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BRIEFING

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Ensuring driving on electricity is cheaper than driving on gasoline

This briefing provides a brief overview of the energy cost per mile for a vehicle using gasoline versus the energy cost per mile using electricity in the United States. It highlights the imperative to consider electricity costs for electric vehicles in the context of all competing gasoline alternatives including gasoline hybrids. In addition, this briefing provides an overview of opportunities to lower the cost of electricity for electric vehicles by better reflecting the utility cost of service.

INTRODUCTION

Ensuring that the cost per mile in an electric vehicle is favorable compared to gasoline underpins the transition to electrification. However, electricity prices vary widely across the United States and can be more expensive than gasoline per mile even at the lowest electricity rate offered by one's local utility. Because electricity prices vary from utility to utility, even within the same geographic area, the consumer value proposition of driving electric is uneven. Currently, some utilities' rates for electric vehicle charging exceed what it costs to serve them. However, by billing electric vehicles at rates that are closer to the actual cost of providing electricity, the cost per mile for their operation can be much less than any current gasoline vehicle. This briefing presents electricity rates faced by electric vehicle drivers in the United States and highlights strategies and policies that utilities use to drive down the cost of electricity and increase the attractiveness of electric vehicles.

Prepared by Michael Nicholas

COMPARISON OF COSTS FOR DRIVING ON ELECTRICITY AND GASOLINE

Although many studies compare the costs of traveling on gasoline and electricity, conclusions vary; there is no consensus on whether operating a vehicle on electricity is more, or less, expensive than operating on gasoline.[1] The results of the studies depend on what gasoline prices are chosen and what gasoline vehicle represents a fair comparison. For example, a gasoline powered 2017 Toyota Prius with 52 miles per gallon (mpg) spending $1.70/gallon, which was a representative price in Tulsa, Oklahoma, in November 2016, would equate to $0.033 per mile. To achieve $0.033 per mile in an all-electric 2017 Nissan Leaf, operating at 3.32 miles per kilowatt hour (mi/kWh), electricity would have to cost $0.11/kWh. Alternatively, one could choose an "average" U.S. light-duty vehicle getting about 25 mpg and an average U.S. price of gasoline at perhaps $2.40 per gallon, which equates to about $0.10 per mile. Using this scenario, the break-even electricity cost for the 2017 Nissan Leaf would be $0.32/kWh. Because electricity prices are usually not more than $0.32/kWh, studies using numbers like these may conclude that driving on electricity is less expensive than gasoline. However, depending where one lives and what vehicle is used for comparison, the per mile cost of gasoline can actually be less than electricity. This makes the cost basis for choosing to plug in or purchase an electric vehicle less clear.

A key question, then, is what is a fair comparison? An often used premise is that everyone is currently driving a chimeric "average" car, and that if they switch to electric vehicles, they will save money. However, it can equally be said that if everyone switches to hybrids that use only gasoline, then some would save a similar amount of money. So the conclusion drawn from using an "average" car can't be that electricity is much cheaper than gasoline, only that most gasoline vehicles are not very efficient. The question is particularly vexing regarding plug-in hybrid electric vehicles PHEVs with both powertrains in the same vehicle. With this type of vehicle, a customer can choose to fill up with gasoline or plug in to an electric outlet, depending on the price and convenience of each. When this choice is made, electricity is often at parity or more expensive than gasoline. In certain utility districts, a rational consumer might choose an efficient gasoline car over an electric one because of this.

