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ROCKY MOUNTAIN INSTITUTE

FROM GAS TO GRID

BUILDING CHARGING INFRASTRUCTURE TO POWER ELECTRIC VEHICLE DEMAND

BY GARRETT FITZGERALD, CHRIS NELDER

ROCKY MOUNTAIN INSTITUTE
MOBILITY TRANSFORMATION

AUTHORS & ACKNOWLEDGMENTS

AUTHORS

Garrett Fitzgerald and Chris Nelder

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

CONTACTS

Chris Nelder (cnelder@rmi.org)
Garrett Fitzgerald (gfitzgerald@rmi.org)

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Lang Reynolds, Duke Energy
Rich Sedano, Regulatory Assistance Project
Matt Stanberry, Advanced Energy Economy
Tom Vosburg, City of Fort Collins
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Jonathan Walker, Rocky Mountain Institute

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Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

ABOUT MOBILITY TRANSFORMATION

Rocky Mountain Institute's Mobility Transformation program brings together public and private stakeholders to codevelop and implement shared, electrified, and eventually autonomous mobility solutions in cities designed for them. Working with U.S. cities, it leverages emerging technologies and new business models to reduce congestion, decrease costs, increase convenience, enhance safety, curb emissions, and ensure economic growth. Please visit http://www.rmi.org/mobility for more information.

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ES EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

With electric vehicles (EVs) coming on fast thanks to undeniable advantages in the cost of ownership and the driving experience itself, it's time to move on from the old debates about when the EV revolution will arrive. It's here. We should not allow the fact that EV sales in 2016 were only about 1% of total light duty vehicle sales in the U.S. to lull us into a false sense of complacency. Under some reasonable assumptions, there could be 2.9 million EVs on the road in the U.S. within five years, bringing over 11,000 GWh of load to the U.S. power grid, or about $1.5 billion in annual electricity sales.[1] That would constitute a nontrivial load that utilities would need to accommodate well within their current planning horizons, and would almost certainly be the largest growth sector in the U.S. electricity market for the foreseeable future.

There is no benefit to further delay, or to waffling over whether investing in charging infrastructure is a good idea. And the chicken-and-egg problem that has stymied the electric vehicle revolution thus far—no one wanted to build EV charging infrastructure until there were more vehicles, but nobody wanted to buy EVs until there was more charging infrastructure—will be swept away by a fast-growing fleet of increasingly affordable EVs that consumers love.

Sticker prices, model options, and range anxiety have long been impediments to electric vehicle adoption, but those barriers are set to fall within a few years. EVs are already cheaper to refuel, and in some cases, such as with high-usage fleet vehicles, they are cheaper to own than conventional internal combustion engine (ICE) vehicles. EVs are on track to sport lower sticker prices than ICEs in Europe by next year, in China by 2023, and in the U.S. by 2025, without incentives or subsidies.[2] By 2020, there will be 44 models of EVs available in North America, and several best-selling models can already go more than 200 miles on a single charge.[3]

These trends, combined with emerging municipal and state targets for EV adoption and charging infrastructure deployment, indicate that the electric vehicle revolution has already begun.

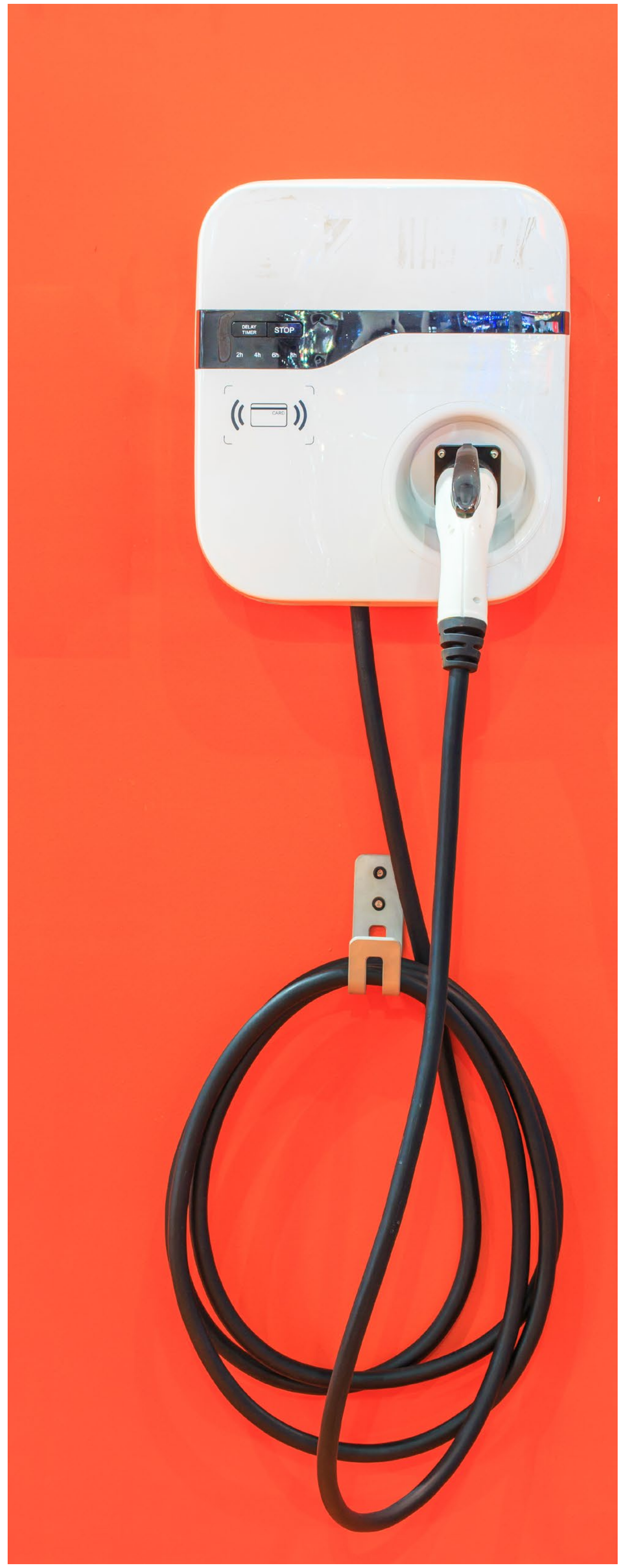
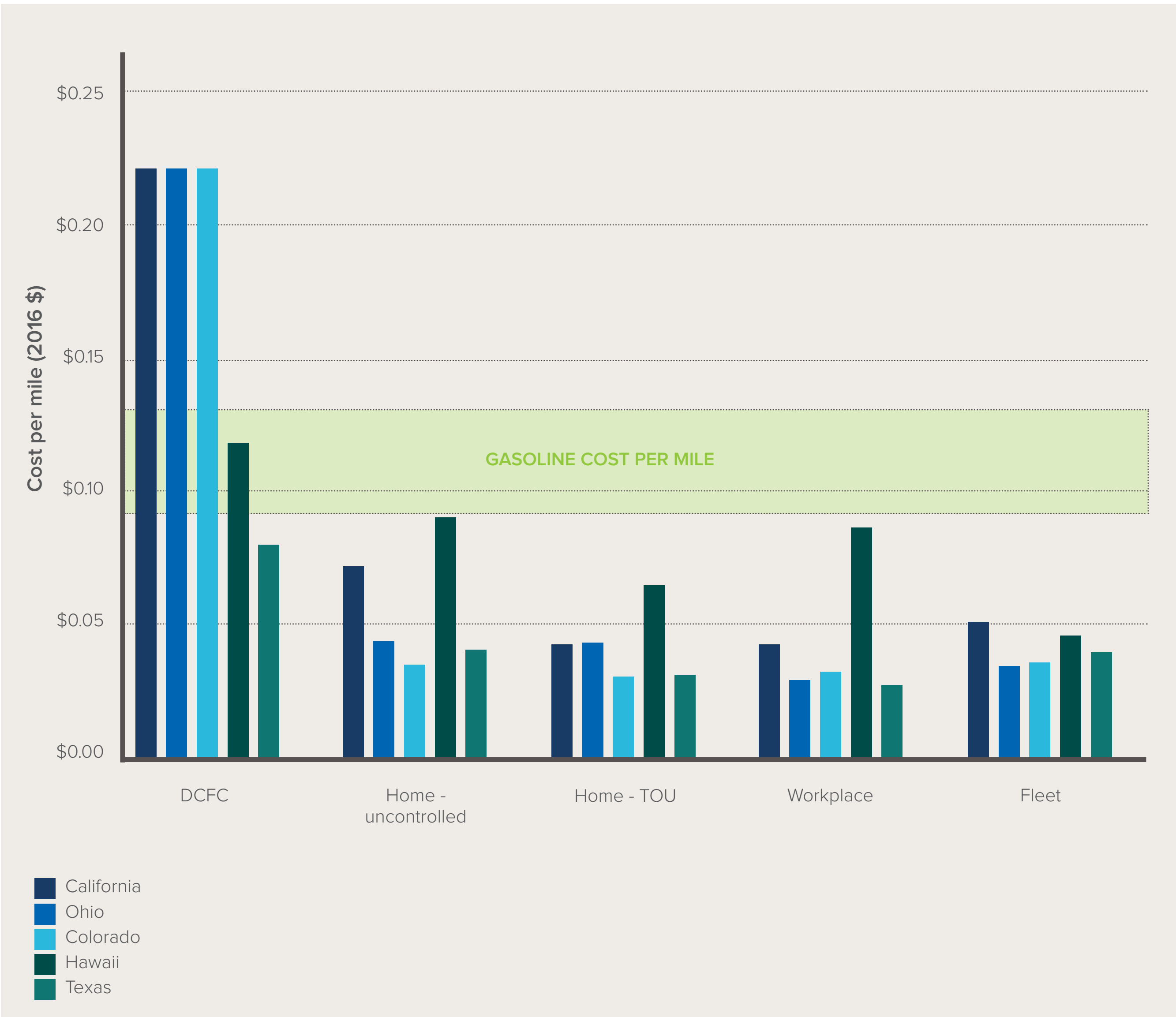


FIGURE 1

RETAIL COST TO EV OWNER, OR EMPLOYER OF EV OWNER, TO CHARGE ONE MILE OF EV RANGE UNDER DIFFERENT UTILITY TARIFFS AND DCFC PROGRAMS

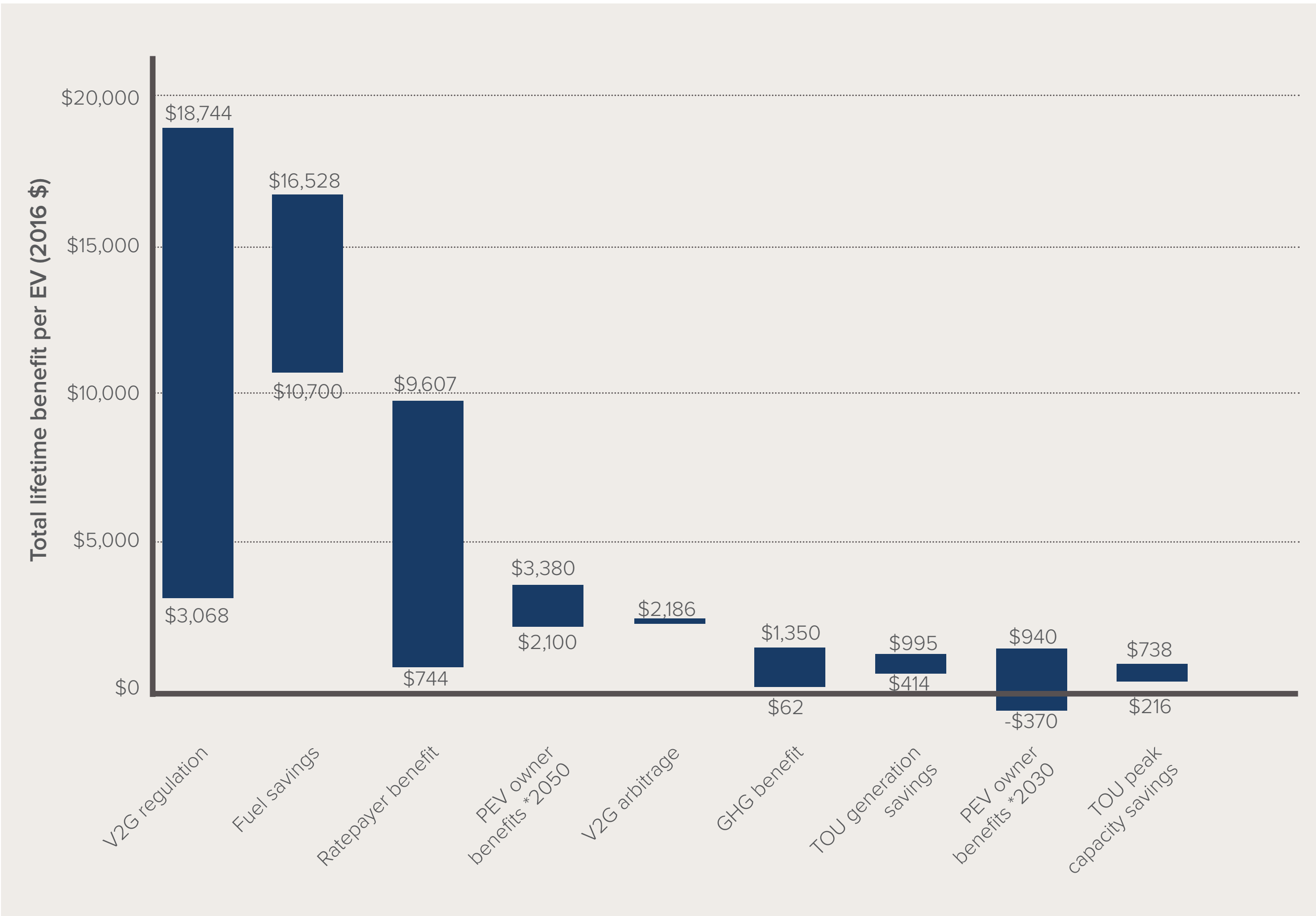


Unlike gasoline vehicles, EV owners have several options for refueling their vehicles. As we show in Figure 1, the cost to fuel an EV varies significantly depending on where the vehicle is charged, what type of charger is used, and the utility powering the charger. In the five states we feature in this report, the cost to charge an EV can be as high as $0.22/mile and as low as $0.03/mile, while the cost of fueling a gasoline vehicle varies in a much narrower band between $0.13/mile and $0.09/mile. Where and when EV owners will refuel their vehicles depends largely on where charging infrastructure is installed and the prices that EV owners encounter, which can vary widely depending on the utility tariff.

The world doesn't need any more cost-benefit analyses; they've already been done, and they show that vehicle electrification has numerous benefits for drivers, utilities, communities, and society as a whole. After reviewing over 150 pieces of recent literature on EVs, we summarized the quantifiable benefits, including greenhouse gas reduction, gasoline savings, savings for all utility customers, savings in system investment, fuel and maintenance savings, and the potential for managed charging of EVs to deliver various grid benefits.

FIGURE 2

RANGE OF STAKEHOLDER BENEFITS FOR EVS FROM THE LITERATURE [4]



The evidence from this research and analysis shows that vehicle electrification provides benefits that are so numerous and overwhelmingly positive for the public that we should no longer doubt the value of it, or become distracted to the point of inaction by arguments about equitability and best practices. Even non-drivers will benefit from the drastically reduced air pollutants of vehicle exhaust, the lower total cost of maintaining mobility infrastructure, and synergistic effects that can put downward pressure on the price of all goods and services, including the price of electricity and climate change mitigation measures. Some of these benefits will depend on smart management of EV charging loads, as we detailed in our 2016 report *Electric Vehicles As Distributed Energy Resources*.[5]

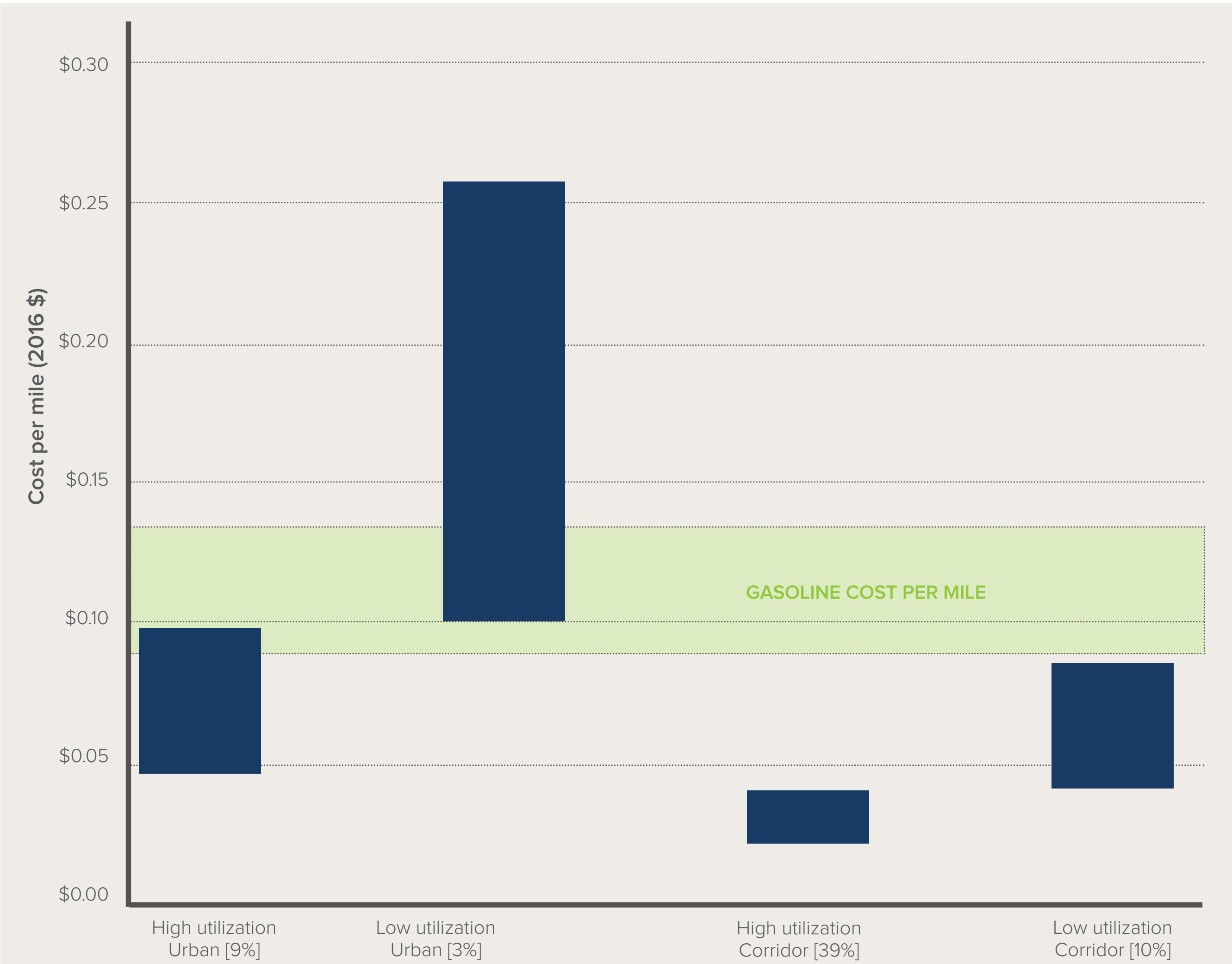
Based on this evidence, we conclude that vehicle electrification isn't an *if* or a *when* question anymore; it's only a question of *how fast* and *Can we be ready in time*. With EV adoption sporting compound annual growth rates of 30–40% in recent years in the U.S., the path to an electrified future is now simpler and more straightforward than it has ever been. The vehicles are coming, and we don't need to question that any longer. What we need to do now is to understand how and where to build charging infrastructure, and then start building it to meet the demand of oncoming EVs in as energy- and capital-efficient a way as possible. This report identifies the key hurdles that have inhibited the growth of charging infrastructure, and explains how they might be overcome, along with the best practices for siting chargers and designing electricity tariffs for EV charging stations.

