, for at least a year each. In the “shadow billing” phase, a consumer would remain on their current rate while receiving bills showing their hypothetical charges under the pending time-of-use rate. This would give consumers the opportunity to learn how they could adjust energy consumption to save money. In the “hold harmless” phase, the consumer would shift to the time-of-use rate but with a guarantee that their bills under the new system would not exceed what they would have been under the old rate. These and other approaches can enable utilities to achieve efficiencies without hurting those who cannot easily alter their consumption patterns. Such rates could be the default for new EVs, with an opt-out option. Over time, a shift toward appropriately designed time-of-use pricing for all would improve economic efficiency.

Currently, electric vehicles are well suited to time-based rates with controlled charging, and the potential exists for them to provide arbitrage in V2G configurations in the future, buying power when prices are low and selling it when prices are high. EVs and other dynamic loads will alter load shapes in response to time-of-use rates. More “smart loads” will reduce profit opportunities—for example, by diminishing the peaks that provide opportunities for demand response. Still, these shifts are unlikely to eliminate profit opportunities, and they will reduce the costs of operating the grid by reducing the prices for demand response.
Time-of-use pricing relies on “peak” and “off-peak” periods as fixed in rate structures. These structures change slowly, and the periods are not dynamically adjusted. Some experts propose time-varying plans that would adjust more rapidly, such as a three-part “full value tariff” (Patel et al. 2016). This approach would provide incentives for such strategies as price-induced load shifting, battery storage, and “smart loads” for EVs and air conditioners. San Diego Gas & Electric is piloting a similar structure, determining hourly rates a day ahead and varying them by location to account for the utility’s predictions about renewables generation and power grid congestion.

The Automaker Perspective

Using EVs as a flexible load would benefit from the involvement of utilities. Getting the vehicles on the road in the first place requires the involvement of automakers.

The automakers contributing to the UCS effort have a range of experiences with EVs in the United States and overseas. They have deployed combinations of solar, storage, and EV charging at several facilities. They have demonstrated demand response from EV chargers, collaborated with the Electric Power Research Institute on a common charging protocol, and developed technological solutions to manage vehicle charging for fleets. And they have launched many research projects.

In general, automakers emphasize placing a priority on driver needs, finding convergence on standards and protocols, and expanding the charging infrastructure. They see value in time-of-use rates, showing evidence of consumer behavior in response to these plans. Automakers that have conducted pilots with smart charging view it as a fairly minor revenue stream that could have value in the future. If so, they want to ensure that some of the value goes to vehicle owners, which would be an incentive to buy EVs.

Automakers recognize that residential charging will continue to provide most charging for EVs, with an extensive infrastructure in place: literally every garage that has a 120V outlet has a Level 1 EV charger. Still, Level 1 charging is not particularly fast, and many drivers have neither a garage nor dedicated off-street parking. Automakers would like to engage utilities in developing charging solutions for these drivers.

Participants in the UCS conferences acknowledged the need for adequate charging infrastructure. The automakers and other stakeholders also discussed more technical topics such as the communication, control, and payment tracking for EV charging.

The major difference of opinion among automakers concerns standards for smart charging. Some favor ISO 15118, which is the standard in Europe. This allows plug-and-charge capability: the charger recognizes the vehicle, with no extra step needed to use an RFID card or a credit card. The charger and the vehicle exchange encrypted digital certificates, automatically and instantly. The system can accommodate smart-charging algorithms, handle location-specific prices, and respect customer preferences. Other automakers favor the OVGIP platform, developed with the utility-industry-supported Electric Power Research Institute. The OVGIP platform is meant to handle not only ISO 15118 but also numerous other communication protocols. Handling many possible uses of smart charging, it is intended to be “future-proof” by being flexible enough to accommodate new features.

Disagreement partly revolves around the need for a smart charger versus having the utility communicate directly with the vehicle. European manufacturers favor smart chargers, and US automakers are more inclined to have their vehicles communicate directly with the utilities (Mültin, Gitte, and Schmeck 2013). Some US automakers are concerned that allowing a third party or intermediary device to affect the rate of charging could lead to poorer experiences for consumers—particularly a vehicle not being charged when needed. On the other hand, the electric vehicle supply equipment industry includes entities that have specialized in working with utilities and ISOs to provide demand response and other grid services, while automakers are less familiar with this area. Some EVSE stakeholders have urged adoption of the ISO 15118 standard. Others seem amenable to working with different standards.

Technical Issues

It is generally agreed that the technology is here for smart charging, and stakeholders are working to resolve remaining technical issues.

Such issues have been addressed on a case-by-case basis in smart charging pilots, but greater standardization will be necessary for broader adoption. Properly designed hardware can be flexible and amenable to over-the-air software upgrades, so not every technical question would need to be resolved immediately.
COMMUNICATION SYSTEMS

How does an electric vehicle know about grid conditions? How much can it vary the charging to provide ancillary services? If the distribution circuit sees a voltage problem, how is a decision made to use one system or another to compensate?

The power grid initially relied on many tons of spinning mass to provide the correct frequency and voltage, and that system was relatively slow to respond. EVs and their chargers are among the new smart grid technologies that can react much more quickly, given a reliable communication pathway between the vehicle and the grid.

That communication pathway has several aspects. Aggregators using EV chargers for demand response or some other service typically maintains two layers of communication. They must communicate with the utility or ISO, which is typically a straightforward process. They also must communicate safely and reliably with either cars or EV supply equipment, and that is more of a challenge. Automakers might not want to navigate dealing with the nation’s 3,300 utilities, which might use a variety of communication systems or have different rules for demand response. Thus, third-party aggregators might provide value.

An aggregator could use Wi-Fi, smart meter systems, cellular networks, or the FM radio network. Any of these could make it possible to communicate with vehicles directly or indirectly through EVSE. The radio pathway is more limited, because it is one-way and cannot confirm that demand response was performed, yet it could be a useful redundancy system (Tuttle 2016).

Wi-Fi infrastructure is likely to be a low-cost solution for providing demand response, whether from EVs or from water heaters and thermostats. The problems with using Wi-Fi include cybersecurity and reliability; neither problem is intractable.

As charging goals become more complex, the software and communications increase in sophistication and cost. This is not due to the price of hardware, which is inexpensive at scale. Developing, validating, and maintaining the code can cost far more. As with many aspects of smart charging, this problem relates to scale. Once software is developed, it can be replicated essentially for free.

SUBMETERING

An important advance in California has been the acceptance of the metering capabilities present in the chargers as suitable for providing billing data (such as for an EV-only, time-of-use rate). This approach, which offers considerable savings over installing a second utility meter, has been accepted in all three areas of California with investor-owned-utilities. It saves $2,000 to $10,000 in capital costs, and the switch to time-of-use pricing saves $800 to $1,000 per year in energy costs, including the savings to other ratepayers when the EV owner reduces on-peak power consumption (White 2016). Subtractive billing would be required if the building where the EV is charged is not on the time-of-use rate but the vehicle itself is. The utilities in California can do this, and others are developing systems.

Case Studies

The utility industry, national laboratories, and other stakeholders have conducted many demonstrations and pilot studies to develop concepts into practice, observe the interactions between participants, and test business models. Such activities explore how intelligent interactions of demand and supply can provide multiple value streams. These benefits can include peak shaving, arbitrage, improved utilization of fixed assets, “green charging,” alleviating transmission bottlenecks, and relieving strain on distribution transformers (Tuttle and Ballick 2012). Existing commercial products feature degrees of smart charging functionality, whether built into cars or as relatively low-cost adapters for EV chargers.

Some pilot projects have utilized these capabilities, while others have enhanced them or implemented V2G. Several of these cases were presented at the conferences organized by UCS. These are discussed below; the conference presentations offer greater detail and can be accessed online at https://tinyurl.com/UCS-Smart-Charging.

DELAWARE VEHICLE-TO-GRID

The pioneer of vehicle-to-grid, Dr. Willett Kempton of the University of Delaware, has implemented the technology for frequency regulation in the PJM Interconnection region. V2G has been providing grid services through this competitive market since 2013. This proof of concept and ongoing business have made it possible to license the technology for international deployment.
Frequency regulation involves short-term adjustments by electricity generators to ensure a balance between supply and demand. Typically, generators providing this service operate at less than maximum capacity and can increase or decrease generation as needed. In a V2G configuration, the vehicles connected to the grid can draw or supply electricity.

The pilot project uses a fleet of BMW Mini E vehicles. It is important that enough vehicles are connected at any one time to meet the fleet’s commitments. In an ideal system, vehicle users would adhere to reservations and a schedule, so that frequency regulation commitments could be based on the number of available vehicles. In practice, the project uses a wide margin of error to ensure adequate regulation.

Vehicle-to-grid applications have benefited from the work done to streamline interconnection of PV systems, such as establishing standards. In addition, many technical issues facing V2G are being addressed for integrating storage into the grid more generally. Resolving these issues will help V2G become more viable, as will resolving outstanding issues regarding utility acceptance of inverter standards.

The PJM frequency regulation market is fairly small and quickly saturated, so this application is likely to become less profitable as increasing competition drives down prices. The demand for frequency regulation would theoretically increase with less predictability in the electricity system, as might be the case with increased renewables.

LOS ANGELES AIR FORCE BASE EV FLEET

A fleet of electric vehicles at the Los Angeles Air Force Base also performs frequency regulation through vehicle-to-grid. Like the PJM fleet, this resource is fully eligible for market participation.

Unlike the University of Delaware, the Air Force Base has a retail rate disincentive in the form of demand charges. However, its fleet has two revenue streams: it is paid both to be available for frequency regulation and to perform the service when called upon. It is larger than the PJM system, certified as a 500 kW resource, although this is small by CAISO standards. The system has been very good at following the signal from the utility to provide regulation, which is also true of using photovoltaic systems (Loutan and Gevorgian 2017). Both systems employ inverters, which appear to be capable of faster, more accurate response than varying the output from conventional generators.

One of the larger challenges is hardware reliability. Many components are prototypes, with only about one-third to one-half of vehicles online and responding at any given time. Another challenge is the integration of the V2G system into legacy systems at CAISO. CAISO’s systems attempt to calculate the aggregate state of charge in the vehicles for purposes of determining their eligibility to participate in the market, but CAISO lacks the information to do this properly.

CAISO utilizes two rounds of resource scheduling (reserve scheduling and re-optimization), followed by frequency regulation at four-second intervals. Participating in this market requires a good understanding of fleet availability and therefore proper use of the trip reservation system. The optimization algorithm minimizes total costs while meeting all operational needs.

A final consideration is that the design of the CAISO frequency regulation market assumes that regulation is energy-neutral—that there is just as much need for regulation “up” as “down.” Were this true, the participation of a vehicle fleet, or any energy storage system, would be simpler and more economic. However, an equal use of up and down regulation is not the case in practice. Performing regulation service in CAISO will change a vehicle’s state of charge over time, rather than having a neutral impact if there were an equal amount of power flowing in and flowing out.

VEHICLE-TO-GRID CONSIDERATIONS

The projects at the University of Delaware and Los Angeles Air Force Base employ fleets of vehicles that have been modified to perform V2G. This configuration can earn more by providing a broader range of grid services. The primary barriers to further application of V2G are interconnection requirements—a system that can put electricity on the grid is regulated differently from one that merely draws power from the grid—and the impacts on battery lifetime.

For most batteries, each cycle of charging and discharging results in some degree of deterioration. If a manufacturer warranties a 50 kWh battery to last for 150,000 miles, it expects the battery to perform up to the warranty standards for about 1,000 cycles (assuming three miles per kWh). If the battery experiences cycles of charging and discharging from V2G as well as from driving, then 1,000 cycles could occur well before the vehicle has traveled 150,000 miles. As V2G pioneer Tom Gage notes, “Almost without exception, [vehicle manufacturers’] first response is, ‘If you use my battery for that purpose, we will void the warranty’” (Halper 2013).
If a battery costs $250 per kWh of capacity and has a useful lifetime of 1,000 cycles, V2G services would need to earn about $0.25 per kWh to compensate for the wear and tear on the battery. V2G will have broader applicability as battery technology continues to reduce costs and improve lifespan.