To illustrate the value proposition that the consumer faces, we show the cost per mile to drive on electricity and gasoline in selected vehicles in Figure 1. The cost per mile depends on the price of electricity and gasoline in a particular region as well as the efficiency of the electric or gasoline drivetrain. The prices shown represent the absolute lowest overnight electricity rate available, or in the case of Seattle, Tier 2 electricity pricing, which is higher based on the total monthly energy increase. Gasoline price is the median price from January to October 2017 by city.[2] We show the per mile cost for four vehicles: a 2017 Nissan Leaf battery electric vehicle (BEV); a 2017 Prius Prime PHEV, which can be plugged in to the electric grid or use gasoline; a hybrid 2017 Toyota Prius, which has electric and gasoline drivetrains, but cannot be plugged

1 California Air Resources Board, "California's Advanced Clean Cars Midterm Review—Appendix B: Consumer Acceptance of Zero Emission Vehicles and Plug-in Hybrid Electric Vehicles" (2017), p. B-92. https://www.arb.ca.gov/msprog/acc/mtr/appendix_b.pdf; Rocky Mountain Institute, "From Gas to Grid" (2017), https://www.rmi.org/wp-content/uploads/2017/10/RMI-From-Gas-To-Grid.pdf; Union of Concerned Scientists, "Going from Pump to Plug" (2017), http://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-fuel-savings#.WiheHLQ-e-Z

2 "Gas Price Charts," GasBuddy, accessed 17 October 2017, https://www.gasbuddy.com/Charts

in, deriving all its energy from gasoline; and a Nissan Versa, a conventional gasoline vehicle of similar size to the others and which gets 29 mpg.

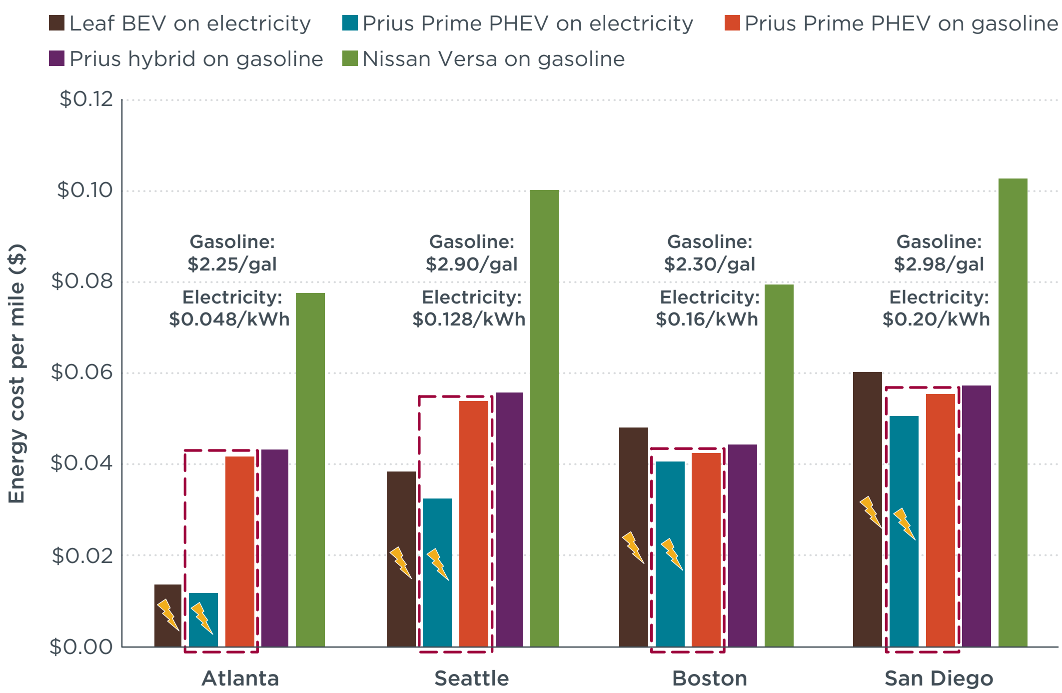

Figure 1. Cost per mile of electricity versus gasoline.

The graph shows that the cost per mile of driving on electricity is much less than driving an efficient gasoline vehicle in Atlanta. By contrast, in San Diego the cost to drive an all-electric 2017 Nissan Leaf is more per mile than driving a gasoline powered 2017 Toyota Prius. In the case of the 2017 Prius Prime PHEV the cost advantage of plugging in over filling up with gasoline (as outlined with the red dotted line) is very small in both Boston and San Diego. As the cost of driving on electricity comes close to or exceeds the cost of driving on gasoline, we risk losing the inherent value proposition that electric vehicles present and may cause more people to not buy an electric vehicle or not plug in.