However, deploying charging infrastructure for optimal benefit to all will require careful planning, robust testing and pilots, and appropriate incentives. Planners need to consider how many and what kinds of chargers will be needed and where, both now and in an autonomous ride-hailing EV future—preferably without stranding charging assets along the way. They will need to consider what the best paths are for charging station deployment, given sometimes-conflicting priorities specifying that public investments should be low-cost, high-utility, equitable, free-market oriented, and expeditious. The current patchwork network of vehicle charging infrastructure in the U.S. is still small enough and young enough that we lack sufficient data and rigorous analysis to answer many of these questions. Where this is the case, regulators and other stakeholders should not delay, but rather design effective pilots that can answer these questions and then scale into full programs—and fast.

The path that a given utility or state might take into vehicle electrification will vary according to different configurations of several fundamental factors, such as whether the regulatory environment dictates vertically integrated utilities or a "decoupled" utility business, available state and utility incentives, driving patterns, the grid power generation mix, load patterns on the local grid, climate and social objectives, and various kinds of costs. State and municipal officials who would promote vehicle electrification in their jurisdictions will need to understand how these factors can work for or against a given electrification strategy. For example, our research shows that direct-current fast charging (DCFC)—also known as fast charging—in an urban environment is much more costly than refueling a conventional gasoline vehicle, and that DCFC charging costs can vary widely from state to state and utility to utility.

FIGURE 3

ELECTRICITY COST FOR HOST SITE TO DELIVER ONE MILE OF CHARGE VIA DCFC



To demonstrate the different paths that result from various combinations of these factors, we look at five U.S. states: California, Colorado, Hawaii, Ohio, and Texas. For each of these states, we investigate and critique:

- The current state of charging station deployment and ownership, and strategies for further charging station deployment
- The regulatory structure of the state, and the implications of that structure for charging station deployment
- The economics of EV ownership
- The cost of owning a charging station under several charging scenarios and types of charger locations
- How chargers are likely to be used
- Utility tariffs for EV charging stations
- The potential benefits that managed charging could provide to the state's power grid
- Additional benefits of vehicle electrification

TABLE 1

EV AND EVSE DEPLOYMENT STATISTICS BY STATE [6]

	EV PENETRATION	EVS ON THE ROAD	NUMBER OF EVS PER L2 CHARGER	NUMBER OF EVS PER DCFC
CALIFORNIA	2.10%	299,038	27	196
HAWAII	1.20%	6,178	14	88
COLORADO	0.56%	10,033	12	76
TEXAS	0.23%	18,930	10	73
OHIO	0.15%	6,973	16	52

Ultimately, our message in this report is that EVs of all sizes, shapes, and applications are coming quickly. Utilities, their regulators, states, and municipalities need to be prepared to implement programs now that will transform the mobility marketplace. States that are ahead of the curve on EV integration will enjoy lower total transportation costs, lower emissions, and a more efficient grid, and will likely be perceived as more favorable business climates able to attract a high-quality labor pool seeking high-quality lifestyles. Conversely, states that fall behind the curve are likely to face a sudden need to install expensive infrastructure and generation for peak capacity, possibly leading to a less-efficient grid with higher prices for consumers. The rapid and unplanned adoption of air conditioning 50 years ago put grid operators in just such a position, and it could happen again now, only at a much larger scale and a much higher cost. It is absolutely critical to get right the programs and infrastructure for vehicle electrification from the start, with appropriate tariffs, well-planned charging infrastructure, and the ability to manage chargers either directly or through aggregators.

With careful planning and early intervention, the electric vehicle revolution can help optimize the grid and reduce the unit cost of electricity, while increasing the share of renewable electricity and reducing emissions in both the electricity and transportation sectors.[7] Passive management techniques, such as using time-of-use (TOU) tariffs to motivate drivers to charge at off-peak times, offer a simple and easily implemented way for utilities to use the charging load of EVs to provide dynamic, real-time grid regulation services, and to provide a flexible load to meet supply. Actively managing the charging of EVs via aggregator companies, or even via direct utility control, may also be useful, although the methods for doing so are still fairly nascent. By using EVs to absorb excess solar and wind, utilities can avoid curtailment of those generators, increase their share of the total electricity supply, and possibly displace or avoid the need for conventional fossil-fueled generation. Utilities can realize these benefits starting now, with each new EV that appears on their grids. There is no benefit to delaying exploring how to accommodate EV loads intelligently.

Areas that are just beginning to install public charging stations may want to begin with a pilot program in a high-use retail area or commuting corridor. Communities that have already done pilots may want to turn insights gained from them into a more comprehensive plan, and start building charging stations in earnest. Every charging station that is deployed should deliver useful data that can be captured and analyzed to help decision makers understand the value/risk proposition of vehicle electrification in their communities. Regardless of how far along they are in deploying charging stations, all communities would be well advised to gather data from pilot projects and then use it to inform subsequent deployments as the charging network scales up. Without careful and early planning, robust testing, and demonstration projects, we could wind up with a lot of inefficient and expensive generation capacity with low load factors, unnecessary transmission and distribution infrastructure permanently embedded into utility rate bases, a network of chargers that doesn't provide cost-effective and accessible support for EVs, higher costs, and unnecessary strife in regulatory proceedings as utilities, interveners, and regulators struggle to catch up and repair damage that was entirely avoidable.

Our message is clear and simple: Building EV charging infrastructure should be an urgent priority in all states and major municipalities. Getting it right will require unprecedented cooperation by many stakeholder groups. The time to act is now.

01 THE EV REVOLUTION IS HERE

Tesla model 3, image © Tesla

THE EV REVOLUTION IS HERE

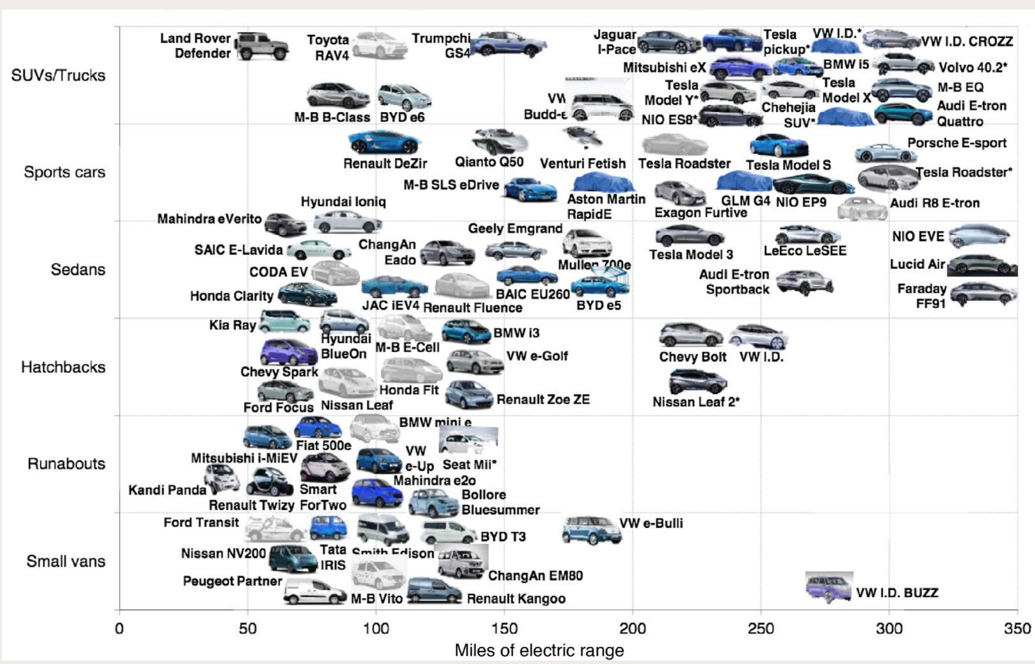
Consumers who have EVs love them. The top four vehicles in the 2015 Consumer Reports Annual Auto Survey were all either full-electric vehicles (aka battery electric vehicles, or BEVs) or electric plug-in hybrid electric vehicles (PHEVs).[8] Their smooth rides, low noise, lack of exhaust, fast acceleration and superior torque, very low maintenance needs, and fueling costs at about one-third of an internal combustion engine (ICE) vehicle, make electric vehicles far more enjoyable to drive and cheaper to own.[9]

The hurdles to widespread consumer adoption of EVs are well known: higher purchase prices, a limited number of models, range anxiety, and a lack of public charging infrastructure (charging stations that are available without restriction to the public). But the first three of those hurdles are now falling.

After tax credits, there are now 15 models of EVs available from major manufacturers under $30,000, which is the price at which widespread adoption is generally considered likely. Of those models, 10 have at least a 50-mile range in all-electric mode.[10] Many more models are expected by 2020, and Ford expects that, within 15 years, the number of EV models available will be greater than the number of ICE models. Ford alone plans to ship 13 EV models in the next five years.[11] Volkswagen has announced that it intends to launch 30 models of EVs over the next nine years.[12] Volvo projects that all of its new models will include electric drive by 2019.[13] BMW and Mercedes-Benz expect EVs to be 15–25% of their sales by 2025.[14] Even Porsche, a longtime holdout on making EVs, has announced that it now thinks electric models will be half of its production by 2030.[15] Bloomberg New Energy Finance anticipates that by 2020, there will be 39 models of PHEVs and 44 models of EVs available in North America.[16]

FIGURE 4

SAMPLE OF EV MODELS AVAILABLE THROUGH 2020

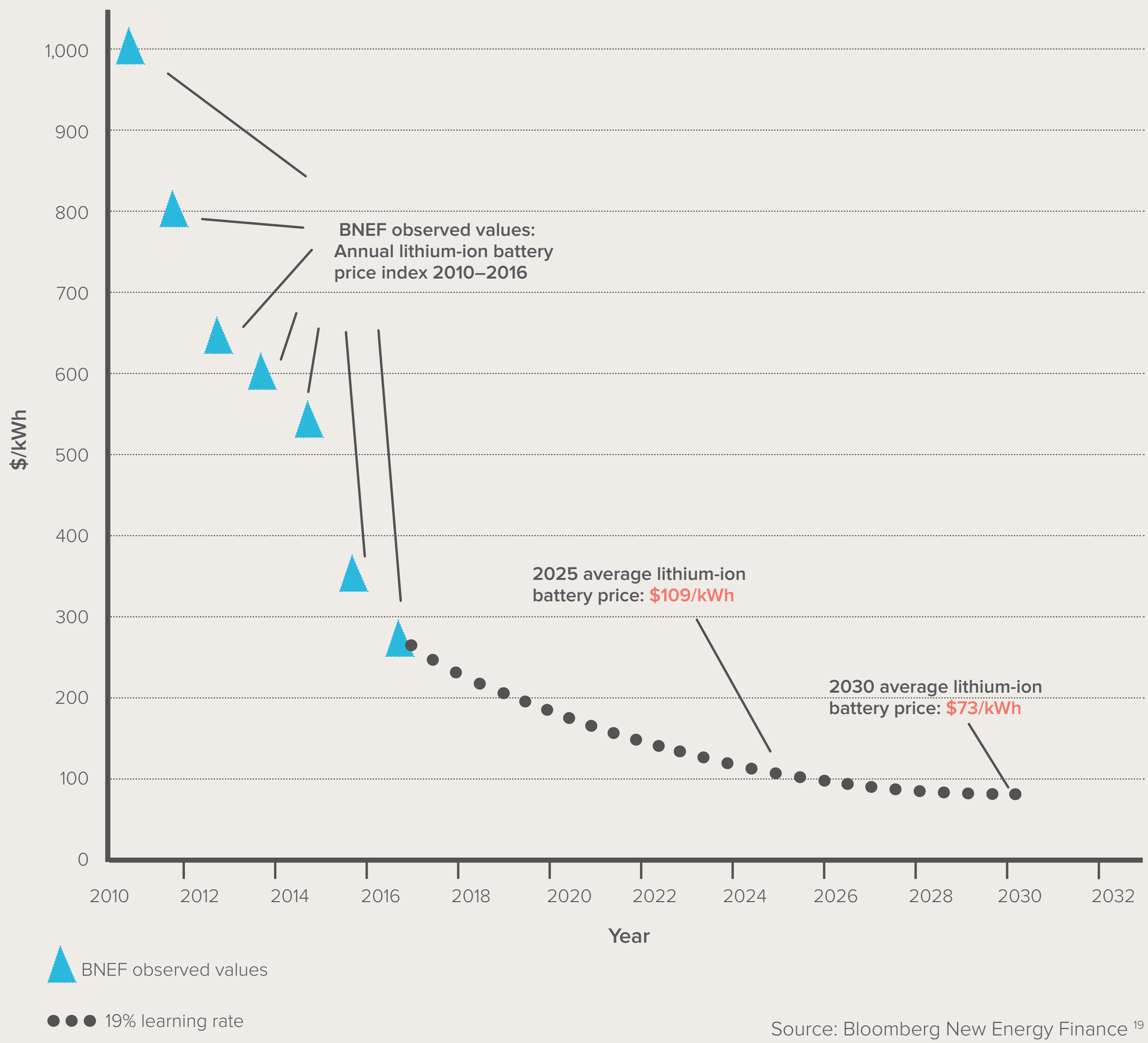


Source: Bloomberg New Energy Finance [17]

The falling cost of EVs is due primarily to the falling cost of battery packs and to vehicle manufacturers moving beyond the production of EVs merely to serve as "compliance cars." That trend looks set to continue with numerous gigawatt-scale lithium-ion battery factories under planning and construction around the world, and an expected sharp increase in vehicle sales by 2020. Bloomberg New Energy Finance expects the price of lithium-ion battery packs to fall 43% by 2021, from $273 per kilowatt-hour today to $156.[18]

FIGURE 5

BNEF FORECAST FOR THE COMBINED COST OF LITHIUM-ION BATTERY CELLS AND PACKS



Source: Bloomberg New Energy Finance [19]

Lower battery costs mean that it's now feasible to calm range anxiety at an acceptable price.[20] The base model Tesla Model 3, which has begun shipping, sells for less than $30,000 after the federal tax credit and sports at least 215 miles of range (and up to 300 miles with an optional larger battery).[21] The 2017 Chevrolet Bolt can be had for less than $30,000 after the federal tax credit, and has a 238-mile range. And by 2020, Ford plans to launch a mass-produced crossover utility model with at least a 300-mile range, which will be priced competitively for the mass consumer market.[22]

The falling cost of EVs has increased sales, and accelerated sales seem destined to continue. Worldwide EV sales in 2016 were up 42% over 2015, and U.S. sales were up 36% over 2015.[23] Total SA, a major oil company, believes EVs will make up 15–30% of new-car sales by 2030.[24] In China and India, the new growth markets for vehicles globally, EVs are expected to take significant market share. China's "road map," released in April 2017, calls for 20% of new vehicle sales to be alternative fuel vehicles by 2025. And in India, the government is aiming for full electrification of all vehicles by 2032.[25]

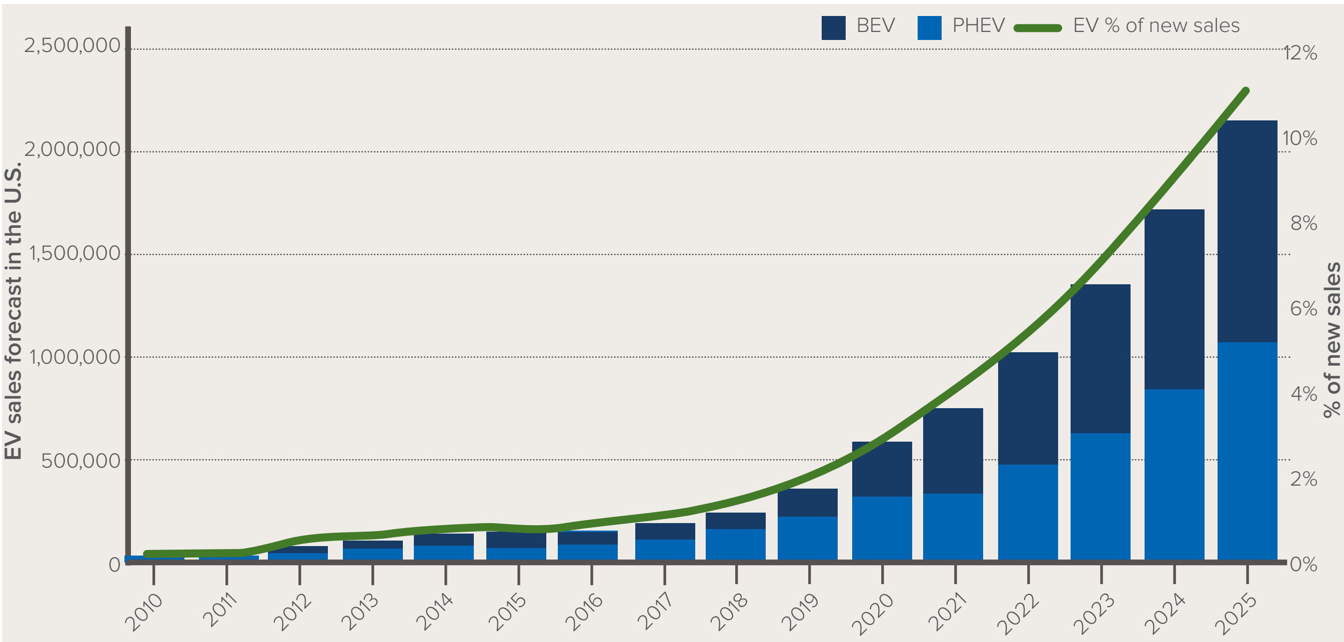
The ongoing battery-cost reductions are finally making EVs competitive with ICE vehicles. According to the investment bank UBS, EVs are approaching cost parity with equivalent ICE vehicles far more quickly than previously expected, as battery costs plunge, actual rock-bottom maintenance costs become more evident, and EV adoption rates accelerate.[26] UBS believes that in Europe, the total cost of ownership of an EV is already nearly equal to that of an equivalent ICE vehicle. It expects cost parity on a total cost of ownership basis to be reached in Europe by next year, in China by 2023, and in the U.S. by 2025, without incentives or subsidies. And although vehicle manufacturers are currently losing money on EV sales on an EBIT (earnings before interest and taxes) basis, UBS sees a positive 5% EBIT margin in Europe by 2023, in China by 2026, and in the U.S. by 2028.