There are three caveats to that calculation.

- The “useful life” is often considered to end when the battery’s maximum capacity, and therefore its range, has declined to 70 or 80 percent of its initial capacity. The difference between 70 and 80 percent changes the necessary level of V2G revenue from about $0.20 to $0.30 for a Nissan LEAF (Saxton 2015). Other research finds that even the 70 percent threshold is overly restrictive when considering actual driving needs; increasing charging infrastructure should enable EVs to remain useful after capacity declines (Saxena et al. 2015).
- Several automakers have found that manufacturing capabilities and battery management systems allow for longer lifetimes than originally anticipated. However, these systems are optimized for driving, not V2G.
- The battery cycles from V2G are not identical to the battery cycles from driving. It may be too simplistic to treat all cycles the same. In particular, those from V2G may be more constant, with lower power output. A test of a Honda vehicle for V2G found no degradation from providing frequency regulation (Shinzaki et al. 2015). Other research suggests that the slower discharge from V2G produces less wear on the battery than does driving (Peterson 2012).

**EMOTORWERKS JUICENET**

As an example of the commercial application of load flexibility, eMotorWerks develops smart chargers and earns revenue by providing a range of grid services. Some of its products include after-market adaptations to make existing chargers “smart.”

The company’s JuiceNet Energy Services Platform can operate with a broader range of loads than just EVs. EMotorWerks, which is starting to work with water heaters, finds a high intrinsic value in modulating large, distributed, shiftable loads. This can help utilities avoid peak generation and capacity expansion.

The platform includes predictive algorithms, a self-learning driver model, a smart phone app, short control latency (three seconds), and instant local grid response. It can benefit ISOs, utilities, and end consumers.

EMotorWerks is participating in California’s Supply-Side Pilot, which entitles EV owners to a $100 rebate on their charging systems for enrolling. The company also won an award through California’s Demand Response Auction Mechanism.

One of the preferred options for many customers is “green charging.” This technology employs an algorithm by WattTime to selectively charge the vehicle when the greenest power is available, with an underlying goal of charging by the departure time regardless. This option would be especially important in an area where the vehicle is charging overnight in the Great Plains or the Midwest, when depending on the grid conditions either coal or wind power could meet the load from vehicle charging. Some modeling shows that smart charging for the lowest cost can increase coal generation, but that does not take into account innovations such as this.

**EVERSOURCE SMART CHARGING**

Eversource, a New England company that delivers electricity, is conducting a smart-charging pilot project. The company participated extensively in the UCS conferences.

When looking at grid impacts, Eversource believes that the speed of EV charging is as important as the time of day. Rather than using time-of-use pricing, its smart-charging pilot focuses on controlling the rate of charging. The company subsidizes EV owners’ purchase of Level 2 chargers that are managed to operate at their full capacity during low-demand periods but are restricted to Level 1 charging during high-demand periods.

This structure avoids the need for the extra utility meter that a time-of-use plan would have required (although the charger itself contains a meter that has been approved as revenue-grade in Europe). It also helps mitigate the post-peak demand surges that might occur in a time-of-use plan because the chargers do not suddenly switch on all at once—many vehicles will be fully charged by the time the system returns to Level 2 charging. Further, this structure is easier to manage for utilities that may not have back-office systems set up to include additional meter readings or offer EV-only, time-of-use billing. Finally, this plan never turns off the charging; it only reduces it to Level 1, and the customer can choose to override.

To date, only about 5 percent of charging events have used the override option. Customers have also proven to be very sensitive to the capital cost of chargers, indicating the importance of the rebate for ensuring the adoption of smart chargers.
GREENLOTS

Greenlots, a charging provider, discussed a number of smart-charging projects at the conferences, with its staff offering observations on workplace charging and the integration of stationary storage.

Greenlots provides demand response through workplace charging in Southern California Edison territory. One of its projects features 80 Level 2 chargers. Upon connecting, drivers select one of three options: a high price to charge as fast as possible with no demand response participation, a medium price for allowing the system to throttle back to a Level 1 charger during a demand response event, and a low price for allowing the system to stop charging during a demand response event. The exact prices, established one day ahead, are displayed at the payment kiosks, on the website, and via a mobile app. When a demand response event is called, users receive a text message and can pay a fee to opt out.

When instructed to cut load by an OpenADR signal from Southern California Edison, Greenlots uses the SEP2.0 protocol to communicate with the vehicles. The system also notifies EV owners to move their vehicles when charging is completed or incur a parking fee (an innovation recently adopted by Tesla for its Superchargers). This is to discourage drivers from leaving fully charged vehicles in charging spots.

In a separate project, Greenlots worked with Hawaiian Electric Company to integrate storage with direct current fast chargers. Here, the motivating factor was that the location could accommodate only 23 kW demand. To operate a 50 kW fast charger in this location without upgrading the distribution service, Greenlots installed a battery with the fast charger. Although fast chargers are normally thought to focus on charging vehicle as fast as possible, Greenlots is examining the value of doing short-term demand response (on the order of a few minutes) with such systems.

REAL-TIME APPLICATIONS FOR SMART CHARGING

The Boston conference included discussions of early pilot studies of smart charging, as well as lessons from the pilots on the use of autonomous features and functions.

Alec Brooks, of Aerovironment and previously of AC Propulsion, offered a series of examples of smart charging dating back to the early days of vehicle-grid integration. AC Propulsion’s tzero, the precursor to the Tesla Roadster, included bidirectional capabilities. Another AC Propulsion project involved demonstrating V2G capability with an electric Volkswagen Beetle in California in 2001 (Brooks 2002). In that market at that time, frequency response was a particularly valuable product. Brooks later took part in a PG&E/Tesla smart charging pilot in 2007 (Brooks and Thesen 2007), as well as a Google smart charging pilot in 2009 (Brooks et al. 2010). The Google pilot was binary: each vehicle would either be charging or not. With many vehicles charging, minor variations in power draw can be accomplished by turning individual vehicles on or off rather than by modulating their charging level. With this approach, the system only needs to communicate with the cars deemed to be on the margin (such as cars that are near a full charge and not expected to be needed for several hours).

Autonomous frequency-responsive charging could provide real-time services while not needing real-time communication with a central source. Vehicles could provide immediate response to grid conditions, at low cost. It would be possible to provide all of California’s necessary frequency regulation with about one million EVs (out of the 22 million cars in California), as long as their charging times were spread relatively evenly throughout the day.

With this or other options for smart charging, the financial benefit per vehicle is likely to be low, so solutions need to be low cost as well. EV chargers will compete with other flexible loads such as water heaters for the same market. As more competitors seek to provide a service, the price falls, which must be kept in mind when developing a business case for smart charging.

OTHER PROJECTS

The California Public Utilities Commission has developed an extensive database of many other vehicle-grid integration pilot projects (Orford 2016). A few notable projects not yet in that database, and also unable to present at the UCS conferences, include the following:

- The Pecan Street Project in Austin, Texas, concluded its Smart Grid Demonstration Program in 2014 (Pecan Street Inc. 2015). The project team created a system to tie together EV charging with PV production, such that the EV only began charging when the PV system was producing power. Participants solved a number of issues related to charging protocols.
Air conditioner energy use was significantly higher than EV energy use in most months, and so the project also demonstrated integration between vehicle charging and air conditioning. The Energy Switch system described in the report utilizes a relatively small battery (2 kWh), greatly smoothes load profiles, integrates PV, and can mitigate peak demand for EV charging.

- ERCOT tested electric trucks for fast frequency response. These trucks were part of a Frito-Lay delivery fleet in Ft. Worth, Texas (Mitchem 2015). The vehicles were technically successful at following the signals from the grid, but the economics were not favorable given the small project size (100 kW), the cost of telemetry requirements, and the low prices for this service in the ERCOT region.

- The Pacific Northwest Smart Grid pilot project and the PNW Final Technology Report were extensive and included a major focus on “transactive energy” (Hammerstrom et al. 2015). This would be a key catalyst for integrating PV-EV into the grid. Communication, interoperability, and system integration were pervasive issues.

- The PowerShift Atlantic project did not include electric vehicles but did use other flexible electric loads, enabling the grid in Atlantic Canada to accommodate high levels of wind power penetration (Losier 2015).
Modeling Results

Widespread deployment of EVs with smart charging could affect the nation’s electricity grid at all scales, from improving power quality from a local distribution feeder to supporting midday electricity demand and making better use of solar power across an ISO territory. EV charging could act as a flexible load on the timescale of hours, vary every few minutes for frequency response, or provide portable storage with vehicle-to-grid technology.

How can we quantify the benefits of smart charging? The electricity system is enormously complicated and subject to any number of changes in the years to come.

UCS has modeled the impacts of smart charging using the Regional Energy Deployment System (ReEDS) of the National Renewable Energy Laboratory (NREL). ReEDs, a long-term capacity-expansion model for the deployment of electric power generation technologies, calculates the cost-optimal mix of technologies to meet demand requirements in two-year increments out to 2050. We used UCS ReEDS, our 2016 version of the ReEDS model, which was based on the version used in NREL’s 2016 Standard Scenarios annual report. UCS adjusted the NREL model based on project-specific data and estimates from recent studies.

Computer models do not predict the future; rather, they are a way to illustrate the possible effects of specific changes. UCS employed three scenarios based on the NREL Standard Scenario. All of these scenarios include the impacts of existing state and federal climate and energy policies, as well as planned power plant construction as of January 2017 and announced retirements as of October 2016. In our reference case, we modeled no load growth from electric vehicles. Two other cases assumed moderately aggressive growth in EV deployment, increasing from about half a million EVs on the road today to about 12 million electric vehicles by 2025 and 120 million by 2050. The eight states following California’s Zero Emission Vehicle (ZEV) regulations account for about 25 percent of US population and have a goal of putting 3.3 million ZEVs on the road through 2025. NREL’s Vehicle Electrification Scenario, the basis for our EV energy demand, assumes no regional differences in EV market penetration. This is not the case of today’s quite pronounced regional differences. EVs have achieved their greatest levels of adoption in states with relatively clean electricity systems, such as California, Oregon, and Washington.

NREL’s Vehicle Electrification Scenario assumes a split between managed and unmanaged charging. We sought to assess the difference between these two strategies, and so modeled one case with entirely managed charging and the other with entirely unmanaged charging. In the unmanaged case, the vehicles add to hourly energy demand according to a specific schedule, potentially increasing peak demand. In the managed case, using a very basic modeling of smart charging, the vehicles’ load is added to the daily energy demand that must be met. The model determines the hours of the day when it is most cost effective to supply that energy but does not consider any benefits or revenues from providing any sort of grid services, reserves, or storage (although V2G could quite well be more widespread by 2030).

This basic form of managed charging lowered average electricity prices slightly (0.4 percent by 2030), but it increased carbon dioxide emissions slightly (1 percent by 2030) relative to the unmanaged charging case. Similar results were found by the NREL (Melaina et al. 2016), the EPRI and the Natural Resources Defense Council (EPRI 2015), and Georgia Tech researchers (Thomas et al. 2013).

One important reason for this is the lack of a Clean Power Plan or similar policy. The ReEDS model optimizes the electricity system for lowest-cost operation. Pollution imposes an economic cost on society, but it is not fully reflected in energy prices and is only recognized by the model when incorporated into policy. As a result, managed charging would take place overnight in some regions and could increase generation from coal power plants (as well as other types of power plants).
A second reason is the limited form of smart charging recognized by the current version of the ReEDS model. Existing smart charging systems demonstrate the ability of EVs to contribute to reserve requirements, provide demand response, and even function as storage. The model does not reflect these capabilities, even though they are likely be widespread by 2030.