Driving an electric vehicle in Atlanta costs approximately 4 times less than driving an electric vehicle in San Diego. So, why does electricity price vary so much from one utility to another? Part of the issue is how utilities choose to allocate costs. The "user pays" principle that utilities are bound to follow means that the cost of providing a service should equal the revenue collected. The average 2017 wholesale price for energy in the United States sold from the generation facility is $0.035/kWh.[3] However, the infrastructure to deliver it is amortized over the energy served. This brings overnight energy prices up to retail rates ranging from $0.04/kWh to $0.20/kWh, with peak daytime rates as high as $0.50/kWh. How this is done is subject to interpretation, and different customer classes can be assigned different rates depending on their system impact. Electricity rates are just now being assigned to electric vehicles to reflect their cost to the system. Utilities have fairly wide latitude regarding acceptable

3 "Wholesale Electricity and Natural Gas Market Data," U.S. Energy Information Administration, accessed 10 January 2018, https://www.eia.gov/electricity/wholesale/

allocation of costs to electric vehicles, resulting in rates that vary widely even given the same inputs. Adding to the challenge of establishing reasonable rates, some utilities do not have the metering technology to accurately assess the impact of additional electric load demanded by electric vehicles.

OFF-PEAK AND SMART CHARGING ARE OPPORTUNITIES TO LOWER ELECTRICITY COSTS FOR ELECTRIC VEHICLES

The good news is that off-peak energy should be relatively inexpensive to serve, such that the cost to travel on electricity can easily be far below the cost to travel on gasoline. Offering lower residential rates for charging off-peak is a strategy that many utilities use to lower the cost of electricity for electric vehicles. We provide a brief review of concepts below for residential electricity.

There are three main components to the electric utility infrastructure, as shown in Figure 2. Power is generated at the power plant, transmission lines carry the electricity across long distances, and the distribution network uses local transformers to deliver electricity to residences.

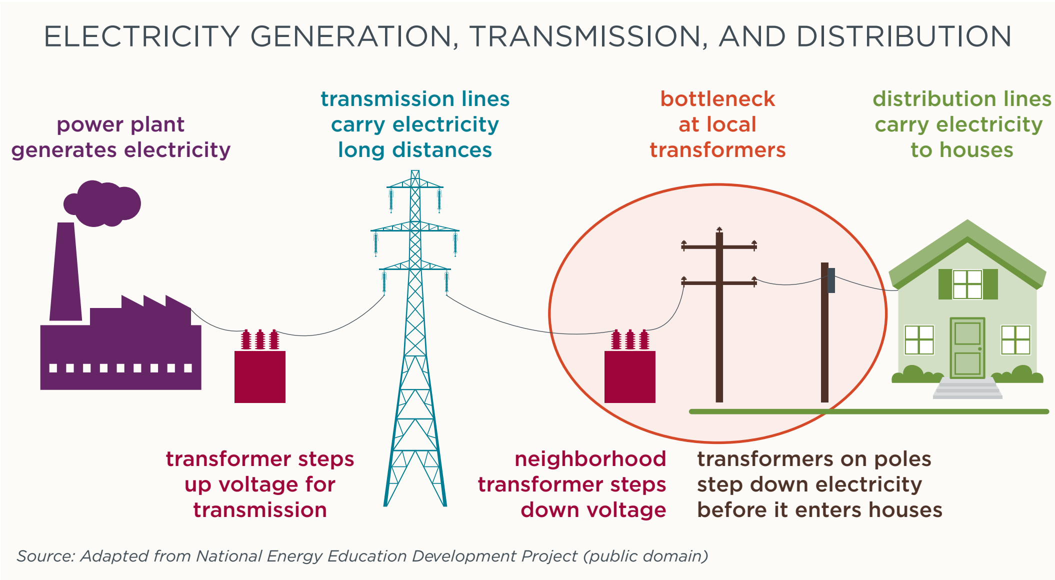

Figure 2. Utility infrastructure to deliver electricity to residential customers (adapted from National Energy Education Development Project [public domain], https://www.eia.gov/energyexplained/index.cfm?page=electricity_delivery)