Even consumers who don't think about the total cost of ownership and only look at the sticker price will soon be convinced that EVs are cheaper. Bloomberg recently suggested that EVs could be cheaper than their ICE equivalents by 2030.[27] Additionally, the second-hand market for EVs, which is only just getting started, will make earlier models of EVs attractive to segments of the market for which premium-priced vehicles were out of reach.

A central EV sales forecast from Bloomberg New Energy Finance sees U.S. EV sales rising to over 640,000 per year by 2021; however, it thinks it's also possible that annual EV sales in the U.S. could rise to nearly 800,000 by 2021, with Tesla selling 250,000 of them.

FIGURE 6

BNEF EV SALES FORECAST THROUGH 2025



Source: BNEF[28]

In addition to the market pull of lower prices, EVs will benefit from a variety of policy pushes. For example, both Britain and France have pledged to ban all new petrol and diesel cars and vans after 2040.[29] The Netherlands, Norway, and Germany have contemplated implementing similar bans as soon as 2025.[30] The mere specter of such policies is likely to accelerate EV adoption, even in the U.S., as elected officials and drivers seek to position themselves advantageously in advance of a well-telegraphed major market shift.

"The future is definitely electric, no question in my mind, it's more of, 'what is the future timeline?' Is it 10 years, 15 years, 40 years?... We don't see an alternative more interesting [than] that, it's just a matter of what the adoption hits at the scale that makes this a slam dunk."

–Tom Gebhardt, Chairman and CEO of Panasonic's North American operations[31]

Sticker prices, model options, and range anxiety will soon disappear as impediments to the adoption of electric vehicles. In fact, the economics and emerging policy targets for EVs indicate that the EV revolution is all but inevitable. It's not an *if* or even a distant *when* question anymore; it's more one of *Can we be ready in time?* EV sales could hit the rapid-growth part of the technology-adoption S-curve as soon as 2026, in the estimation of Bloomberg New Energy Finance,[32] and given the typical lead time on utility infrastructure investments, that might as well be tomorrow. In our view, the balance of risk now tilts toward deploying charging stations too late and with insufficient advance planning, not too early. And there is no benefit to delaying preparations for intelligent EV load management. Utilities can realize the benefits of EV-grid integration today, and increase their learning with each new EV that appears on their grids.

The missing link now is widely available charging infrastructure. How and where to build the charging network, and who should build it, is the subject of this report.

ACCELERATING THE EV REVOLUTION: SHARED MOBILITY AND VEHICLE AUTONOMY

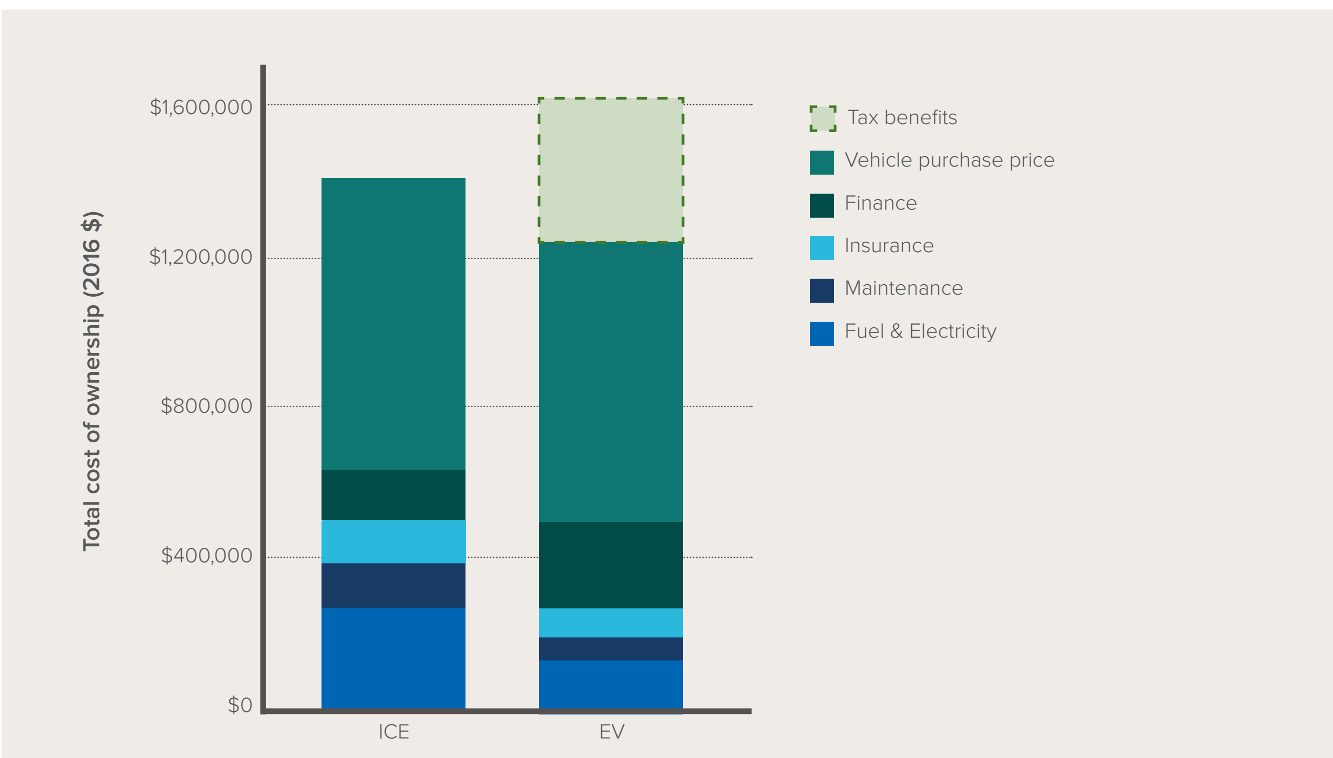
High-usage fleet vehicles are prime candidates for electrification. The total cost of ownership is already lower for EVs than for conventional ICE vehicles. By concentrating charging at purpose-built charging depots, where capital costs can be spread over a larger number of charging events and charging behavior can be managed to provide valuable grid services, fleet operators can lower charging costs further. What has been lacking for operators of EV fleets is sufficient charging infrastructure of this nature.

Fleets can also be managed to use public chargers (chargers that are available without restriction to the public) during times of low demand, and help to optimize the use of those chargers. For example, GM's Maven car-sharing service has found that ride-hailing services using their vehicles tend to charge at times of the day when existing DCFC networks have low utilization, as in the mornings and later in the evenings. DCFC owners could offer time-varying prices for using their chargers that would encourage drivers to charge at times of low demand, which would help fleet operators save money and help DCFC owners increase their utilization rates.

Figure 7 shows the five-year total cost of operation (assuming a 10% discount rate) for a fleet of 30 Chevy Bolts driving 25,000 miles per year, and compares those costs to the cost of operating a fleet of 30 compact ICEs, based on average ICE fleet cost and performance.[33] (See the Appendix for details on the methodology of this analysis.) These results demonstrate the favorable economics of EVs in fleet

FIGURE 7

FIVE-YEAR TOTAL COST OF OWNERSHIP NET PRESENT VALUE FOR A FLEET OF 30 VEHICLES IN COLORADO, ICE VS. EV



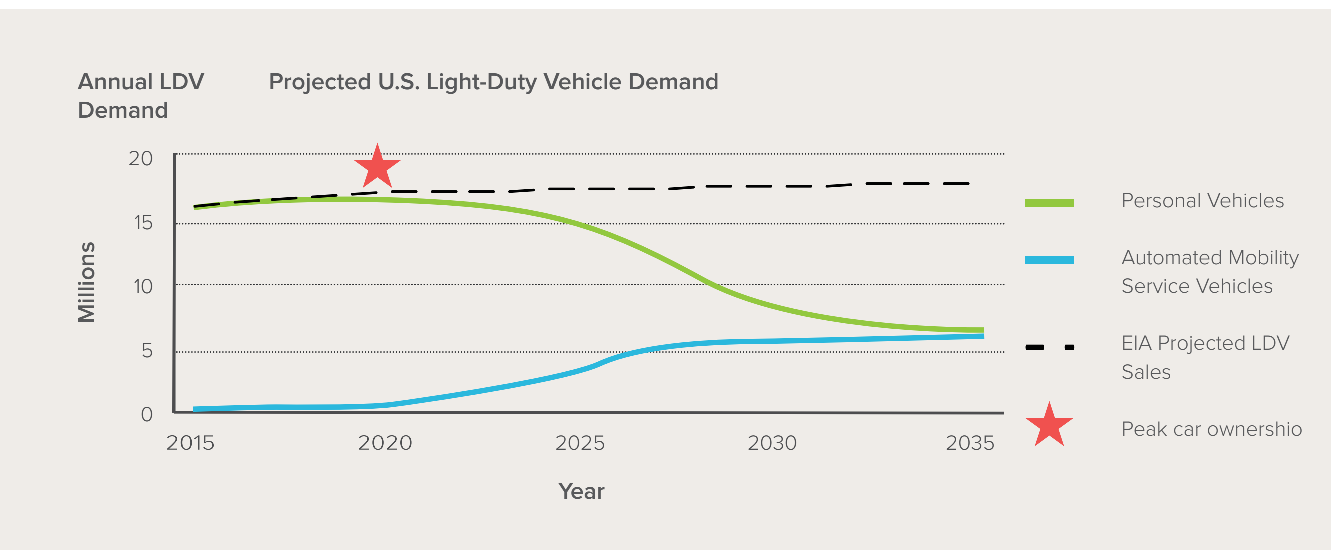
deployment under current capital and operational costs after federal and Colorado state-level tax rebates. As shown in the chart, the primary savings are from lower maintenance and fuel costs. However, those savings are largely offset by the cost premium of the EV. The capital cost of the Chevy Bolt is roughly $10,000 higher than a typical ICE counterpart, and federal and state tax credits are currently necessary to tip the total cost of ownership in favor of EVs. However, as battery costs continue to decline and production volume increases, the tax credits will no longer be needed and EVs will be economically favorable over ICEs without the help of subsidies.

AND THE SELF-DRIVING PHASE OF THE REVOLUTION IS EN ROUTE

The takeover of the personal vehicle market by EVs will be accelerated by the penetration of autonomous (self-driving) vehicle technology. Rocky Mountain Institute's 2016 report, *Peak Car Ownership*, estimated that shared autonomous electric vehicles (SAEVs) could obtain roughly a one-third share of the market for light-duty vehicles by the late 2020s.[34] According to our model, automated mobility services could capture two-thirds of the entire U.S. mobility market in 15 to 20 years, starting with urban areas. Other forecasters are even more bullish. RethinkX projected in its 2017 report, *Rethinking Transportation*, that SAEVs will account for nearly all light vehicle sales by 2030 as ICE vehicles are made obsolete, rendering 97 million of them "stranded."[35]

FIGURE 8

PROJECTED LIGHT-DUTY VEHICLE DEMAND.



Source: *RMI*, Peak Car Ownership (2016)[36]

The Brattle Group observes that the many advantages of SAEVs over individually owned ICE vehicles could engender their rapid adoption, apart from other pressures like decarbonization or utility programs to increase load. Lower accident and fatality rates, better access to mobility for underserved populations, reduced need for urban parking spaces, reduced traffic congestion, better air quality and lower overall transportation costs will all attract riders and reduce the appeal of owning and driving a vehicle.[37]

Automakers are increasingly invested in the SAEV future as well. Uber has been testing autonomous vehicles in Pittsburgh, PA; San Francisco; and Tempe, AZ. Lyft and Waymo have announced their own collaboration on autonomous vehicles. Ford, Volvo, Tesla, GM, Volkswagen, Honda, and Audi have all made investments in self-driving technology, and some have begun testing autonomous vehicles. Tesla alone has already logged more than 200 million "autopilot" miles. Ford has announced that it will mass-produce autonomous vehicles for use in ride-hailing services (with no steering wheel) by 2021. Google, Apple, Intel, and other major tech firms have also been making substantial investments in autonomous vehicle research and development.

Whether the SAEV future arrives in this decade, or several decades from now, if it is well planned and executed and built on an EV platform, it can be safer, cheaper, more enjoyable, and more environmentally friendly than today's personal transportation regime. In fact, its benefits could be so numerous as to make it inevitable.

But between now and then, we will need to deploy charging infrastructure, both for today's rapidly growing fleet of EVs, and for SAEVs when they arrive in large numbers. As we discuss in "The impact of 'Dieselgate'" on p.35, it will be important to consider the different charging needs and adoption rates of electric personally owned vehicles (POVs) and fleets of SAEVs, and plan the deployment of charging stations accordingly.

"'There is a major disruption looming there,' [Apple CEO Tim] Cook said on Bloomberg Television, citing self-driving technology, electric vehicles and ride-hailing. 'You've got kind of three vectors of change happening generally in the same time frame.'"[38]

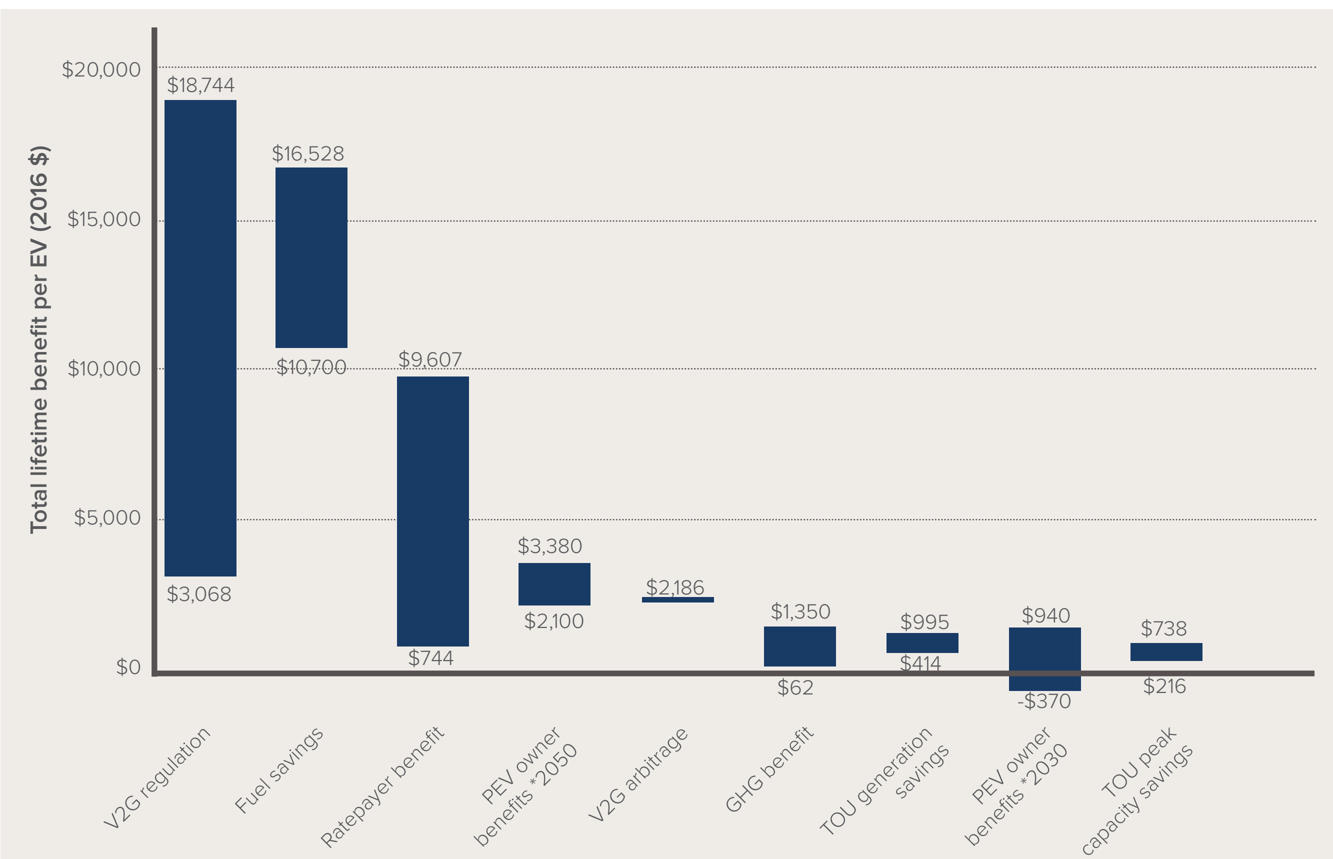
02 THE ECONOMICS OF EVS AND GRID INTEGRATION

THE ECONOMICS OF EVS AND GRID INTEGRATION

Numerous studies from across academia, think tanks, consulting firms, and industry trade groups have exhaustively analyzed the costs and benefits of vehicle electrification. Often these studies present the value and cost of electric vehicles from a single stakeholder perspective and consider only a subset of the full range of values EVs offer. In this report, we aggregate and then normalize results from 11 studies and present the values in dollars per EV, over the lifetime of the vehicle, in 2016 dollars. As shown in Figure 9, the values vary significantly within value categories as well as across them. This range can be attributed to many factors, including but not limited to: electricity market, utility regulation, battery size, tariff structure, generation mix, distribution system age and capacity, and vehicle characteristics (see Appendix for detailed tabulated values). What this exercise demonstrates most clearly is that EVs provide value to all stakeholder groups, but characterizing that value in a generalized way is not useful, due to the myriad variances from place to place. However, we can make the general assertion that when EVs are properly integrated with the grid, they provide value to both customers and the grid, but maximizing the value (and avoiding unnecessary costs) will require thoughtful planning and collaboration across all stakeholder groups. It will also require some courage on the part of decision makers to test early and take action before substantial demand materializes, in the interest of protecting utility customers and society as a whole from hasty, late, and poorly considered infrastructure investments.

FIGURE 9

RANGE OF STAKEHOLDER BENEFITS FOR EVS FROM THE LITERATURE[39]



Below we provide a brief description of the major EV benefit categories.

Gasoline savings – The difference in the cost of fueling an average ICE vehicle as compared to its EV counterpart. This value is sensitive to gas and electricity prices as well as to the assumed fuel economy of the vehicle.