A third reason is the rebound effect. Managed charging lowers electricity costs compared with unmanaged charging, and it even lowers electricity prices slightly compared with the non-EV case. Lower costs induce higher consumption. Both the managed and unmanaged cases stipulate the same energy demand from EVs (about 70 million MWh per year, resulting in about 28 million tons of CO2). The managed case sees slightly increased electricity demand for other applications, with increased CO2 as a side effect of lower electricity prices.

The differences among the scenarios are very small, because EVs will have only a minor impact on the electricity system by 2030 even with optimistic growth projections. These changes are too small to be taken as definitive given the uncertainty inherent in modeling. However, these slight differences do hint at concerns that should be addressed. As the NREL study noted, “An increase in emissions need not always occur. The change in emissions depends on the grid mixture and the structure that encourages vehicle behavior” (Melaina et al. 2016).

The managed charging case found slight cost savings for all consumers from smart charging, due to reductions in electric system costs. Unmanaged charging requires more generation capacity, so that scenario has a higher cost of operating the grid. The total generating capacity of the grid in 2030 in the “managed charging” case is about 17 GW lower than in the “unmanaged charging case.” The difference largely comes from adding new natural gas capacity to meet the unmanaged electricity demand. The unmanaged case features 15 GW of new (post-2015) natural gas generation over the reference case in 2030, while the managed case does not. The additional natural gas capacity in the unmanaged case is primarily combined-cycle gas turbines. Other generation capacity is largely unchanged. There are some slight differences in electricity generation, but these are also too small to be taken as definitive.

Table 1 (p. 22) summarizes the national results under the three models.

We conclude that “smart” charging will have to look beyond “lowest nominal cost” and consider the goal of reducing pollution. Tools such as the WattTime algorithm can help here. This program, incorporated into EMotorWerks’ JuiceBox charger, can allow overnight Level 2 charging that selectively charges when wind is on the margin. A level 2 charger provides about 20 miles of range per hour of charging and might need to operate for only one or two overnight hours. That allows a great deal of leeway.

It would be economically efficient to design regulations so that pollution is no longer an externality (a cost that somebody else pays). Under such a paradigm, the cost of the damages from pollution would be paid by the producer of the emissions. Lowest nominal cost would then better reflect lowest actual cost, including the impacts of pollution. Without such a system in place, other solutions include the charging algorithms mentioned above, “green power” purchasing options to increase the amount of renewable energy, and regulatory action to require emissions-reducing technologies.

When considering pollution, the location of emissions matters as well as the quantity. EVs move emissions out of the city center, and from multiple point sources to relatively few, where they can be more easily controlled.

A study in ERCOT found that EVs reduce emissions of carbon dioxide, nitrogen oxides, particulate matter (PM10 and PM2.5), and ultrafine particulate matter (UFPM), although they can increase emissions of sulfur dioxide due to increasing generation from the remaining coal plants (Legatt 2016). All these emissions can be reduced by smart charging. The reduction and relocation of UFPM is of particular importance: this pollutant does not travel far from its emissions source, so moving it out of city centers yields considerable health benefits. Ultrafine particles can pass through the blood-brain barrier and lodge in the prefrontal cortex; an extensive and expanding literature documents the dangers of continued UFPM exposure (Calderón-Garcidueñas et al. 2008).

At higher levels of renewables, the benefits of smart charging are more notable. NREL conducted a California case study featuring a 50 percent reduction in greenhouse gases by 2030, accomplished by 56 percent renewables in the energy grid (Brinkman et al. 2016). At times, solar in this modeled grid could represent up to 60 to 85 percent of power generation. The study found annual savings from smart charging of $190 to $650 million per year in generation costs, which comes out to $63 to $217 per vehicle. This result is a net economic benefit if the installed cost of the smart charger is under $2,000 (common for residential Level 2 smart chargers but not yet so for workplace or public systems). Also, this does not consider other financial effects, such as changes in building-level or distribution-level peak demand. Nor does it consider the economic value of emissions reductions—managed charging reduces grid CO2 emissions by 1 to 4 percent. Another study found an even greater benefit if the storage mandate is not in
place: smart charging of EVs can provide much of the benefits of storage at a lower cost (Denholm and Margolis 2016). If regulations require a substantial storage capacity, and “smart charging” does not count toward this requirement, then it has only modest additional value as a flexible load.

In general, EVs benefit utility ratepayers. Increased electricity sales enable utilities to spread their fixed costs over more kilowatt-hours, reducing costs per kWh (or at least slowing the rate of increase) for all customers. The benefits to all ratepayers account for $73 to $166 per vehicle per year in a study of several Northeastern states (Lowell, Jones, and Seamonds 2017). Added to this are the benefits to the vehicle owners and the benefits of reducing greenhouse gas emissions. Another study finds a net present value of $850 per vehicle in grid benefits (E3 2014). Other studies also describe these benefits to ratepayers (Malgrem, Roberts, and Sears 2016; Baumhefner, Hwang, and Bull 2016).

### TABLE 1. Modeled National Impacts in 2030

<table>
<thead>
<tr>
<th></th>
<th>Reference Case</th>
<th>Managed Case</th>
<th>Unmanaged Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generating Capacity (GW)</strong></td>
<td>1,102.5</td>
<td>1,104.4</td>
<td>1,121.4</td>
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<tr>
<td>Coal</td>
<td>206.4</td>
<td>206.5</td>
<td>206.7</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>419.1</td>
<td>418.4</td>
<td>434.2</td>
</tr>
<tr>
<td>Nuclear</td>
<td>95.9</td>
<td>95.9</td>
<td>95.9</td>
</tr>
<tr>
<td>Hydropower</td>
<td>84.1</td>
<td>84.2</td>
<td>84.3</td>
</tr>
<tr>
<td>Wind</td>
<td>108.7</td>
<td>111.1</td>
<td>110.8</td>
</tr>
<tr>
<td>Solar</td>
<td>149.8</td>
<td>149.9</td>
<td>151.0</td>
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<tr>
<td>Coal</td>
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<td>758</td>
<td>758</td>
</tr>
<tr>
<td>Hydropower</td>
<td>366</td>
<td>367</td>
<td>367</td>
</tr>
<tr>
<td>Wind</td>
<td>392</td>
<td>401</td>
<td>401</td>
</tr>
<tr>
<td>Solar</td>
<td>239</td>
<td>239</td>
<td>242</td>
</tr>
<tr>
<td><strong>Electric Sector CO2 Emissions (MMT)</strong></td>
<td>1,682</td>
<td>1,733</td>
<td>1,716</td>
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<tr>
<td><strong>EV Electricity Consumption (GWh)</strong></td>
<td>--</td>
<td>69,590</td>
<td>69,590</td>
</tr>
<tr>
<td><strong>EV Electricity CO2 Emissions (MMT)</strong></td>
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<td>28</td>
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<tr>
<td><strong>Vehicle CO2 Emissions Avoided (MMT, estimated at 240 g/mi)</strong></td>
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<td>~50</td>
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<tr>
<td><strong>Average Electricity Rate ($/MWh)</strong></td>
<td>104.88</td>
<td>104.85</td>
<td>105.31</td>
</tr>
</tbody>
</table>

GW=gigawatts; TWh=terawatt-hours; MMT=million metric tons; g/mi=grams per mile; MWh=megawatt-hour
Conclusions and Policy Recommendations

It is no longer novel to say that electric vehicles have considerable potential to support major deployments of renewable energy. This has been demonstrated in theory and practice through many papers and pilot projects. Presently, these capabilities of EVs are not greatly valued, because the electricity generation system has abundant flexibility. However, EVs could provide a low-cost complement to dedicated energy storage systems in the future, and they could be very useful on a grid with abundant renewable energy.

Over the past two years, UCS has had the opportunity to meet with a broad range of experts, many of whom have worked on smart charging for electric vehicles for a decade or longer. From our research, a review of the literature, and the convenings of experts and stakeholders, we have drawn several conclusions.

Support Workplace Charging

Workplace charging can provide many benefits. It provides a natural opportunity to assist with “duck curve” conditions because it tends to be concentrated in the late morning, when solar produces power but air conditioner loads have yet to peak. However, workplace charging is not a prime candidate for demand response, a service that typically has its highest value in the afternoon or early evening. Nor is it optimal for frequency regulation: the vehicles are available only for about 17 percent of the hours in a typical week (Quattrini 2016).

Workplace charging can raise awareness of EVs and improve range confidence. A prospective EV buyer would know they could charge at work and even discuss the technology with colleagues who own EVs. Workplace charging often leads to remarkable, rapid increases in EV ownership (Gaschel 2016).

Two main concerns arise: demand charges and infrastructure cost. Demand charges could be reconsidered to take into account the timing of the peak (Allison and Whited 2017; Lazar and Gonzalez 2015). Alternatively, a greater portion of cost recovery could be shifted to energy costs with time-of-use pricing.

For several reasons, it costs more to install EV chargers at workplaces than at residences (Agenbroad and Holland 2014). As colleagues adopt EVs, charger capacity becomes saturated (Quattrini 2016) and the number of vehicles may exceed the number of chargers. The chargers may remain occupied for the entire day, even though the vehicle may be charged after only an hour or two. Because of the cost of installing new chargers, a business can seek to encourage EV owners to rotate their vehicles. Another idea is a multiplexed charger, a single charger with four cables automatically rotates the charge without requiring moving or even unplugging the vehicles.

On the down side, ensuring that charging capacity is fully utilized at all times would likely result in having far fewer chargers than vehicles, spending considerable time and effort moving vehicles around, and losing opportunities for load flexibility. A preferable solution would be to reduce the installation cost of charging stations. This might involve scheduling the installation to coincide with work on the parking lot or garage to lessen the costs of digging into concrete.

Consider Greater Use of Time-Varying Rates for EV Charging

Changes in the design of rates are crucial for enabling workplace charging. In particular, it is important to reconsider demand charges that ignore the timing of the peak demand. Shifting more of the recovery of utility costs from demand charges to hourly volumetric rates would better align demand with system needs.
Time-of-use pricing offers price signals to limit contributions to system or network peaks, and smart charging works well with that structure. This is already established in policy, encouraging vehicle owners to charge in a manner advantageous for the grid. Some additional management may be necessary to stagger the charging when a low-cost period begins, and this is easy to implement. Both economic and environmental factors motivate customers to enroll in such programs, and once enrolled, customers tend to respond to the time-of-use price signals.

An important consideration here is that ratepayer advocates and others remain unconvinced that promised system efficiencies have happened when utilities installed advanced metering infrastructure, including smart meters. The result is some hesitancy about wider installation until the benefits are better documented. Alternative “sub-metering” approaches rely on the metering capabilities of the EV chargers, which would avoid the costs of installing new utility meters. This approach requires regulatory flexibility on metering requirements, as well as the ability by the utility to implement subtractive billing (if the primary account is not on the time-of-use rate but the EV is).

Another consideration is the need to revisit time-of-use periods and adjust them as more renewable energy comes onto the system, especially solar power with its relatively predictable daily cycle. Some existing peak periods start earlier than appropriate and make preconditioning an EV difficult.

A third consideration is that not all customers have the ability to adjust their energy consumption. It is important to be cautious when applying time-of-use rates broadly. For example, some customers have medical devices that draw significant power and cannot shift that demand. Time-varying pricing with “shadow billing” and “hold harmless” provisions can achieve efficiencies without hurting those who cannot alter their consumption patterns.

More sophisticated time-varying rates are possible, and pilot projects are evaluating the performance of these rate structures for EVs and for other loads.

Align Regulatory Incentives to Realize Distribution System Benefits

Compared with unmanaged charging, smart charging can limit the need for upgrading the distribution system (as could smart technology on solar PV and other distributed energy resources). Incentives should encourage the use of technologies to reduce electric system costs.

A traditional framework for regulating utilities might not give a reason to look at these solutions. Electric utilities are responsible for maintaining the distribution system. They can recoup the costs of necessary investments. But what if flexible loads could enable the utility to deliver equal or better reliability at lower cost than upgrading transformers and substations? If the existing paradigm is to put “steel in the ground” and earn an approved rate of return on it, what would motivate a utility to manage its loads so as to not need to put steel in the ground?