Local transformers are the components most likely to need upgrading as electrical load grows. Energy use follows a daily cycle and utility infrastructure is sized to meet demand at peak usage. At the local level, the cost to deliver electricity is largely determined by the cost and sizing of this peak usage. For example, a transformer may experience a load similar to that shown in Figure 3. If the load at the peak rises, the transformer must be upgraded. However, if the existing transformer has enough capacity that it can be still be used, then the cost to serve the additional load is much closer to the wholesale cost of energy.

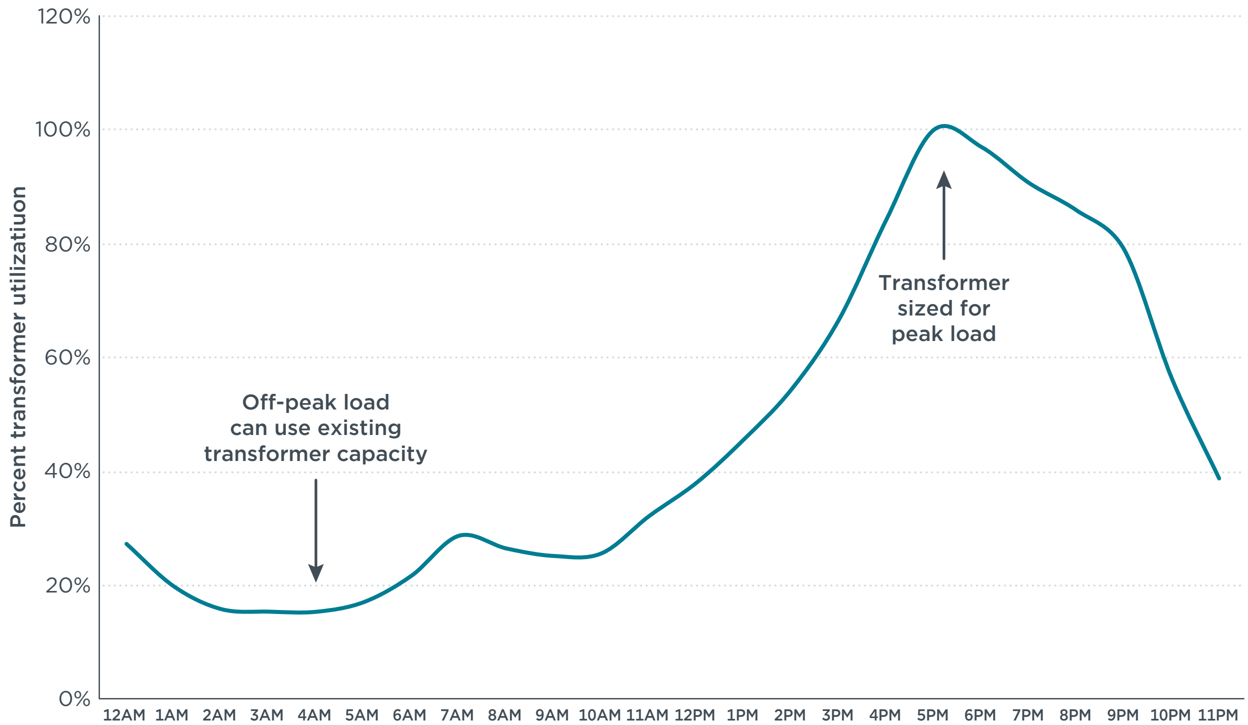

Figure 3. Typical electric load by time of day in California.

Because existing transformer capacity can be used, and upgrades are unlikely to be needed in the near term as detailed below, the cost to serve an electric vehicle if charged off-peak is initially very low. Over time, charging many electric vehicles on the same transformer, even when this is done overnight, triggers some service upgrades earlier than if there were no electric vehicles.