Utility customer benefits – Benefits to utility customers are often calculated using a standard ratepayer impact measure (RIM). The RIM is a calculation that measures what happens to a customer's bill due to changes in utility revenues and operating costs resulting from implementing a new program or tariff. In the case of EV-specific rates or programs, a positive RIM means the revenue generated from EV charging is higher than the marginal cost to serve those customers and thus creates downward pressure on all rates.

Time-of-use generation savings – The difference in cost of energy generation when vehicles charge during the off-peak hours of a TOU rate. This value is highly dependent on the generation mix and the economic dispatch order of the generator fleet. This value is not a net benefit to the grid or to an EV owner. Rather, it should be considered a cost that can be avoided if drivers respond to a time-varying rate designed to reduce on-peak consumption.

Time-of-use peak capacity savings – The avoided cost of building new peaking capacity that can be realized by managed charging as compared to uncontrolled charging. This value is not a net benefit to the grid or to an EV owner. Rather, it should be considered a cost that can be avoided if drivers respond to a time-varying rate designed to reduce on-peak consumption.

PEV net owner benefit – The net benefit or cost of owning a plug-in electric vehicle (PEV) as compared to an ICE vehicle. This value is highly dependent on the capital cost of the vehicles, the fuel economy, the fuel price, and the driving patterns of the vehicle owner. However, it is clear that fueling and maintenance costs for EVs are considerably lower than for ICE vehicles.

GHG benefit – The value of avoided greenhouse gas (GHG) emissions as compared to a typical ICE vehicle, based on the GHG emission intensity (the emissions per unit of grid power generated) for a specific utility or region, and an assumed vehicle fuel economy. This value is typically derived from an assumed \$/ton CO_2 and is often assumed as an externality that is typically not monetized.

V2G regulation – The value of vehicles responding to frequency regulation signals by sending electricity back to the grid, using vehicle-to-grid (V2G) technology. This value is highly dependent on the power capacity of the battery and the electricity market in which it is participating. These values are fairly theoretical, as there are currently no major utilities or vehicles that allow V2G operation at commercial scale in the United States.

V2G energy arbitrage – The value that can be captured by charging an EV battery during low-cost periods and then selling that energy back to the grid during high-cost periods. These values are fairly theoretical, as there are currently no major utilities or vehicles that allow V2G operation at commercial scale.

G2V services – Although they are currently hard to quantify because they are so new that empirical data is hard to come by (hence their absence from Figure 9), managed charging can provide numerous ancillary services to the grid, as we detailed in our 2016 report, *Electric Vehicles as Distributed Energy Resources*.[40] These services include demand response, frequency regulation, voltage regulation, and other technical grid support services, and are sometimes collectively referred to as grid-to-vehicle (G2V) services. Rather than sending energy back to the grid as with V2G services, G2V services are typically provided by an aggregator who turns a group of charging stations off (or down) when the grid is stressed, or when the utility issues a demand-response request. This service does not require bidirectional inverters, but it does require that vehicles charge at rates lower than their maximum capacity to allow for "regulation down" events (e.g., vehicles increase their charging rate to lower grid frequency).

Understanding how to interpret and apply these benefits can be a complicated task. Although a single EV can and does provide these benefits, it is not possible to simply add them up to arrive at a single net benefit, partly because providing one service can limit the opportunity to realize value from another service. For example, one might have to be charging during an on-peak period of a TOU rate in order to be available to provide a frequency response service to the grid. Or charging only during the off-peak hours of a TOU rate may mean charging during times when the GHG emission intensity is higher (for example, charging overnight when coal is the marginal generator on some grids) and thus reducing the GHG-reduction value. This would not be the case where TOU rates are designed to shift charging to periods of excess renewable generation, as is increasingly the case in California.

Therefore, integrating large quantities of EVs into our electricity system will be a challenging optimization problem that must consider the needs of the EV owner or fleet operator, while also considering what is most cost-effective for the grid, in addition to other social goals like decarbonization and equitable access to charging facilities. This necessarily requires granular and intelligently designed price signals that will allow users to make economically guided decisions.

03 GET READY

Charging stations, courtesy of Felix Kramer

GET READY

EV sales in the U.S. have been growing at a compound annual growth rate of 32% for the past four years, and monthly 2017 sales data suggests that the sales rate is accelerating sharply. Under some reasonable assumptions, there could be 2.9 million EVs on the road in the U.S. within five years, bringing over 11,000 GWh of load to the U.S. power grid, or about $1.5 billion in annual electricity sales that utilities will need to accommodate well within their current planning horizons.[41]

It's time to focus on how to deploy charging infrastructure, so that we can do it deliberately, at the lowest possible cost, and with the greatest possible benefit, instead of reactively, inefficiently, and ineffectually.

BARRIERS TO DEPLOYING INFRASTRUCTURE

The best practices in deploying charging infrastructure may vary from place to place. The arguments against deploying charging infrastructure may vary from place to place too, depending on the regulatory environment, the popular perceptions of EVs, and other factors. We interviewed nearly two dozen experts on EV-grid integration to get their perspectives on the common arguments they have heard against investing in charging station networks. Here, we address those arguments.

THE COST OF INSTALLING CHARGERS IS TOO HIGH

There are three major types of charger, and their costs are very different. (See Table 2 Types of Chargers on p.33 for details.)

Level 1 charging is built into every EV, so the only cost is for an extension cord to run from the vehicle to a standard wall outlet.

Level 2 charging requires the installation of a special charging unit and access to 240V service. The cost of installing a Level 2 charger can run from around $500 (to buy a unit off the shelf and install it at home) to around $6,000 (for a commercial public installation involving removing and replacing concrete, trenching, running conductors, and other tasks). The cost of installing a bank of Level 2 chargers, for example at a workplace or shopping mall, is therefore not negligible.

DCFC chargers are expensive, typically running around $50,000 per charger installed, although some installations can cost considerably more. With so few DCFC chargers installed across the U.S., there is limited cost data available, and it varies widely. After including costs for project development, design, permitting, and system upgrades, it's not unusual for the total cost of DCFC deployment to run as high as $300,000 each. These costs limit the business opportunity for public DCFC chargers. Unfavorable rate design (see "Tariffs" on p.42) exacerbates the challenge, and low utilization rates (because there aren't yet enough EVs on the road) make it very difficult to show the business case at present. At a retail price for electricity that would be on par with fueling with gasoline (around $0.29/kWh, according to our analysis,[42] or around $0.09–$0.13/mile cost to the driver), recovering the capital from DCFC investments is extremely slow.

SOLUTION

Rebates or other incentive programs for homeowners and businesses to install Level 2 chargers for customers and employees are a relatively low-cost way to satisfy charging needs over the next decade while offering the greatest grid-interactive flexibility. Therefore, ubiquitous deployment of Level 2 chargers should be a top policy objective. Many utilities already offer rebates on home and workplace charging stations. With modest support, it should be within reach of most homeowners and commercial businesses to install an appropriate number of charging stations to support their own personal needs or those of their employees and customers.

DCFC installations will need more than rebates; specifically, they will need larger amounts of "patient capital" to support their installation and operation for a decade or longer. DCFC installations will need patient capital until there are enough EVs on the road to significantly increase their revenue and shorten their path to profitability, and until the market for these chargers has grown sufficiently to drive down hardware and balance-of-system costs. Numerous financing solutions, from municipal bonds and green bonds, to long-duration purchase agreements, to green bank investments, would be able to answer that need if investors had sufficient confidence in the inevitability of vehicle electrification. In the absence of that confidence, however, the most expedient path would be to allow utilities to rate-base at least the make-ready portion of charging infrastructure (providing wiring to the point where a charging station could be installed). And since all customers would share the benefits of the charging network eventually, that investment seems consistent with sound regulatory principles. However, it would behoove regulators to design such utility investments with performance-based incentives; see sidebar on p.38.

Alternatively, regulators could offer tariffs that shift costs away from private DCFC installers and owners (and onto the general rate base) to enable the private DCFC installers and owners to see a shorter path to profitability, which would in turn enable them to secure low-cost, long-term capital. Although RMI has done extensive research on rate design for new technologies, like EVs, and on the merits of advanced rate design in general, the details and theories of rate design, and the intended and unintended cost shifts between classes of utility customers is not the object of this report. It should be noted that regulators have varying views on whether utilities should be allowed to own charging infrastructure at all, as we discuss in "Ownership" on p.39. By the very design of the U.S. utility and regulatory system, this is a determination that each regulatory body must make for itself, within the scope of its authority and jurisdiction.

Tax relief for the installation and operation of DCFC could also stimulate investment and help lower the cost of capital. The current installed base of DCFC is relatively small and underused, but with a favorable tax structure, there will be incremental investments in equipment and incremental sales that will produce some incremental tax revenue, which can be shared with the investors in consideration for providing a public good.

Programs and credits, like California's Low Carbon Fuel Standard credits, can also help to defray the cost of installing charging infrastructure, and help improve the business case for owning and operating charging stations.

REGULATORS AREN'T CONVINCED THE INVESTMENT IS WORTHWHILE

With few EVs on the roads in most places outside California, it has been difficult for regulators in many states to justify allowing utilities to invest in charging infrastructure and recover the costs through the rate base. While only a few drivers of expensive EVs are even able to use charging infrastructure, it's easy to make the argument that spreading the cost of charging infrastructure over all utility customers amounts to shifting of costs from the rich to the poor. In the face of such a potent political argument, even the best of careful cost-benefit analyses can fail to engender the support of public utility commissioners.

SOLUTION

If vehicle electrification is now an unstoppable trend with proven and quantifiable benefits to society (as we discussed in "The Economics of EVs and Grid Integration" on p.22), and charging infrastructure is well-used, then the cost-shifting argument is really just based on a very near-term question about timing. Since the aforementioned BNEF and UBS projections indicate that EVs will see rapid adoption within two years and reach cost parity with comparable ICE vehicles in the U.S. within seven years, it is difficult to argue for further delay in making infrastructure investments. The availability of charging infrastructure will benefit everyone—even those who don't drive—so distributing some of the costs of building it across the rate base can be justified. But, we hasten to add the caveat that such benefits will accrue *if the infrastructure is* *well used*. It would behoove regulators to ensure that utility investments are money well spent by employing performance-based incentives; see sidebar on p.38.

To invert the argument: Voluminous research has already shown that the social benefits of widespread vehicle electrification are many, and an electrified transportation regime would deliver more than enough social benefit to justify the investment needed to obtain a widely available and commercially viable network of charging stations. If we accept that getting to that point will require significant investment by the public because private companies can't do it on their own (as California's experience suggests; see "Ownership" on p.39), then costs would only be shifted during the first part of the adoption curve. Once owning and operating charging stations is a sustainably profitable business in its own right, the need for public investment would be minimal. In the meantime, investments by utilities and automakers like Tesla, which is building its own network of charging stations, will be important to getting the network built initially. And public investment made in charging infrastructure in order to obtain a long-term good that will benefit everyone is a right and proper use of public funds, especially if that good cannot be secured otherwise. Thus, public investment in charging infrastructure isn't a cost shift from one customer class to another; it's a cost shift from one time frame to another, and is a routine way of paying for things the public wants and needs, in exactly the same way that it pays for roads, water infrastructure, and the rest of the electricity grid.

UTILITIES AREN'T ACCUSTOMED TO CHARGING-INFRASTRUCTURE INVESTMENT

In order to justify investments in charging infrastructure, utilities may need to present complex cost-benefit analyses to regulators, including harder-to-quantify benefits like the effects of load-shifting, demand response potential, net emissions reductions, and so on. Those rate cases will also be burdened by uncertainty about how quickly the market for EVs will grow, and when and how the benefits of managed charging can be realized. It can seem much simpler, easier, and less risky for a utility to invest the same money in routine things like efficiency measures, where the business case for doing so is well established and understood and developing the rate case is a routine exercise.

SOLUTION

If the arrival of ubiquitous EVs (and ultimately SAEVs) is inevitable, then this is a matter of when (not if) regulators will offer an attractive case for utilities to make the investment. Performance-based regulation could be a good way to scale up utility investment in charging infrastructure, providing the incentives to bridge the gap between today's nascent market and tomorrow's large fleets of EVs with their reliable demand for chargers, while not exposing ratepayers to undue risk. (See sidebar on performance-based regulation on p.38.)

It will likely require regulatory leadership in order to overcome this obstacle, so regulators must be prepared to make the case to the public for widespread vehicle electrification before it is blindingly obvious that it is needed, and seize the opportunity to build charging infrastructure using all the tools at their disposal.

Several studies have shown that even before EVs constitute a large share of the total vehicle fleet, they can significantly increase the demand peak on the electricity system. For example, a 2013 study for the Vermont Energy Investment Corporation found that if 25% of vehicles were EVs and they were charged in an uncontrolled fashion, they could increase peak demand by 19%, requiring a significant investment in new generation, transmission, and distribution capacity. However, if that same load were spread out over the evening hours, the increase in peak demand could be cut to between zero and 6%. Further guiding charging to happen only at off-peak hours could avoid any increase at all in peak demand.[43] In order to make the most of ratepayer dollars, utilities should make investments in charging infrastructure and the capability to manage charging long before the market demands it. Indeed, as we detailed in our 2016 report *Electric Vehicles as Distributed Energy Resources*,[44] it is essential to have the requisite systems, programs, and tariffs in place before EVs arrive on the grid if utilities are to realize the full benefits of vehicle-grid integration that we summarized above.

In the longer term, EV charging represents one of the few opportunities that utilities have to increase electricity sales in an era in which load is generally flat to declining. If all light-duty vehicles in the U.S. were replaced with EVs, they would require about 1,000 TWh of additional electricity per year, or an increase of about 25% over our current electricity demand.[45] That's arguably the best growth opportunity that utilities now have. Once a significant number of EVs are on the road, utilities can explore their potential to provide ancillary services, and reduce system demand peaks and capital investment. But first they have to be positioned to capture the value of vehicle-grid integration.

COSTS ARE UNEVENLY DISTRIBUTED

An investment of the magnitude needed to materialize a fully electrified transportation regime in the United States would be very large—possibly on the order of that made in our road and water infrastructure during the New Deal and the post-World War II era. It would not be reasonable to expect private charging companies to be able to attract and invest that much capital on their own, particularly if it must be deployed at outsized risk initially, and then recovered over a long period of time through modest revenue streams. With the exception of Tesla, which is building a significant charging network to support the vehicles it makes, EV buyers and a few charging companies are making nearly all of the investment needed to keep vehicle electrification moving forward. Other deep-pocketed stakeholders in the EV-grid ecosystem, such as utilities and automakers other than Tesla, are arguably not bearing a fair and proportional share of the investment risk, but they stand to capture a significant share of the investment reward. Consequently, those who have borne the investment burden thus far are beginning to ask whether the cost of charging infrastructure has been, or will be, evenly distributed.

SOLUTION

Given that it is in pursuit of a universal public good, public spending seems both justified and reasonable in partnership with private capital and private companies. Rebates offered thus far (federal, state, municipal, and local) for vehicles and charging stations are helpful, but not sufficient. To accelerate the deployment of charging stations in order to meet the demand that new vehicles will entail, the public should make additional investment. That public investment would almost certainly include allowing utilities to take advantage of their very low cost of capital to extend their distribution networks and create make-ready locations for charging stations, along with associated upstream and locally related development of the power grid as demand grows. Depending on the view of the local regulatory authorities, it could also include allowing utilities to install and operate the stations. However, utility investment should be guided by smart performance-based regulations to ensure that the public receives a good value for its investment; see sidebar on performance-based regulation on p.38.

It would also be reasonable to allow public funding to extend to other enabling infrastructure, such as city or municipal funding, to help plan, locate, and construct charging-enabled parking spaces, or to offer tax relief to private investors in charging infrastructure. Municipal bond issuances, privately funded green bonds, infrastructure bank investments, and other investment vehicles to provide large-scale, patient capital could all play roles in the appropriate and fair distribution of investment burden and risk. Defining those specific arrangements is beyond the scope of this report, but we think it is proper and necessary that municipal planners engage with utilities and automakers, as well as with private charging companies, to creatively address this challenge.

IF YOU BUILD IT, THEY WILL COME.

Kansas City Power and Light (KCP&L) offers an instructive object lesson about how the availability of charging infrastructure can boost EV adoption.

In 2015, KCP&L decided to install over 1,000 EV charging stations to jump-start the EV charging station industry in Kansas City, Missouri, and capitalize on a new growth market for power—a rare opportunity in a time of flat-to-declining electricity demand.

Chuck Caisley, vice president of marketing and public affairs for KCP&L, explained the dilemma over how to approach the new market: "You're faced with a chicken-or-egg kind of thing. People won't get over range anxiety unless there are EV charging stations, and nobody around here is putting them up, because they don't think there's any demand."

The overwhelming majority of the new stations are Level 2 chargers purchased from ChargePoint and installed and operated by KCP&L. The Clean Charge Network is the first electric vehicle charging station network to be installed and operated by an investor-owned electric utility in the U.S. It is the largest network in the nation and has given Kansas City the largest number of chargers on a per-capita basis of any city in the U.S. KCP&L offers charging for free to drivers during the first two years of the network's operation.[46]

The results have been dramatic: Kansas City now leads the nation in EV growth, with EV adoption nearly doubling since the Clean Charge Network launched. "The sheer number of charging stations—strategically located where people live, work, and play—KCP&L's Clean Charge Network eliminated range anxiety in the Kansas City region," Caisley said.[47]

INVESTMENT IS INEQUITABLE

Some consumer advocates have argued that since EV charging infrastructure is currently only used by a small fraction of drivers, many of whom are wealthy enough to afford a more-expensive EV, allowing utilities to invest in EV charging infrastructure and recover the costs of those investments via charges that all customers pay amounts to an unfair shifting of costs from the wealthy onto all other customers, and therefore investments in charging infrastructure should be left to the private sector, which has to raise private capital and pay its own costs.

Although EVs are being rapidly adopted now, it's unlikely that they will become widespread until there is also widely available charging infrastructure sufficient to give consumers confidence that they can recharge their vehicles whenever they need to. And it is difficult for private charging companies to create a business case that would make it possible to finance and build additional public DCFC capacity, because utilization rates of existing DCFC are low, which is in turn a reflection of the small share of EVs in the personal vehicle market. Although individual Level 2 charging stations are not expensive, investments in them can be too slow to pay off to interest speculative commercial investors, at least until the market grows up and utilization rates improve.

The net result of this argument around inequitable investment is to delay the build-out of charging infrastructure, binding it to the chicken-and-egg problem that has been a hindrance to EV deployment all along.