A utility commission could directly require a utility to take certain actions. Alternatively, it could allow the utilities to earn a higher rate of return by finding creative solutions that meet specific goals, such as limiting system cost, reducing pollution, or improving reliability. Reforming the Energy Vision in New York is applying some solutions and considering more far-reaching changes, including a range of alternative business and regulatory frameworks. A utility could offer rebates to ratepayers who take actions that help it meet these broader goals.

In designing pilot projects, various stakeholders must recognize benefits, readying them to apply and scale up new options. If a smart charging solution involves the utility, the EV manufacturer, the EV owner, and the charger manufacturer, everybody has to find enough benefit to justify the time and effort needed to implement the solution. The cost-benefit analysis should become less of a hurdle as the scale of smart charging increases (thereby allowing greater grid benefits) and as these solutions become more familiar (requiring less time and effort to implement). As an additional benefit, larger-scale projects will feature greater predictability in performance. The more vehicles in a fleet, the greater the accuracy in estimating how many are charging and requiring grid services at any one time.

Enable EV-Charger Participation in Grid Services Markets

Flexible loads such as EVs can participate in ancillary services markets that offer potential revenue streams. However, smart charging will face competition from other flexible loads (for example, water heaters) and from dedicated batteries. As a result, the
markets may become saturated relatively quickly. Increasing deployment of renewables is not expected to significantly expand ancillary services markets in the coming decade.

Typically, aggregation is required to enable EVs to participate in such markets. Some markets require a minimum 100-kW resource size, which is fairly reasonable. This would enable about 15 Level 2 chargers to cease charging entirely (such as for demand response). Some other markets have higher thresholds. Also, some costs of participating in markets are independent of resource size, making it difficult for small projects to participate. Aggregation is a solution, but some jurisdictions limit the ability of aggregators to participate in grid services markets.

Consider Flexible Loads and Vehicle-to-Grid in Storage Proceedings

Many states are interested in energy storage, particularly for accommodating increased renewables. Compared with dedicated stationary storage, EVs have intermittent connections that cannot be inspected every time, the risks of damage to batteries or cables are greater, and batteries are not optimized for providing grid services. However, the EV battery may be able to provide grid services at lower cost. With more and more EVs on the road and needing to be charged, why not make them a responsive load?

Other flexible loads include electric water heaters and commercial air conditioners. These cannot put electricity onto the grid, so they are not entirely equal to dedicated energy storage. Still, some degree of partial credit toward storage mandates could be appropriate.

The most important challenge for dedicated storage is identifying the value proposition. What outcomes are sought from storage? Can load flexibility achieve them?

Vehicle-to-grid is similar to other energy storage technologies in many ways, except that its mobile nature places it apart. It is not guaranteed to be connected to a particular distribution feeder, for example. This mobility can be a significant advantage, especially if using vehicle-to-home or vehicle-to-building for resiliency during natural disasters. Creative pilot projects around these issues would be valuable.

Define “Smart” to Include Pollution

Our modeling and other studies suggest that under certain circumstances managed charging could increase emissions relative to unmanaged charging. This could occur if the off-peak power in a region has greater emissions per kilowatt-hour than the on-peak power, and if the charging algorithm fails to account for the impacts of pollution. Therefore, we recommend that smart charging pilots or programs evaluate pollution impacts before encouraging charging at specific times. Wherever possible, EV owners should have a low-emission charging option.

An economically efficient solution is to incorporate the costs of pollution into energy prices. Lowest nominal cost would then better reflect lowest actual cost. Until such a system is in place, other solutions should be employed. For EV charging, these can include consumer actions such as “green” charging algorithms and “green power” purchasing, or regulatory action to require emissions-reducing technologies.

Accelerate Learning from Pilot Projects to Develop Local Expertise in Smart Charging

Pilot projects are not necessary to demonstrate proof of concept in smart charging, but they may be useful to ensure that utility personnel, regulators, and consumers are familiar with the concepts involved, as well as to resolve technical issues. We suggest a few questions to consider in designing pilots, although not all will be applicable in every case:

- What type of EV charging will the pilot focus on? Residential charging? Workplace? Private fleets? Public fleets, such as a car-sharing initiative?
- What specific vehicle-grid integration issues will the pilot address? Limiting the demand increases caused by residential EV chargers? Increasing midday demand to take advantage of surplus solar curve? Providing demand response capability? Managing load to limit local congestion? Integrating workplace chargers with a building’s energy management system to avoid demand charge increases?
- What do peers and experts say about comparable pilots, issues encountered, solutions developed, and lessons learned?
• How will the utility use the data generated by the technology? Beyond just the charging profiles, is there an opportunity to make use of chargers’ data on voltage, frequency, and power quality?
• What are the various communication options? What are the advantages and disadvantages of each? Why are certain options selected. Should the utility communicate directly with vehicles, or do smart chargers offer advantages? What other technical issues arise? How can we share practical lessons learned?
• What are the public health benefits of emissions reductions and displacement? How can we quantify them in economic terms?

Participants in the UCS conferences suggested many other ideas for research. Among possible additional topics for future research are:

• How do we design policies to avoid having stranded assets?
• To what degree could public utility commissions relax their metering requirements to allow sub-metering from EV chargers?
• How can we better understand distribution-side costs and benefits?
• How do time-of-use rates affect low-income populations? What are the environmental justice impacts? And how can they be addressed?

We also suggest improving the models to better reflect the actual capabilities of smart charging of electric vehicles in providing grid services. Any analysis looking at 2025 or 2030 should consider vehicle-to-grid arrangements for some fraction of the vehicles.

The greatest uncertainty surrounding smart charging and vehicle-grid integration is the future of the transportation system. What if shared, autonomous, electric vehicles become the norm (McKerracher et al. 2016; Weiss et al. 2017)? They will likely have “charging depots” with high-powered connections for fast charging, and possibly energy storage. Such vehicles would have an economic incentive to maximize their utilization; they would not be idle for 90 to 95 percent of the time, which is now the case with privately owned vehicles. Still, if travel profiles remain similar to today’s, many vehicles could be idle during the workday, with demand surges in the morning and evening rush hours. Midday charging on solar power would remain viable, as would overnight charging from wind power. Flexibility would decline during the evening rush hour. Given this vast uncertainty, it is probably not useful to attempt to quantify the impact of specific smart charging strategies in 2040 or 2050. In general, load flexibility seems likely to prove useful in integrating increasing levels of renewable energy into the electricity system.

Electric vehicles have the potential to significantly reduce emissions and improve the operation of the electricity system. The costs of unmanaged charging, and the benefits of managed charging, will first affect the distribution grid but will ultimately affect generators as well. The promising combination of time-varying rates and workplace charging can enable electric vehicles to charge at low cost from solar power that might otherwise be curtailed. This solution also increases the effective range of EVs and increases familiarity with the vehicles. Rate reform will be important to enable workplaces to make use of the abundant solar electricity in the middle of the day. In some areas, the surplus clean energy is wind power available at night. Smart charging can also make use of this resource, with charging algorithms or policies to ensure the electricity demands of the vehicles are met by clean energy. Along with other flexible loads, EVs can provide a low-cost option for integrating renewable energy into the grid.
[REFERENCES]

Note: all web links accessed May 1, 2017.


Electric vehicles (EVs) benefit both the environment and drivers. For the environment, they reduce petroleum use, global warming emissions, and tailpipe pollution. Global warming emissions from EVs depend in part on the source used for electricity generation, which varies across the United States. According to a 2017 Union of Concerned Scientists (UCS) analysis, driving the average EV in the United States produces the same emissions as a gasoline car getting 73 miles per gallon (mpg), considering total emissions from gasoline and electricity production and distribution (Reichmuth 2017). This environmental benefit will only increase as the nation’s electricity generation continues to move away from carbon-intensive sources like coal to cleaner sources like wind and solar power.

EVs benefit drivers beyond reducing each person’s carbon pollution footprint. Going from Pump to Plug looks at a second critical advantage of EVs: the cost to owners. While the cost of electricity varies across service providers and rate plans, using electricity to power a vehicle is almost always cheaper than using gasoline. Electricity prices are also less volatile than gasoline prices, and they are less sensitive to supply disruptions and international market movements because generation is distributed among many facilities and fuel types.
In addition, EVs lessen or eliminate some vehicle maintenance costs. Because battery EVs (BEVs) have no gasoline engine, they do not need oil changes, spark plugs, or timing belts. Also, EVs offer performance advantages over gasoline vehicles, and they bring the convenience of refueling at home.

With savings on transportation through lower fuel and maintenance costs, US consumers can put more money in their pockets by switching to EVs. However, the costs to manufacture an EV are typically higher than those of a comparable gasoline vehicle, largely due to the cost of battery packs. That said, battery costs are declining rapidly, which should reduce the price gap between a gasoline-powered car and an EV. Presently, government incentives and manufacturer discounts lower EV prices for car buyers, and EV leases are available at competitive rates. All this makes the fuel and maintenance savings of EVs accessible to many car buyers (Reichmuth and Goldman 2017).

**EV Charging at Home: Almost Always Cheaper Than Gasoline**

The cost to fuel an EV depends on the cost of the electricity used. About 80 percent of EV charging happens at home, making the cost of residential electricity the primary factor in the cost to recharge an EV in most cases (ARB 2017a; INL 2015).

The cost of residential electricity varies from provider to provider; even a single service provider might offer several rate plans. UCS examined the rates in the 50 largest cities in the United States, plus seven other US cities. Our analysis looked at EV-charging costs on both the default rate plan and the lowest-cost, time-of-use or EV-specific rate plan available. To express electricity costs as equivalent gasoline prices, we used the average EV efficiency and the average efficiency for new 2016 gasoline vehicles (Reichmuth 2017; EPA 2016). Electric rates included taxes and fees collected on a usage...
bears. UCS did not include fixed charges, such as monthly meter charges. Increased electricity usage from recharging an EV would not change these.

Although electric rates vary significantly across the nation, UCS found that at least one rate plan in each location studied would make driving an EV cheaper than driving the average new gasoline vehicle (Figure 1, p. 4–5). On standard rate plans, electricity costs for recharging an EV range from $0.05 per kilowatt hour (kWh) to $0.41 per kWh (NREL 2017). This translates into a cost for refueling an EV ranging from a low of $0.43 per gallon equivalent to a high of $3.34 per gallon equivalent, with a median of $0.90 per gallon equivalent. Only two of the 60 electricity providers studied had EV recharging costs higher than the current cost of gasoline.

Recharging on a time-of-use (TOU) or EV-specific rate plan can greatly reduce the cost to recharge an EV. TOU plans offer lower-cost charging during off-peak hours, usually during the late evening or early morning. Most cars are parked at home overnight, making TOU plans a good fit for most EV drivers. The off-peak TOU rates vary from $0.03 to $0.21 per kWh, resulting in equivalent costs ranging from $0.25 per gallon in Minneapolis to $1.78 per gallon in parts of Los Angeles (NREL 2017).

Recharging an EV on a TOU rate can yield significant savings on fuel costs. Using TOU pricing, our analysis found that all electricity providers examined have EV fuel costs at least $1 per gallon equivalent lower than the current cost of gasoline. All but one service provider offer electricity on a TOU plan at a cost lower than the cheapest gasoline price over the prior ten years.

Although TOU rates can mean significant savings on off-peak power use, the tradeoff is that power is more expensive during peak periods. If a household cannot shift some of its electricity use from peak to off-peak times, then a TOU rate plan may not be the best choice. Some electricity providers offer the option of installing a second electricity meter dedicated to EV charging; owners can charge their vehicles on a separate rate plan from the rest of the household. This allows using a lower, off-peak TOU rate for the power to recharge the EV, while a flat rate for the rest of the house avoids high peak charges. However, TOU rates still could be inconvenient to some drivers, such as those whose work schedules outside normal business hours prevent them from charging at home during the day. For those drivers, the standard rate plan may be more appropriate.