The cost to serve energy to electric vehicles has been investigated by the Sacramento Utility District (SMUD),[4] the energy consulting firm Energy and Environmental Economics (E3),[5] and others. The SMUD analysis focuses on the residential overnight charging case with daily power fluctuations similar to those illustrated in Figure 3. It shows that a one-time cost in utility upgrades of about $100–$200 per vehicle is needed if charged overnight, with a worst-case scenario of $1,500 per vehicle for high-power chargers charging near the peak at 8 p.m. Because system impacts are low off-peak with few required upgrades, electricity is less costly to serve in the early morning. This is the basis for time-of-use (TOU) pricing, with electricity price fluctuating by time of day in proportion to the costs to serve that demand. SMUD calculates even lower impacts—less than $20 of utility upgrades per vehicle added—with smart charging systems that enable vehicles to respond to grid and transformer conditions on a dynamic basis.

Spreading a one-time cost for expected upgrades over all the electricity that a vehicle uses in its lifetime results in a very small cost increase per kWh. If we assume, for

4 Berkheimer, J., Tang, J., Boyce, B., & Aswani, D. (2014). Electric grid integration costs for plug-in electric vehicles. *SAE International Journal of Alternative Powertrains*, 3(1). doi:10.4271/2014-01-0344

5 Ryan, N., & McKenzie, L. (2016). Utilities role in transport electrification: Capturing benefits for all ratepayers. *Public Utilities Fortnightly,* 14-19.

example, a Nissan Leaf travels 9,000 miles per year, it will use 27,080 kWh over 10 years of operation. Amortizing a one-time $150 cost over 27,080 kWh equates to a $0.005/kWh increase that would enable a utility to recover its incremental costs.

Looking at the situation somewhat differently, the E3 analysis shows an overall electric infrastructure upgrade cost of about $1,500 per vehicle to handle the additional load caused by electric vehicles with regard to generation, transmission, and distribution. However, this analysis covers all time periods and charging locations, not only residential home-overnight, so the cost is necessarily higher.

To understand the difference between the $150 in estimated upgrade costs for nighttime charging versus the $1,500 in costs for all-day charging, it is necessary to show time-of-day impacts. The avoided cost calculator from the California Public Utilities Commission developed by E3[6] gives an idea of the cost to add additional electricity load by time of day. A sample output generated for Southern California Edison, shown in Figure 4, is typical of utilities with a high summer air-conditioning load. However, all utilities have peaks and valleys in daily demand, as displayed in Figure 3, so the concepts are applicable for most utilities.

The vertical axis in Figure 4 shows the cost for each kWh added and the horizontal axis shows the hour that the electricity is demanded. The cost calculator outputs have been grouped into three main categories: energy costs, capacity costs, and environmental costs. Energy costs consist of wholesale energy, transmission losses in the form of heat, and ancillary services that are necessary to maintain power quality in terms of frequency and voltage. Capacity costs include the cost of building new power generation facilities, transmission upgrades, and distribution upgrades including local transformers. Environmental costs are not universally applicable to all utilities but are shown as an optional cost that may be added to encourage a cleaner electricity grid. These factors include monetary CO_2 costs as incurred by California's cap and trade program, environmental externality costs caused by CO_2 emissions, the additional cost of incorporating renewable generation over conventional generation, and environmental harm caused by criteria pollutants, which is to say, pollutants other than CO_2 that have detrimental health effects. Figure 4 also puts electricity price in context by showing the equivalent cost of travel in a 52-mpg 2017 Prius hybrid versus an all-electric Nissan Leaf, in the blue shaded overlay, or a 29-mpg Nissan Versa versus a Leaf, in the orange shaded overlay. The range of costs is due to the possible gasoline prices in this example ranging from $1.70 to $4.00 per gallon. These gasoline prices are not meant to be paired in time with the particular electricity cost in this utility scenario, but rather to represent gasoline price volatility.