SOLUTION

If one accepts our proposition that vehicle electrification is not only inevitable but also a net benefit to the public, given the many advantages of EVs over ICE vehicles, then the issue isn't about cost-shifting so much as it is about timing. When nearly all drivers have EVs, the cost of charging infrastructure will be appropriately distributed among them. Even nondrivers will benefit from the drastically reduced air pollutants of vehicle exhaust, and from the lower total cost of electrically powered mobility in general, which would put downward pressure on the price of all goods and services.

Therefore, the real question isn't about equity, but rather about who will provide the financing to build the infrastructure while the market matures, until all the costs and benefits can be shared equally. It is essentially a quotidian need for low-cost financing of perhaps 20 years' duration, at which point the utilization rate of the charging infrastructure should make a reasonable business case possible for owning and operating it, and drivers of all vehicle classes will be able to make use of it. Utilities could fill this need, but as we discuss in "Ownership" on p.39, that approach may work better in some states than others.

To the extent that regulators see a need to protect low-income and rural households from the shared costs of building charging infrastructure while the market matures, rebates or other cost-relief mechanisms should be preferred to avoiding any public investment whatsoever. That should no longer be considered a viable option.

THE CHARGING STATION NETWORK IS BALKANIZED

The existing network of charging stations developed in a bottom-up fashion through the independent efforts of numerous companies and governments. It was not designed in a top-down fashion and it was not planned for interoperability.

As a result, roaming across networks can be difficult for drivers, because the networks lack cooperative billing agreements and have not supported standards for executing transactions and settlements. Consequently, some EV drivers complain about having to carry a wallet full of payment cards for various charging station networks in order to travel long distances, and it can be difficult to implement managed charging, municipal incentive programs, or other projects across multiple networks. EV drivers who mainly commute over the same routes, or just drive around town, can work out a reliable payment solution that meets their needs. To be truly competitive with the ease of buying fuel for an ICE, however, the networks of EV chargers still need some integration work.

The current situation is analogous to traveling across interstate toll roads. While there is considerably more integration of these roads and their payment systems than there used to be, there are still some inconsistencies across regions that need to be ironed out in order to stitch together a fully integrated system from end to end and prepare for a future with longer-range EVs that drivers depend on to travel further.

SOLUTION

Charging network operators need to work together to develop cooperative billing arrangements. There are numerous protocols in various stages of development and implementation. However, the free, open source Open Charge Point Protocol (OCPP) has become the de facto open standard for charger-to-network communications in many countries, including in Europe and parts of the U.S. It supports interoperable information exchange about transactions and the operation of chargers.[48]

CHARGER DEPLOYMENT CONSIDERATIONS AND BEST PRACTICES

Having understood how to overcome the obstacles to charging station deployment, we can proceed to understanding where to site them.

The best type of charger to install in a given location depends on several variables that should be considered carefully for each location, such as:

- What kinds of vehicles are likely to visit the charger now and in the future?
- How depleted are the vehicles' batteries likely to be when they arrive, and how much of a charge will they need?
- How long is the vehicle likely to remain connected to the charger?
- What is the cost of providing charging service at that location?
- Who owns the charger and what is his or her business purpose for hosting or owning it?

Since the answers to these questions may vary significantly, and there is still very little data available to provide empirical evidence to prove one approach is better than another, we will not attempt to offer a one-size-fits-all answer, but rather identify some of the considerations that should go into siting an appropriate charger.

TABLE 2

TYPES OF CHARGERS

TYPE	VOLTAGE (V)	CAPACITY (KW)	MINUTES TO SUPPLY 80 MILES OF RANGE
LEVEL 1	120	1.4–1.9	630–860
LEVEL 2	240	3.4–20	60–350
DCFC (LEVEL3)[i]	480	50–400	3–24

DCFC ARE VERY DIFFERENT FROM LEVEL 1 AND LEVEL 2 CHARGERS

BEST PRACTICE IN BRIEF

- Level 2 chargers present the lowest-cost option to serve residential and workplace charging needs, and offer the best opportunity to manage EV charging for grid benefits.
- Though considerably more expensive, DCFC are necessary where vehicles need to charge quickly. These chargers will be essential to serve future mobility needs such as electrified public transit, fleets of ride-sharing vehicles, and autonomous vehicles.

[i] Level 3 chargers, which are more commonly known as DC fast chargers (DCFC), include three main types of connectors: CHAdeMO chargers, which have been popular in Asia and are increasingly being used in California and elsewhere; SAE Combined Charging Solution (aka SAE Combo or CCS); and the Tesla Supercharger format. Voltage may vary depending on the configuration.

LEVEL 1 CHARGERS

Because Level 1 charging (simply plugging the EV in to a standard 120V wall socket and using the vehicle's built-in converter) takes eight hours or more to charge up a fairly small-capacity EV battery, we don't expect Level 1 charging to play an important role in the future as EV battery packs get larger.

- In general, Level 1 charging does not require any new equipment, so it does not require any additional investment.
- Since Level 1 is a low-power type of charging, it would not present much of a challenge to grid operators, even if every house had an EV charging on a Level 1 charger—particularly if the charging were managed. But we believe that many households will prefer the speed and convenience of having a Level 2 charger.
- In theory, Level 1 chargers could be managed to provide dynamic grid services in the way we described in our 2016 report, *Electric Vehicles as Distributed Energy Resources*. However, at present, that would require a user to actively control the charging through the vehicle's on-board controls, which would require additional driver education and could be harder to achieve at scale. While some jurisdictions may elect to pursue customer education as a key strategy for managing Level 1 loads, others may wish to use time-varying rates or charging aggregators (see "Tariffs" on p.42).

LEVEL 2 CHARGERS

Level 2 chargers, which typically range from 3–20 kW in power output, are suitable for charging vehicles of any capacity overnight, or wherever EVs might be parked for several hours at a time, such as workplaces and shopping malls.

- Level 2 chargers have relatively low capital costs (around $600 for a residential unit, plus installation costs),[50] so they can be deployed in numbers for a modest investment, and the business case for owning one doesn't depend heavily on its utilization rate. These attributes make Level 2 chargers a good choice for many types of installations.
- Level 2 chargers are the low-cost, reasonably fast-charging option. They do not typically draw enough power to incur demand charges (unless there are several of them on a single meter), which helps to keep the cost of owning or operating one low. Of course, there are always exceptions and uncommon use-cases do happen; for such instances, appropriate rate design may be the best course of action (see "Tariffs" on p.42).
- Level 2 charger loads are generally within the range of normal residential and workplace service capacity. Even a high-end, high-speed, residential charging station, the 50A "wall connector" from Tesla, would draw a maximum of 12 kW of power, which is well within the 48 kW capacity of a typical modern 200A residential main service panel.[51] However, when Level 2 chargers are used in a cluster (such as in a neighborhood where several EVs are charging at once and drawing their power from a single transformer, or in a workplace parking lot with many charging ports), they may require the utility to upgrade distribution grid equipment.
- Level 2 chargers are the best option for using managed charging to provide dynamic grid services. This makes them an essential resource in a widely available and distributed charging network. They are also more efficient than Level 1 chargers, so making it possible for drivers to switch from Level 1 to Level 2 will help reduce the overall EV charging load.

DCFC

DCFC are useful where vehicles need a substantial charge in a fairly short period of time (usually measured in minutes). This capability comes with some important attributes, which must be taken into consideration:

- DCFC are expensive to install. The high capital cost of DCFC (typically on the order of $50,000 each,[52] though they can cost considerably more, depending on the installation), means that it's important to site them where they will have high utilization rates and generate enough revenue to cover their costs.

- DCFC can be expensive to operate. Being able to deliver a lot of energy in a short period of time generally means that they will also draw a lot of power from the grid, and that can mean high costs for providing the charging service. The type of utility tariff that a DCFC is on can drastically affect the cost of owning and operating a DCFC, as we demonstrated in our April 2017 report, *EVgo Fleet and Tariff Analysis*.[53] In one example, a charger in San Diego Gas and Electric (SDG&E) territory cost $3,114 a month under its existing tariff, but just $138 a month under a new tariff SDG&E proposed for DCFC. A sustainable DCFC is a profitable DCFC, and a profitable DCFC will have high utilization, or be on a tariff with limited demand charges, or both.
- Today's DCFC can deliver around 50–140 kW of power, which can mean fairly expensive make-ready infrastructure, especially if they are installed as a cluster on a single distribution circuit. But ChargePoint has already announced a 400 kW charger that it expects to start shipping in 2017, and other higher-capacity chargers are likely to be installed over the coming years, especially for supporting electric mass-transit vehicles. Deploying these new high-capacity chargers will come with substantially increased costs for grid connection and power delivery over the utility distribution network. Clusters of new, high-powered DCFC with high utilization rates will also have uncertain effects on the distribution grid. Siting these chargers optimally—again, especially if they are clustered—will be a nontrivial exercise calling for careful collaboration between utilities, city planners, and site hosts, and for thoughtful and proactive management on the part of distribution grid operators.
- Under the typical use-case, DCFC are not useful as dynamic loads. Users expect to be able to obtain a maximum-speed charge from them in the shortest possible time, so it's generally not practical to turn DCFC on and off (or ramp their power output) in response to changing grid conditions. However, some charging station operators are beginning to pair DCFC installations with on-site battery banks to supply power to the charging stations and avoid demand charges. These battery banks could also be used to respond to grid conditions and provide grid services. If it becomes commonplace to site grid-interactive storage systems with DCFC charging installations, then they, too, could become useful as dynamic loads. DCFC loads could also be more dynamic if DCFC operators were to expose customers to time-varying retail pricing that reflects their time-varying wholesale electricity costs. (See the Appendix for details on the methodology of our site-host cost analysis.)

It's too soon to tell what the right mix of chargers will be; the answers will vary from place to place; and which mix is best will change over time as vehicles become more advanced. However, it's safe to say that a widely available charging network will require a mix of Level 2 and DCFC, and so deployment plans should include both. Several utilities report that customers tend to rely on Level 1 or 2 charging at home for the majority of their commuting needs, then call on public DCFC stations for long-distance trips or for a quick top-off while running a day's errands. This use pattern suggests that TOU rate design could be an effective way to manage charging loads, if drivers are exposed to time-varying retail costs.

THE IMPACT OF "DIESELGATE"

Under the terms of its settlement with the California Air Resources Board, the Volkswagen-funded Electrify America program will invest $2 billion over the next 10 years in zero emission-vehicle infrastructure and education programs in the U.S., of which $800 million will be invested in California and $1.2 billion will be invested in the rest of the states. Although the National ZEV Investment Plan is still in development, we estimate that the first of four 30-month, $300 million investment cycles could result in about a 50% increase over the number of DCFC charging ports that exist nationally today, as well as a slight increase in the number of Level 2 chargers. If the final three investment cycles were similar to the first cycle, the total number of DCFC charging ports nationally could be double the roughly 5,700 ports that exist currently.

The power of this new DCFC infrastructure will be significantly greater than the existing DCFC, however. Most existing, nonproprietary DCFC chargers deliver 25–50 kW of power, and Tesla's proprietary Superchargers currently deliver up to 120 kW. The new DCFC units deployed under the Electrify America investment will be able to deliver 150 kW or 320 kW of power, depending on the model, with the intention of upgrading all of the units to 320 kW capacity by the end of the 10-year investment cycle. Therefore, whereas the first 30-month investment cycle of the Electrify America plan could deliver a 50% increase in the number of DCFC charging ports nationally, their ability to deliver power could double the existing capacity. Regulators should ensure that they have accurate estimates of the additional demand these chargers will put on utility grids, and that they are employing measures to reduce the overall impact on the cost of service.

Although there are no cars that can take a charge at a 320 kW rate today, future vehicles are expected to be able to tolerate much higher rates of charging. Theoretically, a 320 kW charger could deliver 19 miles of range per minute of charging—enough to give a full charge to a 2017 Chevy Bolt, with 238 miles of range, in perhaps 13 minutes. Until vehicles can actually take such high rates of charge, however, both vehicles and chargers can still use these newer ultra-high-speed chargers at an appropriate throttled speed, as controlled by the vehicles.

Since the Volkswagen emissions-cheating scandal broke, other manufacturers including Fiat Chrysler, General Motors, Daimler, Audi, Renault, PSA Group (the maker of Peugeot and Citroen cars), Porsche, and Bosch have all been accused of similar cheating activities.[54] If those companies were found guilty and forced to make investments in EV charging infrastructure as Volkswagen was, it could result in a very significant increase in the number of available charging stations much sooner than most observers expect.

Although the Electrify America investment will result in a significant increase in the number and power of charging stations, increasing EV penetration will demand even greater growth in charging infrastructure. In 2030, three years after the final Electrify America investment cycle is complete, Navigant forecasts that 10 million EVs will be sold annually,[55] while Bloomberg New Energy Finance estimates just under 5 million units,[56] and the U.S. Energy Information Administration (EIA) just over 1 million.[57] If any of those forecasts turn out to be accurate, we estimate that EV charging infrastructure must increase by a factor of 10–100 just to meet the needs of the EVs sold in 2030, let alone the EVs that already existed prior to 2030.

An increase in charging stations of this magnitude underscores how important it will be for municipal planners, property owners, utilities, and regulators to actively engage now with installers of charging stations to ensure that they are located in such a way that they can be used effectively as grid assets, as we described in our 2016 report, *Electric Vehicles as Distributed Energy Resources*.[58] If these new charging stations are not installed with sufficient forethought about how and when they will be used, they could have numerous negative repercussions on electricity grids instead of positive ones, and might not be used frequently enough to enable a profitable business model for charging station operators.

SITING CONSIDERATIONS

BEST PRACTICE IN BRIEF

- Public charging stations should be sited for high utilization.
- Level 2 chargers should be sited where drivers have a preference to charge over a longer interval (i.e., several hours), such as workplaces and residences.
- DCFC should be sited where utilization will be high and their grid impact will be low.
- Hubs that provide a combination of Level 2 chargers and DCFC are likely to be the best way to serve public fleets, transportation network carriers, and autonomous vehicles.

Public charging stations must be sited where they will be used frequently. A high utilization rate is important not only so that chargers can serve a large number of vehicles, but also so that they can earn enough revenue to support a profitable business case and justify the investment made in them. Currently, due to the relatively low number of EVs on the road, most DCFC public charging stations have relatively low utilization rates (in use 15% or less of the time). But in the future, it will be important to increase DCFC utilization rates in order to have a profitable and sustainable network, especially if the utility tariffs those DCFC are under are similar to the tariffs most of them are under today. As we explain below, rate design reform can make it possible for chargers with low utilization rates to be profitable as well.

To site public chargers where they will be used most, planners should look for suitable sites along high-traffic corridors, in shopping centers, at grocery stores, and other such locations. Important siting considerations include the distance between charging stations, the likely dwell time of vehicles at each station, and how convenient it is for drivers to access the stations. Our analysis of EVgo's fleet of charging stations,[59] and usage patterns in some urban municipalities, suggest the following best practices for siting.

- High-traffic retail areas can support a mix of Level 2 and DCFC stations.
- Commuting corridors, highways, taxi and ridesharing depots, and locations that may experience urgent needs for charging would be best served by DCFC.
- Wherever there is, or could be, a fleet of at least 50 high-ridesharing vehicles, charging depots may be appropriate. A typical charging depot might feature one Level 2 charger for every two vehicles, or one DCFC for every 8–10 vehicles, depending on vehicle utilization and driving patterns.

Before embarking on a significant charging station deployment, community planners are advised to study expected usage patterns with these criteria in mind, and ensure that most chargers are installed where they will be well used. Planners would also benefit from having access to data on the usage of existing charging stations, and here, regulators may have a role to play in providing that access. Pilot projects can be a good way to gather usage data and understand what the market needs in specific locations.

However, like a gas station in the middle of nowhere, it is also unavoidable that some charging stations will need to be installed where utilization is likely to be low, but critical—such as emergency use locations, and sites at the extremities of a network. A complete network, even if some stations are underused, is essential to supporting a highly electrified vehicle fleet. Leaving the siting of charging stations entirely up to the market is unlikely to produce a complete network.

A NO-REGRETS PATH TO SAEV

Although fully autonomous vehicles are not yet permitted to operate, their advantages over POVs suggest that the SAEV future will certainly arrive, for reasons we explained in our 2016 report, *Peak Car Ownership*.[60] Those siting chargers must take that eventuality into account, in order to avoid building charging infrastructure for POVs that will be stranded when the SAEV future arrives.

Based on our own analysis and the perspectives of the experts we interviewed for this report, we believe the best, no-regrets path to deploying chargers will be to install Level 2 chargers where practicable and at a reasonable cost in private homes and workplaces (where vehicles will have longer dwell times), and DCFC in high-traffic shopping areas, commuting corridors, and long-distance highway stops (where dwell times will be short). When they arrive, SAEV fleets are likely to have high-capacity battery packs enabling them to run for 200 miles or more on a charge. The lowest-cost way to support those fleets would be, first, to have them fully charge up (receiving perhaps 60–80 kWh) on a daily basis, primarily using Level 2 chargers at purpose-built charging depots designed to provide high-capacity electric service at a low cost. Then, the fleets would get a modest boost (perhaps on the order of 10 kWh or less) as needed from the distributed network of DCFC as the vehicles make their rounds over the course of the day. With this strategy, only the home and workplace Level 2 chargers would be potentially at risk of becoming stranded assets a decade or more from now, but their cost ($580 each per year today,[61] and probably significantly less in the future) is low enough that this would not be enough of a risk to dissuade their deployment in the meantime.

PERFORMANCE-BASED INCENTIVES TO DRIVE DOWN CHARGING INFRASTRUCTURE COSTS

Where the regulatory environment is open to utility investment in charging station infrastructure, regulators may want to consider the best ways to encourage that investment, and where to draw the line between utility and private-sector investment.

While not a comprehensive list by any means, here are some ideas that may stimulate creative approaches to targeted performance-based incentives for each type of infrastructure that are designed to drive down the total cost of the infrastructure to society over time.

MAKE-READY INFRASTRUCTURE

Allow utilities to install make-ready infrastructure and add it to their rate base, but with a lower guaranteed rate of return (as statutes allow), plus a bonus for building make-ready locations that host chargers with high utilization rates. The bonus could increase with the utilization rate, irrespective of who actually owns and operates the charging station.

LEVEL 2 CHARGERS

Require utilities that want to own Level 2 charging stations to offer a series of competitive solicitations for successive tranches of charging stations. Each solicitation could have a price cap per station, which declines with each new solicitation. Or the utility could be permitted to finance and build the stations itself, but only if it could underbid the lowest bids received in response to its requests for proposals.

DCFC

Because DCFC are expensive, and it could take time for the market to mature and utilization rates to rise to the point where an attractive business case exists for private-sector charging companies, utilities could be permitted to build, own, and operate public DCFC, but only earn a rate of return if the stations obtain a specified utilization rate that rises over time. Such a structure would probably be designed around a fixed time frame in order to give utilities enough visibility to make the investment, and enough time to allow the market to mature, while also capping the total return on a station over time.