For most customers, the default is a flat or tiered rate plan. However, in some locations the default rate will be moving to a TOU plan. Under a California Public Utilities Commission ruling, the default rate plan for many electric customers will be a TOU plan, starting in 2019 (CPUC 2017).

### BOX 1.

**Residential Electricity Rate Plans**

Many electricity customers can choose among rate plans. The availability of a time-of-use rate, with lower-cost electricity at night, can be an important factor in EV charging.

**Flat Rate Plans:** Flat rate plans are simplest: the cost to charge does not change based on the time of day. Users pay the same for power in low-demand times, like late nights, as during high-demand times, despite potentially large differences in the cost to the electric provider to deliver power. These plans are often more expensive for EV charging.

**Tiered Flat Rate Plans:** Tiered flat rate plans have a cost to charge that is constant at all times of the day but changes when a household exceeds set usage amounts during a month. Most electric providers using a tiered-rate structure have two to four tiers and charge more for power in higher-usage tiers. Charging an EV at home on a tiered flat rate plan would increase the likelihood that users would be in a higher rate tier.

**Critical Peak Pricing Plans:** Users pay less for electricity during most times in exchange for high prices during a small number of peak events, such as late afternoon on a hot summer day. Because peak events do not occur in overnight hours, the plans can reduce the cost to recharge an EV.

**Time-of-Use Plans:** Time-of-use (TOU) plans offer lower prices for electricity during times when demand is low because electricity providers can draw on less costly generation sources. These off-peak hours are usually late at night and early in the morning, although the exact times depend on the provider’s generation sources and consumer demand.

TOU plans are often the lowest-cost electricity for charging an EV. However, this type of plan also increases the cost of electricity during peak hours, so households that need to use large appliances or air conditioning during the day would need to consider their ability to reduce use during these peak hours. Some service providers allow the installation of a separate meter for the electric vehicle: the owner can charge the EV on a TOU rate while using a flat rate for the rest of household electricity use.

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**Time-of-use rates can mean significant savings on off-peak power use.**
FIGURE 1. Comparing Electricity and Gasoline Refueling Costs

<table>
<thead>
<tr>
<th>Location</th>
<th>Electricity Provider</th>
<th>$/Gallon or $/Gallon Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ Mesa</td>
<td>City of Mesa</td>
<td>$0 $0.50 $1 $1.50 $2 $2.50 $3 $3.50 $4 $4.50</td>
</tr>
<tr>
<td></td>
<td>Salt River Project</td>
<td></td>
</tr>
<tr>
<td>Phoenix</td>
<td>APS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt River Project</td>
<td></td>
</tr>
<tr>
<td>Tucson</td>
<td>Tucson Electric Power</td>
<td></td>
</tr>
<tr>
<td>CA Fresno</td>
<td>Pacific Gas and Electric Company</td>
<td></td>
</tr>
<tr>
<td>Long Beach</td>
<td>Southern California Edison</td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Los Angeles Department of Water and Power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Southern California Edison</td>
<td></td>
</tr>
<tr>
<td>Oakland</td>
<td>Pacific Gas and Electric Company</td>
<td></td>
</tr>
<tr>
<td>Sacramento</td>
<td>Sacramento Municipal Utility District</td>
<td></td>
</tr>
<tr>
<td>San Diego</td>
<td>San Diego Gas and Electric</td>
<td></td>
</tr>
<tr>
<td>San Francisco</td>
<td>Clean Power SF</td>
<td></td>
</tr>
<tr>
<td>San Jose</td>
<td>Pacific Gas and Electric Company</td>
<td></td>
</tr>
<tr>
<td>CO Colorado Springs</td>
<td>Colorado Springs Utilities</td>
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<tr>
<td></td>
<td>Xcel Energy</td>
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<td>DC Washington</td>
<td>Pepco</td>
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<td>DE Wilmington</td>
<td>Delmarva Power</td>
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<tr>
<td>FL Jacksonville</td>
<td>Jacksonville Electric Authority</td>
<td></td>
</tr>
<tr>
<td>Miami</td>
<td>Florida Power &amp; Light Company</td>
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</tr>
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<td>GA Atlanta</td>
<td>Georgia Power</td>
<td></td>
</tr>
<tr>
<td>HI Honolulu</td>
<td>Hawaiian Electric Company</td>
<td></td>
</tr>
<tr>
<td>IL Chicago</td>
<td>ComEd</td>
<td></td>
</tr>
<tr>
<td>IN Indianapolis</td>
<td>Indianapolis Power &amp; Light Company</td>
<td></td>
</tr>
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<td>KS Wichita</td>
<td>Westar Energy</td>
<td></td>
</tr>
<tr>
<td>KY Louisville</td>
<td>Louisville Gas and Electric</td>
<td></td>
</tr>
<tr>
<td>LA New Orleans</td>
<td>Entergy New Orleans, Inc.</td>
<td></td>
</tr>
<tr>
<td>MA Boston</td>
<td>Eversource</td>
<td></td>
</tr>
<tr>
<td>MD Baltimore</td>
<td>Baltimore Gas &amp; Electric Company</td>
<td></td>
</tr>
<tr>
<td>ME Portland</td>
<td>Central Maine Power</td>
<td></td>
</tr>
<tr>
<td>MI Detroit</td>
<td>DTE Energy Company</td>
<td></td>
</tr>
<tr>
<td>MN Minneapolis</td>
<td>Xcel Energy</td>
<td></td>
</tr>
<tr>
<td>MO Kansas City</td>
<td>Kansas City Power &amp; Light (Missouri)</td>
<td></td>
</tr>
<tr>
<td>NC Charlotte</td>
<td>Duke Energy</td>
<td></td>
</tr>
<tr>
<td>Raleigh</td>
<td>Duke Energy Progress Carolinas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Piedmont Electric Membership Corporation</td>
<td></td>
</tr>
</tbody>
</table>

Electricity – Time-of-Use Rate
Electricity – Standard Rate
Gasoline – 10-Year Low to 10-Year High
Gasoline – Current Rate

$/Gallon or $/Gallon Equivalent
The cost of electricity to recharge an EV using the standard rate plan is often lower than the equivalent cost of gasoline, and using a TOU rate plan is always lower. In fact, refueling an EV is often cheaper than even the lowest gasoline price of the last 10 years.

Note: Both electricity and gasoline costs include taxes and fees. Gasoline equivalency based on average electric efficiency of 0.325 kWh per mile and average new gasoline vehicle efficiency of 25.6 mpg.
<table>
<thead>
<tr>
<th>Location</th>
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</tr>
<tr>
<td></td>
<td>Piedmont Electric Membership Corporation</td>
</tr>
</tbody>
</table>

**FIGURE 2.** Annual Fuel Savings from Using the Average EV Instead of the Average New Gasoline Vehicle
The median EV driver could save more than $770 per year compared with the cost of driving the average new gasoline vehicle ($706 on a standard rate plan, and $818 on a time-of-use plan). Annual savings were calculated using the lowest electric rate plan available for EV charging and October 2017 gasoline prices in each city. Values in dark blue represent cities where a time-of-use rate plan is the lowest cost option and light blue shows cities where a standard (flat) rate plan is the lowest-cost or only option for residents.
This could help EV drivers: customers will default to a plan that is cheaper for most EV drivers. Those who do not have EVs can still save money if they can shift their electric use to lower-cost time periods.

Off-peak charging benefits electricity providers by lessening peak demand, but off-peak periods may not align with the availability of low-emission sources of electricity like wind and solar power. In areas with higher amounts of intermittent renewable generation, it may be important to coordinate electric rates for EV charging with the availability of renewables. This would reduce the cost of charging and minimize emissions from EV recharging (O’Connor and Jacobs 2017).

By comparing the cost of refueling the average new gasoline vehicle with the cost of recharging an EV on the cheapest electric rate plan available, UCS estimated the average annual fuel cost savings for switching from gasoline to electricity (Figure 2, p. 6–7). For every city in the study, the annual savings exceed $440 per year, and the median savings are more than $770 per year. In four cities, at least one electricity provider offers a rate plan that would lead to more than $1,000 in annual fuel savings. Most providers with the highest savings offer a TOU rate.

### Electricity Prices: Less Volatility

While the price of electricity varies among electricity providers, the average is much less volatile than that of gasoline (Figure 3). US electricity prices often rise in the summer, but year-to-year variations are low (EIA 2017a). In comparison, regional and national gasoline prices vary greatly and unpredictably, whether in response to refinery accidents, natural disasters, global politics, military actions, or other events.

Over the past 15 years, the average residential electricity rate in the United States has remained nearly constant except for minor and predictable seasonal variations. In constant dollars, the price of electricity as vehicle fuel has ranged from $0.88 to $1.17 per gallon gasoline equivalent over the last 15 years. Gasoline prices have swung from below $2.00 per gallon to more than $4.50 a gallon (EIA 2017b; BLS 2017).

While EV drivers benefit from lower and more predictable fuel costs, gasoline-powered vehicles expose car buyers to potentially large increases. For example, hurricanes in 2017 caused gas spikes of more than 30 cents per gallon in one week, and a 2015 refinery fire in California led to price jumps in the state of 25 cents in one week (Anair 2017; Flaccus 2015).

### Cost of Charging at Public Charging Stations

About 80 percent or more of all EV charging takes place at home (ARB 2017a; INL 2015). However, some charging uses facilities away from home—workplace charging, free public charging, or paid public charging (often via a charging network provider).

The cost of charging outside the home varies considerably. Many workplace chargers are free, as are some public chargers. Public chargers that are not free have a number of cost structures. Some are free to use but are located in paid parking facilities. Others base costs on the length of time charging or the amount of energy used, or they simply have a flat fee per session. Some charging network companies offer subscription plans that include unlimited charging or result in a discounted rate. And some automakers include free access to public charging networks, either through a third-party network or, in the case of Tesla, through infrastructure built and owned by the EV manufacturer. Many of the slower, Level 2 chargers in the United States are available for free (Figure 4). Except for the Tesla chargers, most of the high-power, DC fast chargers (DCFC) require payment (Box 2, p. 10) (Recargo 2017).
The cost for charging an EV away from home can vary: some chargers are free but others require a subscription fee.

**FIGURE 4.** Public EV Charging Outlets in the United States, by Type

<table>
<thead>
<tr>
<th>Parking Status</th>
<th>Free Charging</th>
<th>Pay Charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Parking</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>Parking Status Unknown</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Pay and Restricted Parking</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Free Parking</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Parking Status Unknown</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pay and Restricted Parking</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**DC Fast Charger – Non-Tesla**

**DC Fast Charger – Tesla Supercharger**

**Level 2 – Tesla Destination Charger**

**Level 2 – Non-Tesla**

Many Level 2 stations are free or free with paid parking. Most DC fast charge stations, except for Tesla Superchargers, require payment for charging, parking, or both. Some stations, such as Tesla destination chargers, are installed at businesses (such as hotels and restaurants) and are free to patrons of the businesses but require payment otherwise.

**SOURCE:** UCS ANALYSIS OF RECARGO INC. 2017.
Public Charging: Minimal Impact on Overall Cost Savings

Because the costs of charging at public stations and workplaces vary highly, it is not possible to calculate exact costs for recharging outside the home. However, we can estimate the costs to use an EV with some of the charging occurring at public facilities. Using San Francisco as an example, if 20 percent of EV charging happens at Level 2 public chargers, average fuel costs could increase from $0.78 per gallon equivalent to $1.05 per gallon (Table 1). If 20 percent of the charging occurs at faster, but typically more expensive, DC fast chargers, then the cost would increase to the equivalent of $1.36 per gallon, still well below San Francisco’s average gasoline price in September 2017 of $3.30 per gallon.

Most fee-based, DC fast charging is priced at a premium and serves as a way to enable occasional longer trips. However, some fast charging is being deployed in urban locations in order to serve the needs of those without easy access to home recharging. For example, Tesla has announced plans to install DC fast charging units in urban parking structures (Lambert 2017).