6 "Avoided Cost Calculator," Energy and Environmental Economics and California Public Utilities Commission, http://www.cpuc.ca.gov/General.aspx?id=5267

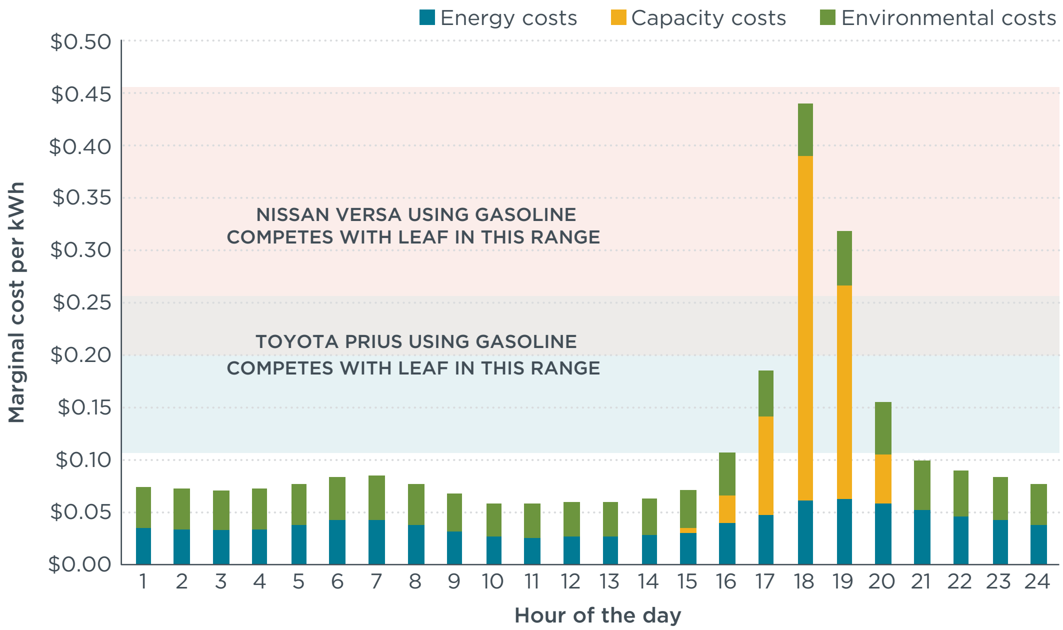

Figure 4. Marginal cost to serve additional electricity demand by time of day in a California utility with overlay of breakeven per-mile energy costs for gasoline in two vehicle models versus an electric vehicle.

The figure shows that electricity is only costly for the utility to serve at certain times of day. If charging is restricted to off-peak hours, capacity upgrades are less necessary. With off-peak electricity, upgrades are likely to be closer to $150 per vehicle as estimated by SMUD. When considering charging at all hours including at peak times, capacity upgrades might be higher as suggested with the $1,500 estimate by E3. However, if vehicles can avoid peak hours or respond to periods of grid stress on a real-time basis, such as with smart charging, costs can be much lower even when environmental costs are included. For the period from midnight to 6 a.m., the average energy-related cost is $0.035/kWh and the average environmental cost is $0.039/kWh. Combining these costs and the additional $0.005/kWh we assume to cover distribution upgrades as estimated in the SMUD analysis brings the cost to a total of $0.079/kWh to recover all environmental and energy costs in this example, or a total of $0.04/kWh if environmental costs are ignored.

Figure 4 also shows that the cost to serve electricity to an electric vehicle during off-peak hours is below the blue shaded region, indicating that the cost of electric energy per mile in an electric vehicle can be less than any gasoline vehicle on the market today even using the least expensive gasoline in this example. However, as shown by the off-peak utility rates in Figure 1, some rates would be in the blue shaded region shown in Figure 4. Every utility has a unique peak and an analysis needs to be done for each utility, but as stated earlier, 2017 average nationwide wholesale electricity prices before distribution were $0.035/kWh. With off-peak or smart charging, utility rates can approach wholesale costs—or, as an option, wholesale and environmental costs—mirroring the conditions shown in Figure 4.