ANY UTILITY INVESTMENT

Shift some or all of the cost recovery for a utility investment into the volumetric rate (the charge for energy delivered through the charging station), so that in order to recover the capital investment and potentially earn additional income, the charging stations have to be well used. To ensure utility interest in this approach, the volumetric rate premium could start at a high level and then decline over time, to create an incentive to sell more energy through the charging station as the market matures and demand scales up.

OWNERSHIP

BEST PRACTICE IN BRIEF

- There remains too little data to unequivocally say one ownership model is better than another.
- Where states and municipalities have limited experience and limited data, they should use pilots and demonstrations to test multiple ownership options, but should not delay in launching these tests.
- States and regulatory bodies should both seek to test different models, as well as collaboratively engage relevant stakeholders (such as utilities, municipalities, and charging network operators) before making long-lasting decisions.
- Allow for future flexibility, as the ownership model that is most appropriate while the market is young and small may not be the best model for a mature EV market.

The question of who should own charging stations has no simple or universal answer. Since the deployment and operation of charging stations can fall under state authority as a form of public utility, it will be up to each of our 50 states—our "laboratories of democracy"—to decide which approach is best for them. We see pros and cons with each approach, and believe that the regulatory environment in each state is potentially a key factor in choosing a path.

At a minimum, most legislative and regulatory bodies seem to agree that utilities should be permitted to build and own make-ready locations (i.e., power supplied to the point where a charging station might be installed), and to recover those investments via the rate base as a general social good. As we noted above, the public benefits that can come from vehicle electrification are numerous, including reducing pollutant emissions that are harmful to human health, reducing the overall cost of mobility, and even reducing the cost of grid power if vehicle-grid integration is done in such a way that it optimizes the entire grid.

Further, extending the grid to make-ready locations would be entirely in keeping with the long-established principle of line extension, in which all customers pay for extending the distribution grid, including new service for rural customers where the cost of providing that service is far greater than that for customers living in densely populated urban environments. By this reasoning, an extension of the distribution grid is not justified by a cost-benefit analysis for a specific customer or group of customers. Rather, the value of the entire network is considered to be shared by all customers. The same kind of reasoning allowed telephone companies to build out the pay telephone network. Each phone wasn't necessarily expected to turn a profit, but was considered necessary in order for the entire network to be functional and accessible.

Allowing utilities to also install and own charging stations could be the fastest way to build them, since utilities have access to large amounts of very low-cost capital and the ability to recover investments over decades. This may also be the easiest path in fully regulated electricity markets, where it would be routine to recover investments in the charging infrastructure through the rate base. It could also serve as insurance against price gouging by private sector companies.

Conversely, regulators must also be careful to avoid creating a situation where a utility can leverage its low internal cost of power generation and delivery to undercut private sector competitors on retail charging prices. Full utility ownership could stifle a competitive private sector market in charging stations, and utility deployments might not be as innovative in terms of technology or business model design as the private sector would likely produce. Regulators who do allow utility ownership of charging stations should take care to preserve some opportunity for private sector companies, or ensure that there is an opportunity for private companies to re-enter the business once it matures and there is a better business case for nonutility owners.

Dedicating the charging station market to the private sector only, and disallowing utility ownership of anything beyond a make-ready point, would likely yield the usual advantages of a competitive market, such as lower cost over time, and more rapid technological and business model innovation. Leaving charging station investment to the private sector would probably be the easiest path in largely deregulated states. However, the private sector may not be able to deploy charging stations at the speed required by the growth of vehicles, due to the need for large amounts of patient capital and the lack of a guaranteed demand for charging stations until the EV market matures.

The experience of California is instructive on this point. The California Public Utilities Commission (CPUC) originally found that "the benefits of utility ownership of EVSE [electric vehicle supply equipment, i.e., charging stations] did not outweigh the competitive limitation that may result from utility ownership," and disallowed utility ownership, reserving the vehicle charging market for the private sector.[62] When the deployment of charging stations by the private sector proved to be too slow to meet the state's objectives, the CPUC then removed the blanket prohibition on utility ownership of charging infrastructure in favor of an "interim approach" which uses a "balancing test that weighs the benefits of electric utility ownership of charging infrastructure against the potential competitive limitation…on a case-specific basis."[63] That decision permits third-party providers to offer charging products to the marketplace.

Instead of viewing the gap between deploying charging stations and their eventual full utilization as an argument against deployment because of the risk of cost-shifting in the short term, we view it as an indication that regulators, utilities, and charging station providers should work together to seek a more profitable business opportunity for private charging companies sooner than might otherwise materialize, and to ensure that adequate patient capital can participate in the deployment.

As we describe in "Different Strokes" on p.46, the regulatory environment in a state can be a key factor in the business opportunity for charging station operators. Some jurisdictions allow utilities to own charging infrastructure, and some don't. In some areas, charging station operators may resell electricity to end-users, and use a markup on the electricity they sell to improve their overall economics. In other areas, such as where a distribution utility has sole authority to sell electricity, they may not resell electricity, and so they may be restricted to charging customers on a per-use basis, or another arrangement (such as bundling "free" charging into a parking space rental). Regulators and municipal officials should consider the restrictions that apply in their areas, and whether the business opportunity exists to support private-sector charging station providers.

PENETRATION

BEST PRACTICE IN BRIEF

- There is currently too little data to indicate what the best ratio of charging stations to electric vehicles is.
- In the absence of evidence, collect and share data about infrastructure utilization early and often.
- Give special attention to sites that provide charging services to meet unique needs, such as transit corridors and multifamily dwellings.

A final important consideration for transportation planners is the extent and timing of charging station deployments.

Ultimately, major municipalities should plan to have charging capacity at a charging depot for every high-usage service vehicle in is territory. Because they have many charging stations at a single site, charging depots have economies of scale and will be the lowest-cost, highest-efficiency way to charge fleets of vehicles used for city services, ridesharing services, delivery services, and the like. The specific numbers and types of charging stations needed will depend on the usage patterns and numbers of vehicles in those fleets.

In most cases, it is probably best if nearly all households and workplaces have a Level 2 charging station, if they have garages or carports that can accommodate one, or that they use Level 1 charging when parked there. These low-speed charging loads are relatively straightforward for utilities to accommodate, and they offer the greatest opportunity for managed charging to provide grid services to utilities. Ideally, Level 1 and Level 2 charging would meet a large share (perhaps 80% or more) of the total charging demand for personally owned vehicles.

The number of public DCFC needed should be determined from the number of vehicles likely to visit a retail center or commuting corridor. As a first approximation, a low-risk way to approach this question is to calculate how many DCFC in a given location could sustain a 50% utilization rate within a feasible investment horizon. For example, if a city believes that it will have enough EVs circulating through its downtown area such that DCFC in that area could be in use 50% of the time within the next ten years, it should probably begin to deploy those DCFC now.

Multiunit dwellings present a special set of challenges for charging infrastructure, which may include a mixture of Level 1, Level 2, and DCFC charging stations, depending on the unique attributes of a given building and its residents. Detailing those factors is beyond the scope of this paper, but the State of California has several reports and resources offering useful guidance.[64]

Although it's hard to generalize, given the wide variance from place to place, charging station deployments appear to be lagging behind EV growth. A recent analysis by Bloomberg New Energy Finance asserts that more public chargers are needed,[65] despite an increase in deployments over the past five years; that a lack of home charging will restrict sales once EVs reach cost parity with ICE vehicles; and that the U.S. will hit an "infrastructure cap" in the mid-2030s due to a lack of charging stations, causing EV sales growth to slow significantly. To avoid this unfortunate circumstance and keep the EV revolution going, we'll need to install chargers faster.

TARIFFS

BEST PRACTICE IN BRIEF

- Create dedicated tariffs for EV chargers because their demands will be different from that of a household or business, and can be controlled separately and more flexibly than those loads.
- Slow and fast chargers require different tariffs in order to optimize utilization, charging station economics, and grid impacts.
- All EV tariffs should feature some level of time-variance or dynamic pricing in order to optimize charging patterns for grid services and reduced grid impacts.
- DCFC chargers should be on tariffs with reduced, delayed, or no demand charges until the market matures and utilization rates are high enough that demand charges constitute a normal portion of monthly bills (e.g., 30%, not 90%).
- Consider creating specific tariffs for DCFC to promote a strong and sustainable business case for owning and operating them.

It's important for utilities to offer appropriate tariffs for EV charging before significant numbers of EVs appear on their grids, because once EV drivers acquire a habit of charging at a particular time and place, those habits can be hard to break. This was a key finding of an EV tariff pricing study conducted for San Diego Gas & Electric.[66] With EVs now set to arrive in significant numbers, it is critical that utilities and regulators ensure that they have tariffs at the ready that will guide charging toward the valleys of system load profiles and off the peaks, and that will enable a healthy ecosystem of charging stations.

Field experience to date indicates that the optimal tariffs for EV charging employ a time-of-use design, and are usually dedicated to EV charging only, because these tariffs offer the maximal opportunity to shift charging to the off-peak periods and provide the greatest grid benefit and the lowest cost of charging.[67,68] Additionally, we believe these tariffs should offer lower prices for Level 1 and Level 2 charging than for DCFC, because the cost of providing service for Level 1 and Level 2 chargers is lower, and because they are more easily managed to deliver grid services.

Time-varying tariffs are a simple, passive way to implement managed charging. Good price signals, if well designed, should be able to produce the desired load shape without impeding a vehicle owner's control over vehicle charging. Active management techniques, such as allowing utilities or aggregator companies such as eMotorWerks to directly control chargers to provide grid services, may also play more of a role in the future. However, field experience using active management is still fairly limited.

DEDICATED TARIFFS FOR EV CHARGING

The load profile of a Level 2 charger should be very different than that of a typical household or business where it is hosted, because the charger should be actively managed to encourage, or drivers should be offered an incentive to encourage, charging during the off-peak hours of the local grid. For example, a business may find that a commercial tariff with a flat rate for electricity is best for its general, nondiscretionary loads, but that Level 2 charging stations provided for customers and employees should be on a TOU tariff that features a large differential between on- and off-peak rates, to encourage discretionary charging when the cost of generating power is lowest. To enable this, many utilities require that a charging station be connected through a dedicated meter, separate from other loads at the site, although this does incur additional cost.

DIFFERENT RATES FOR SLOW AND FAST CHARGERS

In order to guide charging as much as possible toward low-cost, low-speed, Level 1 and Level 2 charging, which can help reduce overall system costs and offer the best opportunity for managed charging, we believe that customers should be able to use those chargers at a much lower cost than public DCFC charging. In practice, non-dedicated, public DCFC charging is generally more expensive than Level 1 or Level 2 charging already, but that appears to be an artifact of the way that charging stations and the tariffs they're under evolved, and not an explicit outcome that regulators and utilities sought. But we believe it should be. Retail public DCFC charging should be relatively expensive, to reflect the much higher capital cost of installing DCFC and the higher cost of providing electricity to those stations, and Level 1 or Level 2 charging should be significantly cheaper, to reduce the driver's cost of fueling and enable the use of flexible, low-cost infrastructure that can be managed to deliver grid services.

TIME-VARYING RATES AND DYNAMIC PRICING

As we discussed in detail in our 2016 report *Electric Vehicles As Distributed Energy Resources*,[69] experience in several significant test projects shows that TOU rates are effective at shifting loads to off-peak periods, and that the greater the price differential between on- and off-peak periods, the greater the shift. Results from a joint research project between The EV Project and SDG&E found that a price ratio of 2:1 was sufficient to shift 78% of all charging to the super off-peak period, while a ratio of 6:1 shifted 85% of all charging to the super off-peak period.[70]

Dynamic rates may be even more effective than TOU rates at matching a charging station's demand for power with the utility's cost of providing that power at a specific point in time. A pilot program being conducted by SDG&E called "Power Your Drive" will use such an approach, based on a dedicated EV tariff that will feature hourly dynamic prices reflecting grid conditions.[71] The prices will be published a day ahead and posted on a publicly available website, which will also include a database of the most recent hourly prices that reflect both system and circuit conditions, and include a circuit-level map of current hourly prices on all participating circuits. Customers will be able to use the website or a smartphone app to enter their preferences for charging durations and times, including the maximum price they're willing to pay. Then the app will match those preferences with the price information in order to provide the customer low-cost electric fuel based on their preferences and the hourly day-ahead prices. The Power Your Drive program is still getting under way and has not yielded any data yet, but regulators and utilities in other states would be wise to look carefully at its results when they are available, and determine if a similar program might be effective in their territories.

REDUCED OR NO DEMAND CHARGES FOR PUBLIC DCFC

Until the market for EVs matures such that public DCFC experience substantially higher utilization rates, it may be necessary for utilities to offer special tariffs, or variations on existing tariffs, that are more conducive to profitable DCFC ownership than are conventional commercial and industrial tariffs.

In our 2017 report *EVgo Fleet and Tariff Analysis*,[72] we examined every charging session in 2016 on all 230 of charging-infrastructure provider EVgo's 50-kW DCFC stations in California. The study showed that where a charger's utilization rate is low, demand charges can be responsible for over 90% of its electricity costs, depending on the tariff. That analysis showed that demand charges, more than other rate components, are the primary reason why it is economically challenging to operate public DCFC profitably in California, while utilization rates are still low. Until the market matures and utilization rates climb to the point where conventional demand charges would make up a more reasonable portion of the utility bill, it makes sense to deemphasize their role in the tariff.

This is the approach that Southern California Edison (SCE) has taken in its most recent proposed tariffs for EVs. SCE's new EV tariffs would suspend monthly demand charges during a five-year introductory period and recover more costs through energy charges, and then phase in demand charges for a five-year intermediate period. As the demand charges increase, the energy charges will decrease. During this intermediate period, the demand charges would collect an increasing share of distribution capacity-related costs, up to 60%, while the remaining 40% of distribution capacity costs would be collected via TOU energy charges. At that point, SCE claims that the demand charges will "still be lower than what new EV customers would pay on their otherwise applicable (non-EV) commercial rates today."[73]

Similarly, the new Public Charging GIR tariff proposed by San Diego Gas & Electric (SDG&E) for public chargers eliminates the grid integration charge (a type of demand charge) and recovers more costs through "dynamic adders" which are incurred for demand that occurs coincident with the top system hours of the year for a given circuit. This approach would be more likely to reflect the actual costs of providing service during high-demand hours, and less likely to trigger costly demand charges regardless of when the demand occurred. It would also offer the opportunity for a DCFC operator to avoid the peak hours, or switch to on-site storage to provide the power, or try some other means of avoiding the charges.

Both the SCE and SDG&E proposed tariffs would substantially improve the economics of operating a public DCFC, while still allowing the utility to recover costs adequately, being consistent with good rate-design principles, and helping to achieve the societal objective of widespread vehicle electrification.

As next-generation fast-charging stations featuring 150 kW and higher rates of charging begin to be deployed this year, the proper role of demand charges and the question of appropriate rate design will become even more important. Tariffs should reflect the actual cost of providing service, and should charge more for coincident peak demand. A charging depot with just six 150 kW DCFC, or two 450 kW DCFC, would be able to generate a power draw equivalent to the power demand of a large high-rise office building, which would impose nontrivial demands on the system and a significant cost of providing service. On the other hand, it's also important to give the market for high-powered public DCFC time to mature. Indeed, as we have asserted in this report, it's probably best to build charging infrastructure before there is high demand for it, to allow time for learning how to shape the demand for best effect. That approach would implicitly mean operating DCFC before they are able to afford conventional demand charges.

In short: demand charges are a blunt instrument for aligning costs with uses. They should not be ruled out, especially where DCFC are likely to bring very large new loads onto utility systems. But neither should they be a default characteristic of public DCFC rate design, being blindly triggered by rare charging events that might not even incur additional system costs because they are not coincident with system demand peaks. Rate design approaches such as scaling up demand charges over time, shifting some cost recovery to volumetric charges initially, and using dynamic adders to recover the cost of providing service during system peaks should all be considered in addition to demand charges, as utilities and regulators seek to accommodate the novel loads of public DCFC.

RATE DESIGN FOR SUSTAINABLE DCFC BUSINESSES

Electricity tariffs designed to create a sustainable business case for owning DCFC would have the following characteristics:

- Time-varying volumetric rates for electricity, such as a TOU rate. Ideally, these volumetric charges would recover all, or nearly all, of the cost of providing energy and system capacity. The highest-cost periods of the TOU tariff should coincide with the periods of highest system demand (or congestion) to the maximum practical degree of granularity.
- Low fixed charges, which primarily reflect routine costs for things like maintenance and billing.
- The opportunity for site hosts or charging station aggregators to earn credit for providing grid services such as demand response.
- Rates that vary by location. For example, a utility could offer low rates for DCFC installed in overbuilt and underutilized areas of the grid, in order to increase the efficiency of existing infrastructure and build new EV charging infrastructure at low cost.
- Limited or no demand charges, at least until charging stations reach significant utilization rates. Where demand charges are deemed to be necessary, it is essential that they be designed to recover only location-specific costs of connection to the grid, not upstream costs of distribution circuits, transmission, or generation. Generally, demand charges should reflect demand spikes that are coincident with system load peaks.
- Critical peak pricing can help recover the cost of meeting a charging station's peak demand without unduly burdening a charging station with a low utilization rate, and without shifting costs from EV drivers to all ratepayers.

Our analysis shows that while utilization rates are low, reducing or eliminating demand charges for the commercial public DCFC market is consistent with good rate-design principles and helps to achieve the societal objective of widespread vehicle electrification.[74] Recovering nearly all utility costs for generation, transmission, and distribution through volumetric rates is appropriate for tariffs that apply to public DCFC. Other approaches to rate design, in which cost components scale with usage rather than being based on the demand peak in a month, can be appropriate ways to recover costs without stifling a nascent market. For example, as the utilization rate of a DCFC increases, a utility could reduce the volumetric rate and increase the demand charge.

For more of RMI's original research and analysis on tariffs and rate design, please see our reports *Rate Design for the Distribution Edge* (2014)[75] and *A Review of Alternative Rate Designs* (2016).[76]

DIFFERENT STROKES

The path that a given utility or state might take into vehicle electrification will vary according to different configurations of several fundamental factors.