In California, most DC fast chargers have effective charging costs of less than $4 per gallon equivalent (Figure 5), although some are priced above $5 per gallon. For EV drivers who rely on DCFC for most or all of their needs, the pricing needs to be competitive with that of other options like gasoline-powered vehicles. Some EV charging providers offer plans with monthly fees that allow for lower-cost DC fast charging.

**Box 2. Types of Charging**

**Level 1—Home Charging:** Level 1 charging cords are standard equipment on a new EV. Level 1 charging only requires a grounded (three-prong) 120V outlet and can add about 40 miles of range in an eight-hour overnight charge. Overnight Level 1 charging is suitable for low- and medium-range plug-in hybrids and for battery electric vehicles with low daily driving usage.

**Level 2—Home and Public Charging:** Level 2 charging typically requires a charging unit on a 240V circuit, like the circuit used to power a common electric clothes dryer. The charging rate depends on the vehicle’s acceptance rate and the maximum current available. With a typical 30 amp circuit, about 180 miles can be added overnight during an eight-hour charge. Level 2 chargers are the most common public chargers. Public Level 2 chargers have a standard EV connection plug that fits all current vehicles, except for Teslas, which require an adapter.

**DC Fast Charging (DCFC)—Public Charging:** DC fast charging is the fastest currently available recharging method. It can typically add 50 to 90 miles in 30 minutes, depending on the station’s power capacity and the make of EV. Tesla’s Superchargers are even faster, adding up to 170 miles of range in a half hour. DC fast chargers are most useful for longer trips, cars in use most of the day (like taxis), and drivers who have limited access to home recharging.

DC fast chargers use three different plug types and are not interchangeable. Japanese automakers typically use the CHAdeMO standard; most European and American makers use the CCS system. Tesla’s Supercharging stations use a proprietary connector specific to their vehicles.

**Table 1. Illustrative Costs to Charge in San Francisco, Based on Mix of Charging Types**

<table>
<thead>
<tr>
<th>Home Charging</th>
<th>Free Level 2 Charging</th>
<th>Paid Level 2 Charging</th>
<th>Paid DC Fast Charging (DCFC)</th>
<th>Average Fuel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>$0.78/gallon equivalent</td>
</tr>
<tr>
<td>80%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
<td>$0.62/gallon equivalent</td>
</tr>
<tr>
<td>80%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>$1.05/gallon equivalent</td>
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<tr>
<td>80%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>$1.35/gallon equivalent</td>
</tr>
</tbody>
</table>

The majority of EV owners will use a mix of charging types to fuel their vehicle. A combination of home and free charging represents the biggest savings.

Note: Home charging represents Clean Power SF’s time-of-use-rates. Paid Level 2 and DC Fast Charge represent EVGO’s Flex non-subscription plan.
The cost to charge at DCFC stations in California varies greatly, but it is often less than $4 per gallon equivalent. Most EV drivers use DCFC only occasionally, so they offset the higher charging costs for DCFC with lower Level 1 and 2 charging costs at home.

Note: This analysis does not include charging providers’ membership plans, which can reduce the effective cost to charge. Some EV manufacturers include free DCFC privileges for a set period after purchase.


Charging Infrastructure: Spreading but More Is Needed

The availability of charging stations is an important consideration for EV owners. Level 2 chargers are most common, with more than 16,000 stations in the United States (Figure 6, p. 12) (DOE 2017). Concentrated in California and other states with higher EV sales, they are available across the country. When it comes to DC fast chargers, non-Tesla outlets are less common nationwide and concentrated in coastal states and urban areas (Figure 7, p. 13). Tesla’s DCFC Supercharger network shows better coverage for nationwide long-distance travel, with fast-charging stations spaced along major travel routes (Figure 8, p. 13).

The difference between Tesla’s DCFC deployment and that of other DCFC networks reflects different business models. Tesla has built a network of stations to build confidence among drivers; low utilization of charging stations is not a concern because Tesla derives little revenue from charging. (Most Tesla drivers can charge for free, although drivers of their new Model 3 EV will be charged.) In contrast, the charging networks that supply most non-Tesla DC fast chargers earn more for their investors when utilization is high. Hence, they place chargers in locations with a high density of EVs.

continued on page 14

DC fast chargers allow for longer distance travel and could help provide charging for those unable to charge easily at home. The cost to use DC fast charging varies greatly, but is often less than $4/gallon equivalent.
More than 16,000 Level 2 chargers are spread across the United States.

**Level 2 chargers are available across the country, though they are most common in states with high EV sales.**
**FIGURE 7. Public DC Fast Chargers – Non-Tesla**

DC fast chargers (non-Tesla) are less common and concentrated in coastal states and urban areas.  
Note: As of publication, there are no DC fast chargers in Alaska.  

**FIGURE 8. Public DC Fast Chargers – Tesla**

Tesla DC fast chargers (also called Superchargers) cover major cities and are spaced along many interurban highways.  
Note: As of publication, there are no DC fast chargers in Alaska and no Tesla DC fast chargers in Hawaii.  
To increase the rate of EV adoption, other automakers could coordinate with charging providers to improve the DCFC infrastructure. Volkswagen is taking steps in this direction, investing in a network of DC fast chargers in cities and along highway corridors (ARB 2017b, VW 2017). These investments, mandated as part of the settlement over illegal emissions from Volkswagen’s diesel vehicles, may not be applicable to other automakers.

**Purchase Costs**

Declining vehicle costs, combined with savings on vehicle maintenance and fuel, are making electric vehicles more affordable.

On average, the manufacturer’s recommended retail price (MSRP) of an electric vehicle is higher than that of a comparable non-plug-in vehicle. The average transaction price for EVs (excluding Teslas) is about $4,000 higher than the overall average for new vehicles (Table 2) (KBB 2017). However, MSRP and transaction price data do not include significant incentives from manufacturers and federal and state governments.

Incentives vary in amount and type. For example, Colorado offers a $5,000 income tax credit; California provides rebates of $1,500 to $4,500, depending on the vehicle type and the purchaser’s income. EV buyers also qualify for a federal income tax credit of up to $7,500. After incentives, the net MSRP for an EV can be similar to or even lower than that of a comparable gasoline car (Table 3).

In the case of a lease, the federal tax credit typically goes to the leasing company and allows for significantly lower lease costs. Deals vary quite a bit, but some manufacturers offer EVs at low rates using both the federal incentive and dealer incentives (Table 4). For example, dealers have offered Nissan LEAF and Fiat 500e leases for less than $150 per month, inclusive of down payment (Charge!!! 2017). When paired with fuel savings of $50 to $80 per month and potential state incentives, the net price of some leased EVs could be cheaper than a mobile phone plan or a cup of coffee every day for a month.

The cost to produce the EV’s battery pack leads to higher manufacturing costs for EVs than for gasoline vehicles and hence higher EV prices. Over time, though, the cost of batteries will fall, as it has in recent years, due to increased production and technological advances. Lower battery costs and the availability of more EV models will likely bring the selling prices of EVs in line with those of gasoline vehicles, gradually reducing the need for incentives (Reichmuth and Goldman 2017).

An additional cost for some EV buyers is the purchase and, potentially, installation of a home charger unit (also known as EV supply equipment or EVSE).

---

**TABLE 2. Average Transaction Price for New Cars, August 2017**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Average Transaction Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcompact Car</td>
<td>$16,442</td>
</tr>
<tr>
<td>Compact Car</td>
<td>$20,377</td>
</tr>
<tr>
<td>Subcompact SUV/Crossover</td>
<td>$24,387</td>
</tr>
<tr>
<td>Midsize Car</td>
<td>$24,782</td>
</tr>
<tr>
<td>Hybrid/Alternative Energy Car</td>
<td>$25,922</td>
</tr>
<tr>
<td>Compact SUV/Crossover</td>
<td>$28,416</td>
</tr>
<tr>
<td>Sports Car</td>
<td>$30,069</td>
</tr>
<tr>
<td>Midsize Pickup Truck</td>
<td>$32,473</td>
</tr>
<tr>
<td>Minivan</td>
<td>$33,872</td>
</tr>
<tr>
<td>Van</td>
<td>$34,529</td>
</tr>
<tr>
<td>Average New Gasoline-Powered Vehicle</td>
<td><strong>$34,646</strong></td>
</tr>
<tr>
<td>Full-Size Car</td>
<td>$34,699</td>
</tr>
<tr>
<td>Midsize SUV/Crossover</td>
<td>$37,421</td>
</tr>
<tr>
<td>Average New Electric Vehicle Before Federal Tax Credit (up to $7,500) and Potential State Incentives</td>
<td><strong>$38,701</strong></td>
</tr>
<tr>
<td>Entry-Level Luxury Car</td>
<td>$41,797</td>
</tr>
<tr>
<td>Luxury Compact SUV/Crossover</td>
<td>$43,175</td>
</tr>
<tr>
<td>Full-Size Pickup Truck</td>
<td>$46,464</td>
</tr>
<tr>
<td>Luxury Midsize SUV/Crossover</td>
<td>$53,915</td>
</tr>
<tr>
<td>Luxury Car</td>
<td>$57,061</td>
</tr>
<tr>
<td>Full-Size SUV/Crossover</td>
<td>$60,933</td>
</tr>
<tr>
<td>Luxury Full-Size SUV/Crossover</td>
<td>$81,880</td>
</tr>
<tr>
<td>High-Performance Car</td>
<td>$92,009</td>
</tr>
<tr>
<td>High-End Luxury Car</td>
<td>$95,219</td>
</tr>
</tbody>
</table>

**EV buyers qualify for a federal income tax credit of up to $7,500.**

Notes: Prices include both lease and purchase transactions but not taxes, fees, or customer incentives. Tesla EVs are not included in the average transaction price for EVs due to lack of data from nondealer sales.

Source: KBB 2017.
Plug-in hybrids (PHEVs), especially those with lower-capacity batteries (and shorter ranges), may not require the installation of a charging unit; they can fully recharge in less than eight hours using the included Level 1 charging cable and a standard grounded 120V outlet. Many drivers of BEVs, especially those with higher-than-average daily driving needs, will require a dedicated home-charging unit installed on a 240V circuit. Level 2 charging units for home use typically cost $400 to $800, depending on power level and features like internet connectivity. Installation costs vary, depending on the existing home electric circuit, the potential need to upgrade or add a circuit, and any permits or professional electrician services required. In California, the median cost for the equipment and installation is $900 (ARB 2017a).

### Table 3. Comparing the Purchase Prices of EVs and Comparable Gasoline Vehicles

<table>
<thead>
<tr>
<th>Powertrain</th>
<th>Ford Focus EV</th>
<th>Ford Focus Titanium</th>
<th>Toyota Prius Prime Plus</th>
<th>Toyota Prius One</th>
<th>VW eGolf</th>
<th>VW Golf S</th>
<th>Chevy Bolt LT</th>
<th>Chevy Sonic Hatchback Premier</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSRP</td>
<td>$31,075</td>
<td>$24,074</td>
<td>$27,100</td>
<td>$23,475</td>
<td>$28,995</td>
<td>$19,895</td>
<td>$37,495</td>
<td>$22,170</td>
</tr>
<tr>
<td>Federal Tax Credit</td>
<td>$7,500</td>
<td>-</td>
<td>$4,502</td>
<td>-</td>
<td>$7,500</td>
<td>-</td>
<td>$7,500</td>
<td>-</td>
</tr>
<tr>
<td>Total Before Manufacturer Incentives, Taxes, and Fees</td>
<td>$23,575</td>
<td>$24,074</td>
<td>$22,598</td>
<td>$23,475</td>
<td>$21,495</td>
<td>$19,895</td>
<td>$29,995</td>
<td>$22,170</td>
</tr>
<tr>
<td>EV Cost Difference</td>
<td>(-$499)</td>
<td>-</td>
<td>(-$877)</td>
<td>-</td>
<td>$1,600</td>
<td>-</td>
<td>$7,825</td>
<td>-</td>
</tr>
</tbody>
</table>

*EVs are affordable, with pricing that compares favorably with that of similar gasoline vehicles when federal incentives are available. Some EVs have a list price below the comparable gasoline car after applying the federal income tax credit.*

Note: BEV stands for battery electric vehicle; PHEV stands for plug-in hybrid electric vehicle. Some states make additional incentives available to further reduce the cost of an EV. California is shown as an example. All numbers represent the 2017 model year.