STRATEGIES FOR REDUCING THE COST OF ELECTRICITY FOR ELECTRIC VEHICLES

There are several simple strategies for reducing the price of electricity for electric vehicles. The most straightforward is a TOU rate. Another option is a smart metering rate where the timing and power of a vehicle responds to grid conditions to minimize cost. Separate metering can be combined with TOU and smart meter rates for further cost reductions.

TOU rates are fairly common in the utility industry but require an advanced meter to differentiate usage by time of day. Out of the 2,057 utilities that answered the Energy Information Administration's 2016 survey,[7] only 13% had TOU rates available to customers. These were generally larger utilities that in total accounted for 47% of customers nationwide.

Table 1. Access to TOU rates

Number of residential utility customers	**133,043,647**
Number of utilities	2,093
Number of utilities with TOU rates	262
Number of residential customers in utilities with TOU rates	62,573,745
Number of residential customers enrolled in dynamic pricing (including TOU)	6,078,766

Many smaller utilities do not have the metering technology or billing to support a TOU rate structure. However, there are several strategies to enable TOU rates that do not involve replacing current meters. One innovative approach taken by the small utility Alameda Municipal Power is to do subtractive billing. With no TOU metering technology, the utility directs electric vehicle customers to charge overnight and extends a lower rate on the electricity that an average vehicle is assumed to use.

Smart metering promises to enable the lowest cost energy for the utility and the consumer. There are some technical hurdles that must be addressed including the method by which the utility communicates with the vehicle about how much electricity is desired by the consumer. The ISO 15118 standard[8] in development allows the vehicle to communicate with the charger which can connect to the utility. This can enable the vehicle to respond to grid conditions and prices.

Metering an electric vehicle separately and applying a TOU or other rate only to that meter is another strategy to help assess the unique energy use patterns of an electric vehicle and lower costs. Separating usage with a separate meter often can take the confusion out of utility rates for customers as well and disentangle household electricity usage versus vehicle usage. Although electricity billing is easier for the utility if all vehicle and household usage is combined in one meter, it can be confusing for the customer to assess the actual cost attributable to the vehicle. And in some households, particularly those with low overall demand but where someone stays at home during the day, a TOU rate for the house can increase a customer's household electricity

7 "Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files," U.S. Energy Information Administration, https://www.eia.gov/electricity/data/eia861

8 "ISO 15118-1:2013: Road vehicles—Vehicle to grid communication interface," International Organization for Standardization, https://www.iso.org/standard/55365.html

costs independent of any vehicle. In these cases, separate metering would leave the current electricity bill unchanged and more fairly assess a vehicle's marginal impact on the system independently. This would remove a cost barrier to owning and driving an electric vehicle.

There are at least three ways to accomplish separate metering. The first is by using a second meter, which requires installing a traditional utility meter connected only to circuits with electric vehicle chargers. The second is submetering in the charger. In this case, an accurate meter is integrated into the charger hardware, but uses the existing household wiring. The third is a meter in the vehicle itself. Many current vehicles have cellular communication and the ability to meter electricity, suggesting costs for this option may be quite low.

A traditional second meter from the utility that measures electricity only to a vehicle is typically very easy to integrate into existing utility billing protocols. This type of separate meter requires that a separate wiring system be installed for vehicle charging only. These costs can range from $1,000–$10,000 to retrofit one's home to create this arrangement. Because of the expense, this is usually practical only when integrated as part of new construction.

A submeter integrated into a charger does not require separate wiring, simply communication with the utility to report usage. The utility Pacific Gas and Electric (PG&E) is conducting a submetering pilot[9] where owners install a home charger that meters electricity and PG&E separates vehicle usage from other household usage. Vehicle usage and household usage are assessed and billed separately.

The New York utility Con Edison uses submetering in vehicles with third-party hardware[10] connected to the vehicle's diagnostic port. Customers pay their bills as normal, but receive rebates based on their charging behavior. They receive $20/month for avoiding charging in the peak 2 p.m. to 6 p.m. time frame and earn a $0.05/kWh rebate when they charge "super" off-peak between midnight and 6 a.m. in Con Edison territory. Although the electricity bill and rebate are separate, the overall cost of charging is reduced. The $0.05/kWh rebate reflects the possibility that electric vehicles charged off peak do not cost as much to serve.