For example, the regulatory environment takes several forms in U.S. states, and can be quite nuanced, affecting how investments in chargers can be made, how chargers are used, and what the business opportunity is for third-party charger providers. For example, the California PUC does not assert jurisdiction over third-party charger providers offering charging services, but it does require Southern California Edison (SCE) to force third-party site hosts who own and operate chargers using SCE's make-ready infrastructure to follow certain standards and requirements.[77] The Missouri Public Service Commission ruled in April 2017 that it did not have jurisdiction over chargers at all, arguing that chargers are equivalent to smart phone charging stations or kiosks, or electricity hookups at RV parks, and that "the charging service is the product being sold, not the electricity used to power the charging system."[78] The Massachusetts Department of Public Utilities ruled similarly in August, 2014. And the New York Public

FIGURE 10

RELATIVE PUBLIC-CHARGER DISTRIBUTION BY CHARGER TYPE

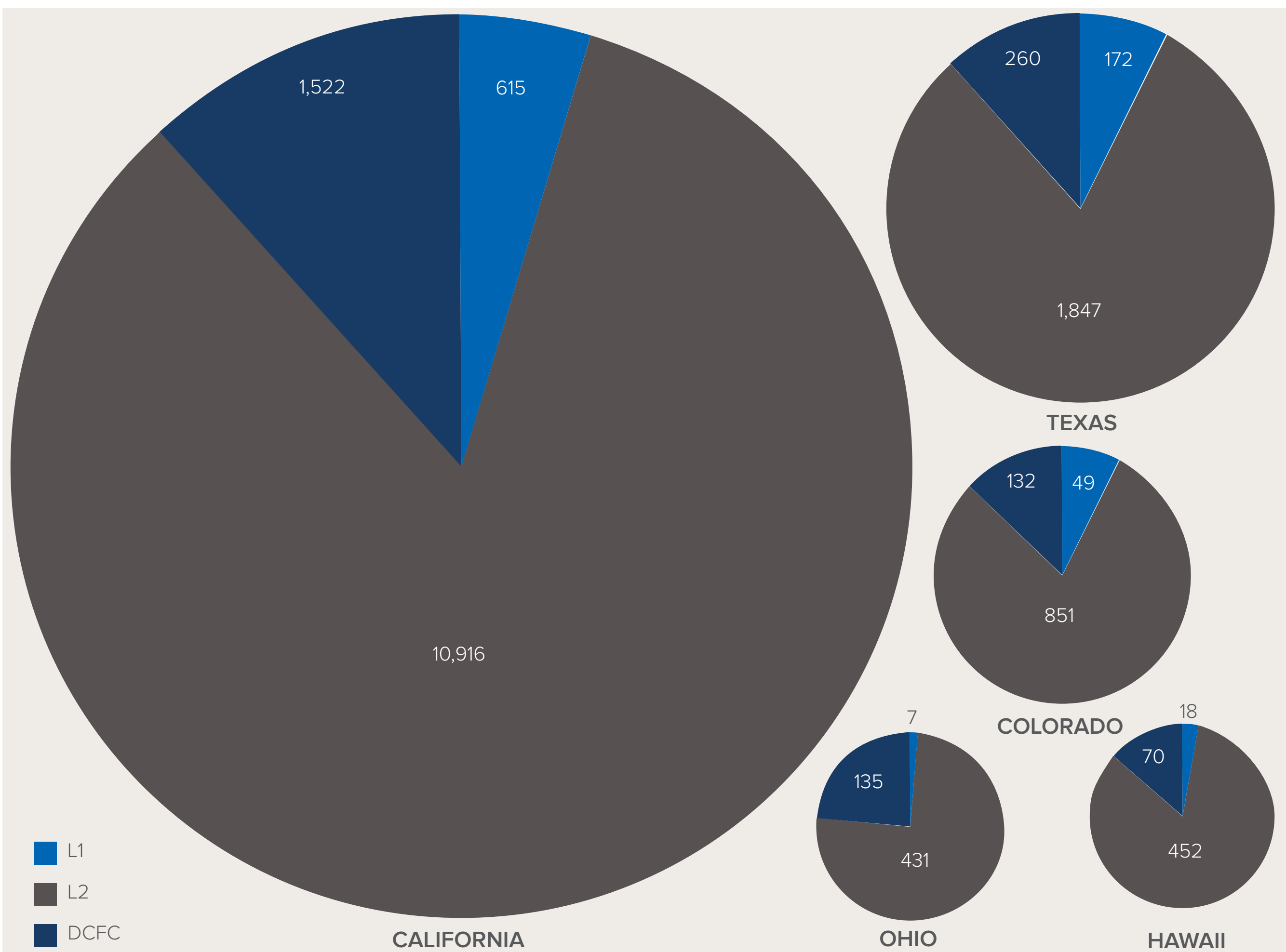


TABLE 3

EV AND EVSE DEPLOYMENT STATISTICS BY STATE[80]

	EV PENETRATION	EVS ON THE ROAD	NUMBER OF EVS PER L2 CHARGER	NUMBER OF EVS PER DCFC
CALIFORNIA	2.10%	299,038	27	196
HAWAII	1.20%	6,178	14	88
COLORADO	0.56%	10,033	12	76
TEXAS	0.23%	18,930	10	73
OHIO	0.15%	6,973	16	52

Service Commission ruled in November 2013 that it did not have jurisdiction over public chargers, their owners and operators, or transactions between them, if they did not meet the law's definition of "electric corporation."[79] This is just one factor that can determine which paths to deployment are best in each state.

Each state will also have to determine for itself how to ensure that its charging network will be adequate to meet demand, deployed at a reasonable cost, and that it will be neither deployed too early nor too late. Each state may also need to determine ways to limit the retail cost of charging, and to limit the cost of owning and operating charging stations, in order to ensure a vigorous market. On these questions, there is a natural tension between what is best done via top-down planning by a central authority, and what is best done by letting a market seek the right solutions, and there are no one-size-fits-all answers.

To demonstrate the different paths that result from various combinations of these factors, we look at five U.S. states as exemplars: California, Colorado, Hawaii, Ohio, and Texas. We present an overview of the current state of charging station deployment in these states, along with the economics of EV ownership and charging station use from different stakeholder perspectives.

We begin with a look at EV penetration for each state (Table 3). Interestingly, California has the highest EV penetration in the U.S. while also having the highest number of EVs per charger. For example, there is one DCFC per 196 EVs and one Level 2 charger per 27 EVs in California, while in Texas there are nearly three times the number of DCFCs and twice the number of Level 2 chargers per registered EV. We also note that Hawaii, Colorado, Texas, and Ohio all have very similar ratios of EVs to charging stations, from about 1% in Hawaii to about 0.15% in Ohio. This suggests that where EV growth is strongest, charger deployment is lagging EV adoption. It is unclear at this early stage of EV adoption what the ideal ratio of public charging stations to EVs is, however.

These results suggest that California is moving ahead with EV adoption while utilities, regulators, and charging station companies are tied up in the debate around ownership models, siting, and tariff design, and thus impeding the charging station growth that will be needed to meet demand. This could make it more difficult for California to capture the full value EVs bring to the grid—particularly the value from managed charging.

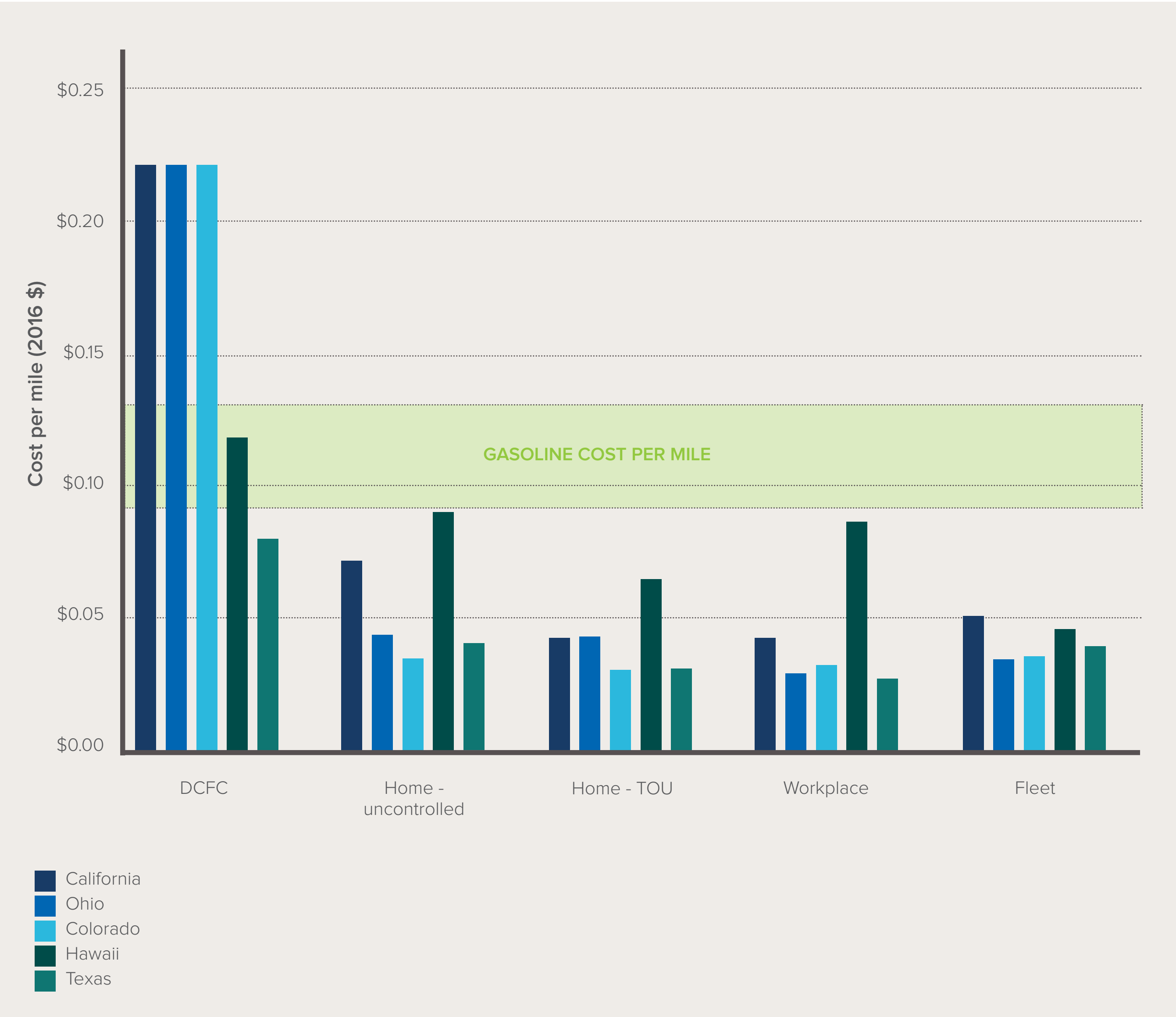
For each of our exemplar states, we then compare the cost per mile for fueling an ICE vehicle to the cost of charging EVs under five different charging options:

- Uncontrolled charging at home on a Level 2 charger under a flat electricity rate
- At home on a Level 2 charger under a TOU rate with 95% of charging occurring at non-peak times
- At work on a Level 2 charger
- On a public DCFC network
- As a commercial fleet charging at a centralized charging depot

This analysis considers the different tariffs available for home, work, and commercial public charging based on the customer class and the typical load profile of each type of site.

FIGURE 11

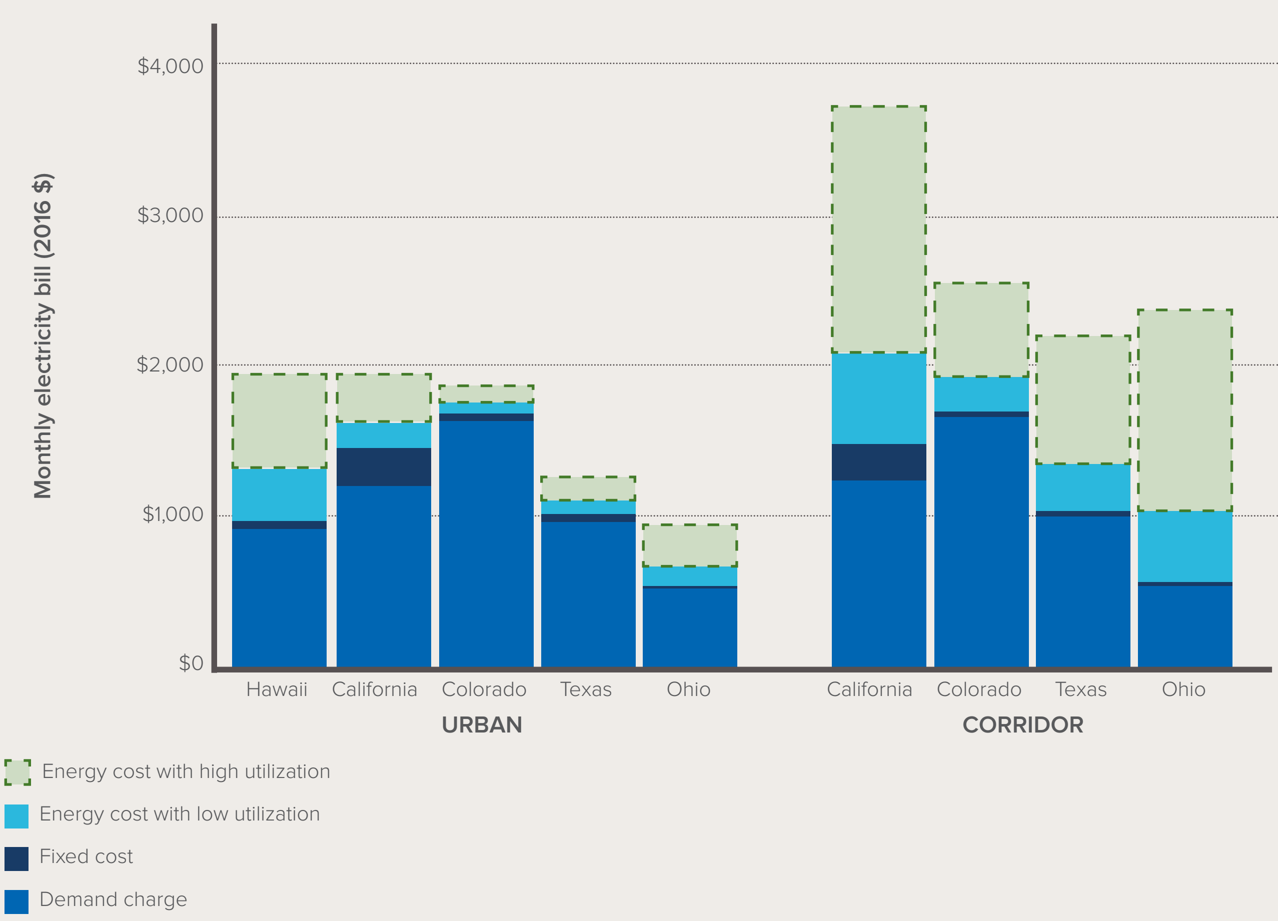
RETAIL COST TO EV OWNER, OR EMPLOYER OF EV OWNER, TO CHARGE ONE MILE OF EV RANGE UNDER DIFFERENT UTILITY TARIFFS AND DCFC PROGRAMS



Finally, as shown in Figure 12, we break down the monthly utility bill of a representative public DCFC station with two 50 kW ports for each state, and identify the portions of the cost that come from demand charges, energy charges, and fixed charges.

FIGURE 12

MONTHLY HOST-SITE UTILITY BILL FOR DCFC OPERATION (TWO 50 KW PORTS)

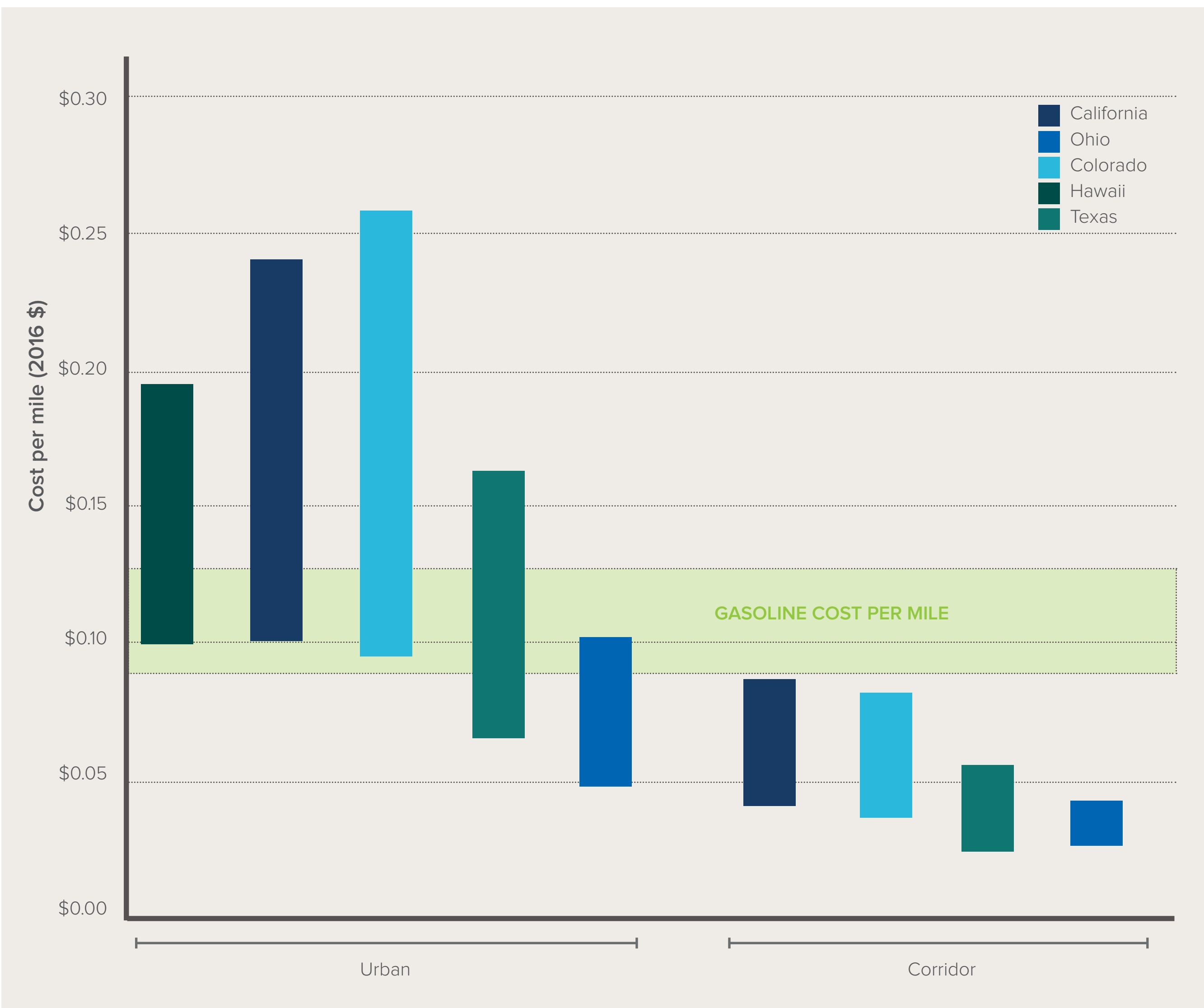


We show in Figure 13 how those host-site utility costs translate to a cost per mile of charge delivered under two utilization scenarios (high and low) for two different DCFC locations: an urban location, and a rest-stop location along a long-distance corridor. In this analysis, urban utilization ranges from 3% to 9% and corridor utilization from 10% to 39%. It is important to note that findings for urban charge sessions were based on actual EVSE utilization in 2016 that was primarily composed of shorter-range EV charge events, while the corridor utilization was simulated and based on higher-range EVs fueling as often as an ICE vehicle would.[81]

See the Appendix for details on the methodology of this analysis.