### Table 4. EV Lease Offers

<table>
<thead>
<tr>
<th>EV</th>
<th>Lease Term (months)</th>
<th>State</th>
<th>Effective Monthly Cost</th>
<th>Effective Monthly Cost after State Incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissan LEAF S</td>
<td>24</td>
<td>MA</td>
<td>$144</td>
<td>$144*</td>
</tr>
<tr>
<td>Fiat 500e</td>
<td>36</td>
<td>CA</td>
<td>$147</td>
<td>$78</td>
</tr>
<tr>
<td>Chevrolet Volt</td>
<td>36</td>
<td>MA</td>
<td>$148</td>
<td>$79</td>
</tr>
<tr>
<td>VW e-Golf SE</td>
<td>30</td>
<td>CA</td>
<td>$170</td>
<td>$87</td>
</tr>
<tr>
<td>Chevrolet Bolt EV</td>
<td>36</td>
<td>CA</td>
<td>$193</td>
<td>$124</td>
</tr>
</tbody>
</table>

*EV lease offers are available for well under $200 per month.*

Note: The monthly cost includes the down payment and monthly payment but not taxes or fees. Lease offers may include conditional manufacturer incentives such as discounts for new college graduates or current company lessee. Not all buyers will meet the income eligibility requirements for the California rebate.

* 36-month lease term required for Massachusetts rebate

**Lower Maintenance Costs**

Maintenance presents further potential savings for the owners of plug-in EVs, especially battery electric vehicles, because they have no gasoline engine to maintain. Electric motors require no routine maintenance, and EVs often have much simpler gearing and transmission systems than do gasoline cars. Therefore, BEVs avoid most periodic changes of oil, oil filters, and transmission fluid.

Compared with the similarly sized, gasoline-powered Chevrolet Sonic, the recommended maintenance for the Chevrolet Bolt EV costs more than $1,500 less (Table 5). EVs do require some upkeep, of course, such as replacing worn-out tires and brake pads. The tires may require replacement slightly earlier due to the battery packs’ additional weight.

Unlike gasoline motors, electric motors require no routine maintenance.

### TABLE 5. Lower Maintenance Costs for Electric Vehicles

<table>
<thead>
<tr>
<th>Service</th>
<th>Frequency (per 150,000 miles)</th>
<th>Cost per Occurrence</th>
<th>Cost for Chevrolet Bolt EV</th>
<th>Cost for Chevrolet Sonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire rotation</td>
<td>20</td>
<td>$30</td>
<td>$600</td>
<td>$600</td>
</tr>
<tr>
<td>Engine oil and oil filter replacement</td>
<td>20</td>
<td>$45</td>
<td>0</td>
<td>$900</td>
</tr>
<tr>
<td>Cabin air filter replacement</td>
<td>6</td>
<td>$45.50</td>
<td>$273</td>
<td>$273</td>
</tr>
<tr>
<td>Engine air filter replacement</td>
<td>3</td>
<td>$69</td>
<td>0</td>
<td>$207</td>
</tr>
<tr>
<td>Spark plug replacement</td>
<td>2</td>
<td>$219.50</td>
<td>0</td>
<td>$439</td>
</tr>
<tr>
<td>Coolant flush and replacement</td>
<td>1</td>
<td>$110</td>
<td>$110</td>
<td>$110</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>–</td>
<td>–</td>
<td><strong>$983</strong></td>
<td><strong>$2,529</strong></td>
</tr>
</tbody>
</table>

The manufacturer’s recommended services are $1,500 more expensive for a Chevrolet Sonic than for a similarly sized Chevrolet Bolt EV when driven for 150,000 miles.

**SOURCE:** UCS ANALYSIS OF REPAIRPAL 2017.
However, an EV’s brake pads should last considerably longer because EVs have regenerative braking systems that reduce friction braking and therefore pad wear. Overall, the average EV will save $2,100 over a medium-sized, gasoline-powered sedan for maintenance, repairs, and tires when driven 150,000 miles, according to estimates from the American Automobile Association (AAA 2017).

Findings

- Driving an EV instead of a gasoline-powered car can lead to significant fuel cost savings. In every city examined in the UCS study, an electric rate plan would allow for EV charging at an effective cost lower than that of gasoline. Estimated annual savings range from $443 to $1,077, depending on the electricity provider and the local cost of gasoline. In general, the savings are higher if providers offer time-of-use rate plans with cheaper off-peak rates, but even a standard rate plan leads to savings for all but five California electricity providers. Using paid public charging for a portion of EV recharging can increase the cost of fuel for an EV, but total costs remain lower than those for the average new gasoline vehicle.

- The initial cost of an EV compared with that of a gasoline vehicle is a barrier to adoption, but federal and state incentives make EVs affordable to more buyers. After applying the federal income tax credit, the effective MSRP of an EV is often less than that of a comparable gasoline car. In states that offer additional EV purchase incentives, EVs are even more affordable. In addition, a number of manufacturers offers attractive EV leases, with effective lease prices sometimes less than $100 per month. Incentives and policies that make the initial cost of an EV affordable enable more drivers to take advantage of maintenance and fuel cost savings.

Policy Recommendations

EVs reduce harmful emissions from transportation and can save drivers from high and unpredictable fuel prices. More EV models are becoming available and EV sales are rising, which are encouraging signs of the transition from petroleum to cleaner fuels like electricity. Policymakers, automakers, and electric service providers can accelerate this necessary transition.

ELECTRICITY POLICIES

- Regulators and electric service providers should ensure that EV owners can access lower-cost electricity. This is key to making EVs a reliable and affordable alternative to gasoline vehicles. The providers can help by offering TOU rates—to EV owners or more generally to all customers—with lower-cost charging during off-peak periods when use of the electric grid is lower.

- Public policies that encourage the deployment of charging stations in urban areas and multi-unit dwellings (like apartment parking facilities) can help address the needs of those who cannot charge at home and those who drive long distances. Access to reliable and affordable public charging, especially DC fast charging, will broaden the base of drivers who can choose an EV.

- Electricity providers and regulators should ensure the availability of separate rates for EV use and household electricity use. This would lower charging costs for those whose electricity needs would not benefit available, an electrician can help you evaluate options and costs.

- Get information on rate options available for charging an EV. You can get this from your local electricity provider’s website or by contacting the provider. In particular, find out if your electric provider offers TOU rates. Some providers offer personalized assessments to help you choose the right plan.

- Research the availability of state, local, and electricity provider incentives for buying an EV or EV charging equipment. The US Department of Energy’s EV incentives database is a good starting point for federal and state incentives: https://energy.gov/eere/electricvehicles/electric-vehicles-tax-credits-and-other-incentives. Your local electric provider may also be able to provide information.

Consumer Recommendations

EVs enable drivers to realize significant fuel cost savings, but determining the cost of purchasing and charging a specific model can be complex. Prospective EV buyers should consider the following actions:

- Evaluate the availability of electric power in the area where you intend to park. A shorter-range PHEV (or a BEV driven shorter distances) may only need access to an unused 120 volt outlet. If you intend to install a higher-power, Level 2 charger and do not have a 240 volt circuit available, an electrician can help you evaluate options and costs.
from TOU rate plans. Normal household electricity usage could remain on regular rates while EV charging could move to lower-cost off-peak rates.

- **Electricity providers and regulators should explore rate plans and charging technologies that encourage the coordination of EV charging with the availability of renewable electricity.** This could reduce the cost of charging, minimize emissions from EV recharging, and support additional renewable electricity integration onto the grid.

**VEHICLE POLICIES**

- **Policymakers, consumers, and automakers should advocate for extending the federal income tax credit and encourage more states to provide purchase incentives.** Purchase incentives are vital to making EVs an affordable and competitive option for car buyers at this time. The cost differential between producing an EV and a comparable gasoline vehicle is dropping and will continue to do so as sales volumes increase and EV technology improves. However, it is too soon to remove these important policies.

- **Policymakers should encourage programs targeting communities and demographics that could best benefit from lower fuel costs yet lack the ability to purchase EVs.** EVs offer significant savings on fuel costs, but the upfront cost can be a barrier to adoption, especially for lower-income households.

- **Public policies should encourage manufacturers to produce both more EVs and a greater diversity of models and sizes.** Increasing production volumes will help drive down costs and drive up investment in charging infrastructure. Adding EV models and vehicle types will increase the number of choices for consumers who want to take advantage of electricity as a fuel that saves money and reduces emissions.

**David Reichmuth** is a senior engineer in the UCS Clean Vehicles program.
ACKNOWLEDGMENTS
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REFERENCES


APPENDIX: METHODOLOGY

Costs for Home Charging

Rate design and costs were obtained via the US Department of Energy’s Utility Rate Database (https://openei.org/wiki/Utility_Rate_Database), with confirmation using the websites of the electric service providers. The marginal volumetric rate including adjustments (taxes and fees) was determined for each service provider. Fixed charges (meter charges) were not included. Seasonal rates were averaged based on the proportional length of the season, with the assumption that EV electric use occurs at a constant rate throughout the year.

Demand charges were added if they were applied at all hours, assuming 30A, 240V (7.2 kW) charging with 1.4 hours of charging required per day (11,440 miles per year, 0.325 kWh per mile). If demand charges were applied only on peak hours, then no demand charges were added; it is
assumed that charging would be avoided during peak periods. Tiered non-TOU rates assumed that EV charging was above the average household consumption as reported by the Energy Information Administration or more than 100 percent of baseline (if data were available). EV monthly charging was assumed to require 310 kWh/month (10.2 kWh/day). When both tiered and non-tiered TOU/EV rates were available, the non-tiered rates were used. If multiple TOU/EV rates were available, the rate with the lowest nighttime rate was chosen. Rates that required installation of an additional meter were not considered due to the difficulty in quantifying the expense and charges associated with installation and use of a second meter.

Rates for Texas and other deregulated markets were estimated by selecting representative rate plans with a 12-month contract period. Because the rate structures in deregulated markets can vary significantly between electricity providers, rates available in these markets may have resulted in lower electricity costs than those presented in this report.

For each rate where a per kWh charge (and per kW demand charge, if applicable) was known, the $/gasoline gallon equivalent was calculated using $/kWh × kWh/mile × miles/gallon, where the EV efficiency was the sales-weighted US EV efficiency (0.325 kWh/mi) and miles per gallon were 25.6, the average new vehicle efficiency for all vehicles manufactured in 2016 (EPA 2016).

The price for gasoline in each city was determined using data from GasBuddy (www.gasbuddy.com/Charts), using prices on October 24, 2017.

**Cost for Public (Away from Home) Charging**

The cost distribution for public charging stations was determined using the proprietary Plugshare database purchased from Recargo. To determine the number of free and pay public charging stations (Figure 4, p. 9), stations marked as “restricted” access were excluded from the totals. Additionally, stations that were identified as located at dealerships were excluded; access to these stations can be restricted to specific EV brands.

To determine the cost to charge at DC fast charge stations, a 30-minute session with 25 kWh electricity delivered was assumed. Per minute EV charging costs were included, but additional daily parking fees were not included in the charging costs. Several charging networks offered subscription or membership plans that reduced the cost of DC fast charging; however, this analysis assumed pay-as-you-go charging without a membership.