Separate metering shows promise, but has not yet gained traction due to hardware and integration costs. A traditional second meter requires significant hardware costs, whereas submetering hardware is inexpensive, but its incorporation into utility billing has been a hurdle. The lowest cost options promise to be charger-based or vehicle-based metering. With greater uptake of these metering technologies, the cost of billing integration can be spread over more customers making these options promising in the long term.

9 "Electric Vehicle Submetering Pilot Program," Pacific Gas and Electric, accessed 10 January 2018, https://www.pge.com/en_US/residential/solar-and-vehicles/options/clean-vehicles/electric/ev-submetering-pilot-program.page

10 "FleetCarma and Con Edison Charge Ahead with SmartCharge Rewards™ for Electric Vehicle Owners," FleetCarma, 19 April 2017, https://www.fleetcarma.com/press-release-con-edison-smartcharge-rewards/

UTILITY AND REGULATORY POLICIES HAVE ROLES TO PLAY IN THE TRANSITION TO ELECTRIFICATION

Based on the preceding assessment of the current cost of travel in the context of utility prices and rate structures, we make the following three conclusions.

Pricing electricity too high risks losing electric vehicle customers and electric miles. When using electricity costs as much or more than using gasoline, the value for the consumer of plugging in or buying an electric vehicle is eroded. Hybrids today are less expensive to operate on an energy basis per mile than electric vehicles in some utility jurisdictions, highlighting the need reduce electricity price when driving electric approaches the price of driving on gasoline. Utilities can better encourage the market for electric vehicles by providing a lower cost per mile than any gasoline alternative.

The marginal cost to serve electric vehicles with time-of-use rates or smart charging is very low. Unused distribution capacity often exists at certain times of day such that plugging in a vehicle will have low marginal impact. Time-of-use pricing allows utilities to reflect this in lower electricity prices. Smart charging that adapts to rate signals allows for an even lower cost to serve those vehicles. Our time-of-use scenario (Figure 4) suggests that the cost to serve off-peak electricity is $0.04–$0.08/kWh, but some utilities charge up to $0.20/kWh for this type of load, even with time-of-use rates. This means that many utilities currently have a significant financial surplus for each electric vehicle they serve. Retail rates for electric vehicle charging can be significantly reduced in many cases while still ensuring that utilities are financially equipped to invest in the necessary infrastructure upgrades needed to support the transition to transportation electrification.

Separate metering of an electric vehicle provides the consumer with a clearer view of costs and a transparent evaluation of system impact. When consumers switch from using gasoline to electricity to power their vehicles, the change is often very confusing. Suddenly, household costs are mixed with vehicle costs and consumers don't know if they will be paying more or less for the pre-existing household electrical load. If vehicles are metered separately, the existing household usage and bills are unaffected, lowering the barrier to buying a vehicle for some. Further, new vehicle- and station-based meters can be tailored to electric vehicles. With communication, they can take advantage of the flexible timing of charging a vehicle. Charging impact on the grid can be reduced and charging price lowered.

This briefing highlights the highly variable prices consumers face for charging their vehicles and the opportunity for much lower costs if vehicles charge overnight. However, more research is needed. Charging at other times of day can be low cost and desirable for other reasons, including providing opportunities for those with no access to a home charger, or shifting loads to coincide with renewable energy sources that may not be available overnight. A more comprehensive study on the marginal cost of electricity in different utilities in the United States and internationally will help define where opportunities exist to shift load to the lowest cost periods. Finally, a better understanding of how consumers respond to changes in electricity and gasoline prices is needed. This will help contextualize its role among other influences such as vehicle purchase incentives and public charging availability. Further research into vehicle energy costs will help policymakers, utilities, and automakers support the growing electric vehicle market, and ensure electric vehicles are a compelling alternative to gasoline.