**Scheduled Maintenance Cost Analysis**

Scheduled maintenance costs for a 2017 Chevrolet Bolt EV and 2017 Chevrolet Sonic Premier Hatchback (1.4L turbo engine) were calculated using the schedule from the respective owner manuals, assuming ordinary driving conditions. Maintenance costs were estimated using the median national estimates for part and labor costs according to RepairPal (www.repairpal.com).
New Data Show Electric Vehicles Continue to Get Cleaner

DAVID REICHMUTH, SENIOR ENGINEER, CLEAN VEHICLES | MARCH 8, 2018, 10:48 AM EDT

New data from the US EPA on power plant greenhouse gas emissions are in, and electric vehicles (EV) in the US are even cleaner than they were before. The climate change emissions created by driving on electricity depend on where you live, but on average, an EV driving on electricity in the U.S. today is equivalent to a conventional gasoline car that gets 80 MPG, up from 73 MPG in our 2017 update.

Cleaner electricity means cleaner EVs

Based on data on power plant emissions released in February 2018, driving on electricity is cleaner than gasoline for most drivers in the US. Seventy-five percent of people now live in places where driving on electricity is cleaner than a 50 MPG gasoline car. And based on where people have already bought EVs, electric vehicles now have greenhouse gas emissions equal to an 80 MPG car, much lower than any gasoline-only car available.
To compare the climate-changing emissions from electric vehicles to gasoline-powered cars, we analyzed all of the emissions from fueling and driving both types of vehicles. For a gasoline car, that means looking at emissions from extracting crude oil from the ground, getting the oil to a refinery and making gasoline, and transporting gasoline to filling stations, in addition to combustion emissions from the tailpipe.

For electric vehicles, the calculation includes both power plant emissions and emissions from the production of coal, natural gas and other fuels power plants use. Our analysis relies on emissions estimates for gasoline and fuels production from Argonne National Laboratory and power plants emissions data recently released by the US EPA.

EVs getting cleaner over time
An important difference between EVs and conventional cars is that existing EVs can get cleaner—and, over time, they are getting cleaner. It’s difficult to make burning gasoline cleaner, and electricity is trending cleaner over time as we shift away from coal and add more renewables. This means that EVs that were sold years ago can run much cleaner than when they were purchased. Our initial analysis of EV emissions used data from 2009, while this update incorporates 2016 data. By switching between these two maps, you can see the improvement made in many regions of the US.

More efficient EVs now available too

The maps shown above are based the efficiency of the average EV. However, there are now options on the market that are even more efficient. Using one of these more efficient EVs (Hyundai Ioniq BEV, Prius Prime, and Tesla Model 3) means lower
emissions. With these cleaner EVs, 99 percent of the country is in a region where electricity emissions would be lower than a 50 MPG gasoline vehicle.

How do other EVs compare? Use our EV emissions tool to estimate the emissions from a specific EV in your area.

The most efficient EVs are much cleaner than even the best gasoline cars in many regions of the US. Currently the most efficient EVs are the Hyundai Ioniq BEV, Tesla Model 3, and the Toyota Prius Prime (while operating on electricity).

A trend that’s likely to continue

Electric vehicles produce less emissions now because the electric grid is getting cleaner. Over the last ten years, the fraction of power from coal has fallen from nearly 50 percent to 30 percent. Over the same time, utility-scale renewable power like solar and wind power have grown to make up 10 percent of electricity generation.
This analysis relies on data from power plants for 2016, the most current data that includes details on the geographic location of emissions. However, based on the overall data on from 2017, it looks like emissions will continue to fall, with both coal and natural gas declining while renewable power continues to increase.

The falling emissions from electric power over the last decade also highlights the need to work to clean up electricity generation and transportation now. While we are moving in the right direction with renewable power and growing numbers of EV models, it takes time to replace existing power plants and gasoline cars. It’s vital that we accelerate the adoption of EVs, even if all power is not yet from renewable or low-carbon sources.

Utility-scale electric power generation. Power from coal has dropped over the last decade and clean renewable power has increased. Data Source: US Department of Energy, Energy Information Agency.
Support from UCS members make work like this possible. Will you join us? Help UCS advance independent science for a healthy environment and a safer world.

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Electric vs. Diesel vs. Natural Gas: Which Bus is Best for the Climate?

JIMMY O’DEA, VEHICLES ANALYST | JULY 19, 2018, 1:05 PM EDT

Battery electric buses – the people’s electric vehicle – are becoming more and more common. An increasing number of transit agencies – large and small – are making announcements about purchasing electric buses and putting them into operation.

The obvious benefit of electric buses is that they don’t have any tailpipe emissions. A question we often get at UCS is, “What about emissions used to generate electricity for electric vehicles?”

We answered this for buses charged on California’s grid and found that battery electric buses had 70 percent lower global warming emissions than a diesel or natural gas bus (it’s gotten even better since that analysis). So what about the rest of the country?

You many have seen my colleagues’ work answering this question for cars. We performed a similar life cycle analysis for buses and found that battery electric
buses have lower global warming emissions than diesel and natural gas buses everywhere in the country.

What the map shows

The map above shows the miles per gallon that a diesel bus would need to have equivalent life cycle global warming emissions as a battery electric bus on today’s grid (really the 2016 grid, the most recent data available).

This means a battery electric bus operated in North Carolina, for example, has the same life cycle global warming emissions as a diesel bus that gets nearly 15 miles per gallon! That’s impressive considering a comparable diesel bus actually gets 4.8 miles per gallon. So, you can operate three electric buses in North Carolina and have the same emissions as a single diesel bus.

Electric buses are better for the climate than diesel buses everywhere in the country

Battery electric buses range from 1.4 to 7.7 times better than a diesel bus, as shown in miles per gallon emissions-equivalency. Another way of saying this is that a diesel bus has nearly 1½ to 8 times the global warming emissions as an electric bus, depending on the region.

And the grid is getting cleaner every year. Emission rates from electricity have steadily declined the last sixteen years. Transit agencies can also choose cleaner power than what’s provided on their grids by installing solar panels and batteries on site or through renewable electricity contracts.

Charged with the national electricity mix, a battery electric bus has global warming emissions equivalent to a diesel bus getting 12 miles per gallon. This is 2.5 times better than an actual diesel bus (4.8 miles per gallon).

They’re also better than natural gas and diesel-hybrid buses
Everywhere in the country, battery electric buses also have lower life cycle global warming emissions than natural gas and diesel-hybrid buses. Charged with the national electricity mix, an electric bus produces 1,078 grams CO₂e per mile, while a natural gas bus produces 2,364 grams CO₂e per mile and a diesel-hybrid produces 2,212 grams CO₂e per mile.

(Note, values for CO₂e per mile reflect the same analysis as the miles per gallon emissions-equivalent values shown in the map, just presented in different units).

<table>
<thead>
<tr>
<th>Type of Transit Bus</th>
<th>CO₂e (g/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>2,680</td>
</tr>
<tr>
<td>Natural gas</td>
<td>2,364</td>
</tr>
<tr>
<td>Diesel-hybrid</td>
<td>2,212</td>
</tr>
<tr>
<td>Battery electric</td>
<td>1,078</td>
</tr>
</tbody>
</table>

Natural gas buses have 12 percent lower global warming emissions than diesel buses.* Electric bus emissions range from 29 to 87 percent lower than diesel buses and 19 to 85 percent lower than natural gas buses.

Here’s a table showing the life cycle global warming emissions per mile from electric buses in all regions of the US.
Cleaner electricity means cleaner electric buses

In upstate New York, the region with the lowest carbon grid in the country (roughly 30 percent hydropower, 30 percent nuclear, 30 percent natural gas), a battery electric bus has nearly 90 percent lower global warming emissions than a diesel bus.

A battery electric bus charged in upstate New York even has lower life cycle emissions than the average passenger vehicle on the road (new and old combined)! An electric bus charged there produces about 350 grams carbon dioxide equivalents (CO₂e) per mile, while the average gasoline car/SUV in the US is responsible for 500 grams CO₂e per mile.**

Other grid regions (California, Alaska, New England, and the Pacific Northwest) aren’t too far off at about 650 grams CO₂e per mile, without even accounting for the fact that a bus can carry a lot more people than a car.

The time is right to get more electric buses on the road.

With zero-tailpipe emissions and low life cycle global warming emissions, battery electric transit buses offer significant local air quality and climate benefits. The more of these buses that are deployed the better. Encourage your local transit agency to begin exploring electric buses, if they haven’t already. Also encourage your state and federal representatives to provide incentive funding to help get these clean vehicles on the road.

Methods

*Life cycle emission data and models*

Life cycle global warming emissions for battery electric buses include those from generating electricity and extracting, processing, and transporting the fuels used to generate electricity. These emissions were compared to the life cycle emissions of diesel and natural gas buses, which include tailpipe emissions and emissions from extracting, refining, and transporting the oil and natural gas.

Emissions from electricity generation are from the US Environmental Protection Agency’s [eGRID 2016](https://epa.gov/energy/electric-grid-inventory-model) database, reflecting emissions from calendar year 2016. Emission rates include transmission losses associated with delivering electricity, roughly 5 percent, depending on the region.

Emissions from extracting, processing, and transporting the fuels used to generate electricity, diesel, and natural gas were determined using Argonne National Laboratory’s [GREET 2017](https://www.transportation.gov/greet) model. This model was also used to determine the tailpipe emissions from diesel and natural gas vehicles.

*Methane emissions and global warming potential*

Life cycle emissions from natural gas vehicles depend greatly on the extent of methane leaks throughout the fuel’s life cycle and the global warming potential used for methane. Our analysis uses conservative estimates for both, including...
global warming potentials over a 100-year period from the IPCC’s 5th Assessment Report. Using higher, yet justifiable, assumptions for methane leaks and its global warming potential, the global warming emissions of natural gas buses can change from 12 percent less than diesel (as used in this study) to 20 percent greater than diesel.

**Fuel efficiency**

The bus manufacturer New Flyer makes the same bus (40-foot Xcelsior) in diesel, diesel-hybrid, natural gas, and battery electric versions. These buses have undergone testing by the Federal Transit Agency, allowing for comparison of fuel efficiencies across vehicle type and over the same test conditions.

Fuel efficiencies used in this analysis were as follows: diesel bus: 4.82 miles per diesel gallon; diesel-hybrid bus: 5.84 miles per diesel gallon; natural gas bus: 4.47 miles per diesel gallon equivalent; and battery electric bus: 2.02 kWh per mile, which accounts for a 90 percent charging efficiency.

The on-road fuel efficiency of any bus will depend on the specific route, including the vehicle’s speed, number of stops, and terrain; passenger load; auxiliary uses of
energy, e.g. air conditioners or heaters; and the inherent efficiency of the engine or electric motor, which varies by manufacturer.

Standardized testing of the New Flyer buses shows that electric buses are four times more energy efficient than natural gas buses. In contrast, a study of electric and natural gas buses operated on the same routes by Foothill Transit in Southern California showed electric buses had eight times better fuel efficiency.

Note, converting the fuel efficiency of the electric bus (i.e., 2.02 kWh per mile) into an equivalent miles per diesel gallon (using the amount of energy contained in a gallon of diesel, 129,488 British thermal units per gallon), gives an equivalent fuel efficiency of the battery electric bus of 18.8 miles per diesel gallon equivalent.

Comparing this fuel efficiency to a diesel bus reflects only how much energy the two vehicles use over the course of a mile. The MPG numbers shown in the map above go several steps further and include upstream emissions, which is why we refer to them as “the equivalent life cycle global warming emissions from a diesel bus with X miles per gallon efficiency.” A mouthful, but a critical distinction.

Fuel efficiency is representative of global warming emissions if you’re talking about the same type of vehicle using the same type of fuel, e.g., comparing a diesel bus made by company X to a diesel bus made by company Y. But, if you want to compare two different types of vehicles, e.g. a battery electric bus and a diesel bus, the upstream emissions associated with the fuel or electricity production need to be accounted for, as reflected in the values on the map.

* This result is similar to the finding that natural gas buses have just 9 percent lower global warming emissions than diesel buses in our previous analysis, which was specific to California.

** This result makes use of our life cycle emissions analysis for passenger vehicles and the average fuel efficiency of these vehicles on the road.
Posted in: Vehicles Tags: alternative fuels, clean energy, clean vehicles, climate, electric buses

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