FIGURE 13

ELECTRICITY COST RANGE FOR HOST SITE TO DELIVER ONE MILE OF CHARGE VIA DCFC



CALIFORNIA

California is by far the leading state for vehicle electrification, with nearly half the national fleet of EVs, the largest fleet of charging stations, the largest share of EVs on the road, at over 2% (299,038 as of May, 2017),[82] and the most aggressive official target for EV adoption (1.5 million EVs by 2025).[83]

OWNERSHIP

California has an organized, quasideregulated electricity market with competitive generation and a burgeoning number of customers who are enrolled in Community Choice Aggregations (CCAs), which have control over procuring electricity for their customers. Since California straddles the line between being a fully regulated and fully deregulated market, it is perhaps unsurprising that regulators are reviewing plans that will test several ownership models for EV charging infrastructure. The three major investor-owned utilities (IOUs) in California—Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), and Pacific Gas and Electric (PG&E)—propose to spend over $1 billion on charging infrastructure. We summarize these large, multi-faceted investment programs as follows:[84]

- Most of the money in SCE's plan would be spent on make-ready locations that would support a variety of third-party charging stations, of which most would be for medium- and heavy-duty vehicles like delivery trucks and forklifts.
- SDG&E would spend most of its investment on Level 2 residential chargers that it would own and operate. These chargers would be under SDG&E's TOU rate and would be programmable to take advantage of that rate.
- PG&E's charging station deployments would be a hybrid of programs, and mostly aimed at DCFCs. It would include investments in make-ready locations for third-party chargers, as well as chargers that it would own and operate.

In time, California's "all of the above" strategy for charging station ownership could show which approaches to deployment are most effective. For example, it may show that utilities are able to deploy charging stations faster than private companies are. It may also give regulators some insight on what kinds of investments are appropriate to be socialized through the rate base. For example, it may show that deploying charging stations into low-income areas is best accomplished as a rate-based investment, whereas wealthier areas are more easily served by private sector companies who can earn sufficient revenue in those areas to make the investment worthwhile.

SITING STRATEGIES

In our view, hubs of high-speed DCFC charging stations located to serve high-usage fleet vehicles are probably sensible, no-regrets solutions for California's major cities. High-speed hubs are practical for high-usage corridors and commuting routes as well. Widespread home and workplace charging on Level 2 chargers would also make sense for California, since the state has a goal to achieve a high degree of vehicle electrification.

GRID INTEGRATION

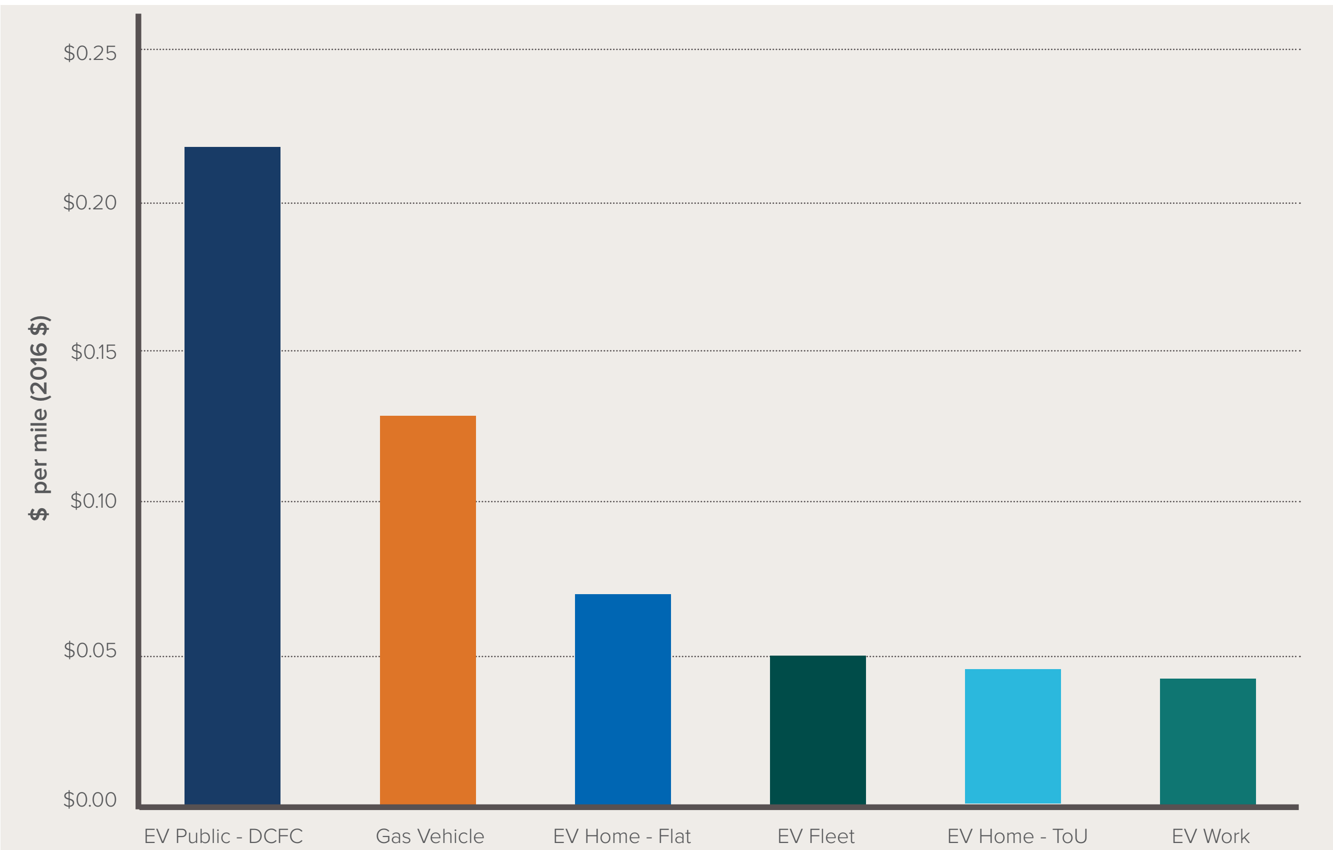
California's "duck curve," in which demand for dispatchable electricity sharply increases as the sun goes down and solar generation tapers off, has gotten steeper sooner than the state's forecasters expected.[85] A surfeit of solar power on the California grid is contributing to an oversupply condition in the midday, which is forcing the grid operator to curtail wind and solar output and driving wholesale power into negative pricing. Managing the charging of a larger number of EVs in California, preferably using passive management techniques like TOU tariffs, could help alleviate these conditions and flatten out the curve for dispatchable supply. By using EVs to absorb excess solar and wind, California could increase its share of the total electricity supply, and displace some of the state's natural gas consumption. Colocating solar and battery storage with charging depots could increase the share of solar power on California's grids even further, by absorbing it even when the charging stations are not in use.

COST OF CHARGING

The cost of charging an EV in Southern California can be as low as $0.04/mile if charged during workday hours at a workplace and as high as $0.22/mile if using a public DCFC network.

FIGURE 14

EV CHARGING COSTS IN CALIFORNIA, SCE

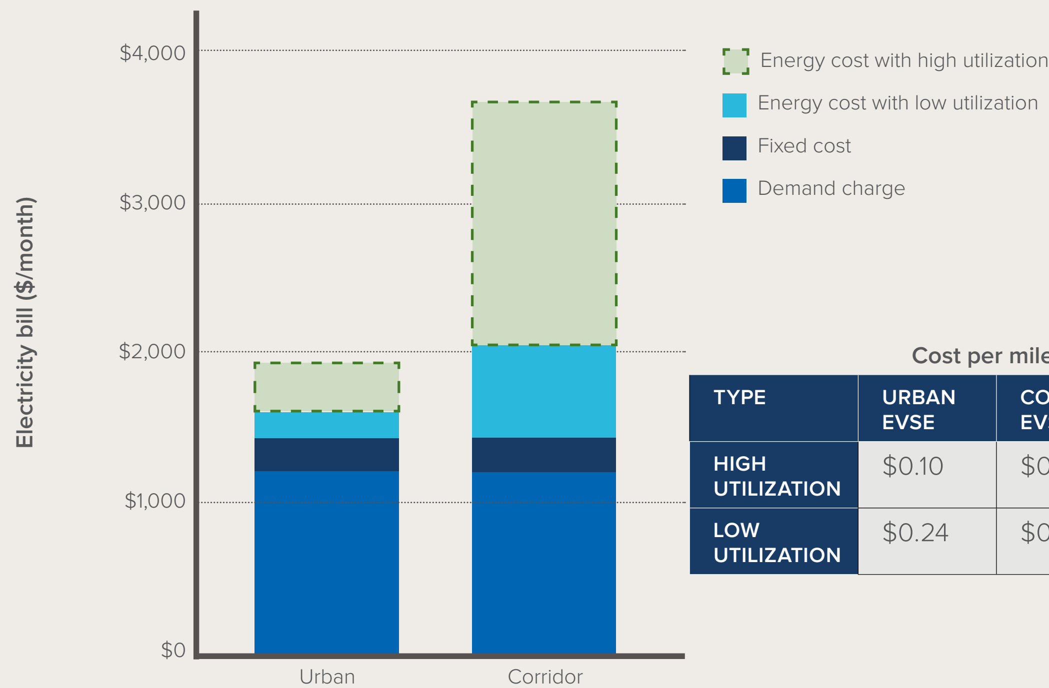


Looking across the various charging options and the price signals they send to the EV owner, we developed a set of hypotheses around these results:

- Workplace charging is significantly cheaper than uncontrolled home charging, and slightly cheaper than home smart charging. This sends drivers a signal that it's better to charge at work, or at home on a TOU rate.
- All non-fast charging options are significantly cheaper than fueling an ICE vehicle. This suggests that consumers will seek the lower cost of Level 1 or Level 2 charging, which could enable managed charging to provide grid services.
- Charging on a DCFC is costlier per mile than fueling an ICE vehicle. As such, nonfleet drivers are likely to view it as a premium option that they'll use infrequently, which does not make it cheaper to own an EV than an ICE.

FIGURE 15

UTILITY BILL FOR A REPRESENTATIVE DCFC IN CALIFORNIA ON THE SCE GRID



Cost per mile

TYPE	URBAN EVSE	CORRIDOR EVSE	GAS
HIGH UTILIZATION	$0.10	$0.04	$0.13
LOW UTILIZATION	$0.24	$0.09	

In Figure 15 we present the monthly utility bill as a stacked bar chart, by bill component, including the energy cost range associated with a high and low charger utilization rate. The inset table shows the subsequent cost to deliver a mile of charge under each scenario for high and low utilization rates. The maximum monthly demand is based on the maximum power output of the DCFC, which does not vary with utilization, so the demand component of the bill is the same for urban and corridor stations regardless of the charger utilization. This utility bill analysis provides a few key insights into DCFC operation in Southern California:

- In all but the low-utilization urban locations, the cost to deliver one mile of charge is lower than the gasoline equivalent.
- The demand charge is the largest component of the bill in urban locations under both high and low utilization scenarios, and ranges from 30%–60% for the corridor locations.
- Properly sited and highly utilized corridor DCFC can deliver reasonable costs per mile under existing tariff structures, but it will be challenging for urban DCFC to compete with gas-equivalent costs under existing tariffs.

The cost to deliver one mile of charge via DCFC stations represents only a subset of the total cost burden to a DCFC network operator or host site, and thus should not be confused with the price that that host/owner will be able to offer to a prospective EV charging customer. For example, a DCFC operator may also need to pay for charger maintenance, network fees, routine overhead, and parking space leases.

COLORADO

With EVs comprising 0.56% (10,033 as of May, 2017)[86] of vehicles on the road, Colorado was 15th in the nation in terms of the absolute number of EVs, and 10th in EVs per capita in 2015.[87] Colorado offers a variety of other incentives for purchasing an EV, including the largest state income tax credit (up to $5,000), in addition to the $7,500 federal tax credit.[88] Xcel Energy, the largest utility in the state, supports additional incentives, such as special offers for the Nissan Leaf, home charging for as little as $1 per gasoline-gallon equivalent, and multiple electricity rate plans.[89]

OWNERSHIP

Colorado has a fully regulated electricity market, so one might think the path of least resistance for deploying chargers in the state would be as a rate-based utility investment. However, although Colorado state law allows IOUs to own and operate charging stations, they are prohibited from using regulated funding to purchase or support these stations.[90] And a corporation or individual that resells electricity supplied by a public utility to charge EVs is specifically exempted from regulation as a public utility.[91] This legal framework is more likely to favor private ownership and deployment of charging stations, and accordingly, the state offers significant rebates for charging station deployments.[92] However, there is no prohibition against utilities building make-ready infrastructure.

SITING STRATEGIES

Charging hubs designed to support ride-hailing services can work in the major population centers of Denver, Boulder, and Colorado Springs. But many drivers will want to be able to drive to the mountains, where chargers are scarce and temperatures can be cold. This suggests that, at minimum, destination communities (like the ski resort towns) will want to install a sufficient number of DCFC and Level 2 chargers to give drivers confidence that they can make a trip there and back home without the need to recharge interfering with their recreational plans, perhaps with dedicated staff at the resorts to manage and optimize the use of the charging stations. For residents in the nonmetro areas of Colorado, home and workplace charging on Level 2 chargers may be the most practical option.

GRID INTEGRATION

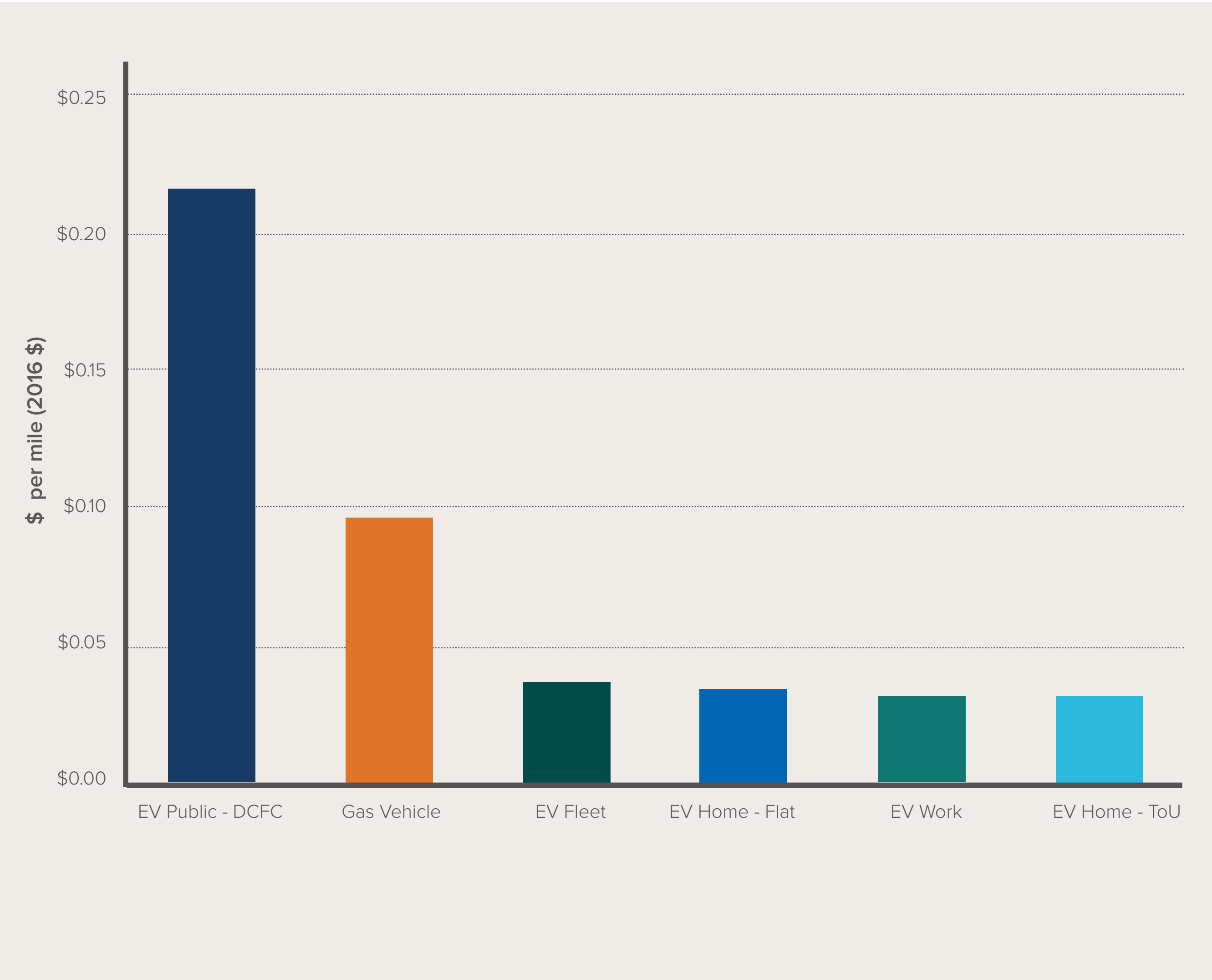
Although Colorado has abundant wind and solar resources, as well as a significant base of residents who support renewable energy, its grid is primarily coal-fired. Demand on the Xcel Energy grid is also typically low during the midday solar peak of the non-summer months.[93] This suggests that if Xcel Energy were to offer a TOU or other special rate for Level 2 EV charging, preferably on a dedicated meter, which featured off-peak pricing during the midday, it could take advantage of the midday solar power availability and potentially begin to displace its coal generation. Similarly, a TOU rate coupled with Xcel's non-EV specific commercial rate ("Secondary General Low-Load Factor") could offer DCFC operators a low-cost electricity supply coincident with transportation demand.[94] Occasionally, Xcel Energy has also had to curtail wind production, primarily for balancing (e.g., oversupply) and transmission (e.g., line constraints and outages) reasons.[95] This suggests an opportunity to use managed Level 2 charging to alleviate such temporary grid conditions and avoid curtailment. On the whole, there is significant opportunity for Colorado to displace coal and increase the share of wind and solar on its grid through the use of time-varying rates and active charge management.

COST OF CHARGING

The cost of charging an EV in Colorado can be as low as $0.03/mile if charged at home during the off-peak hours of a TOU rate, and as high as $0.22/mile if using a public DCFC.

FIGURE 16

EV CHARGING COSTS IN COLORADO ON THE XCEL GRID

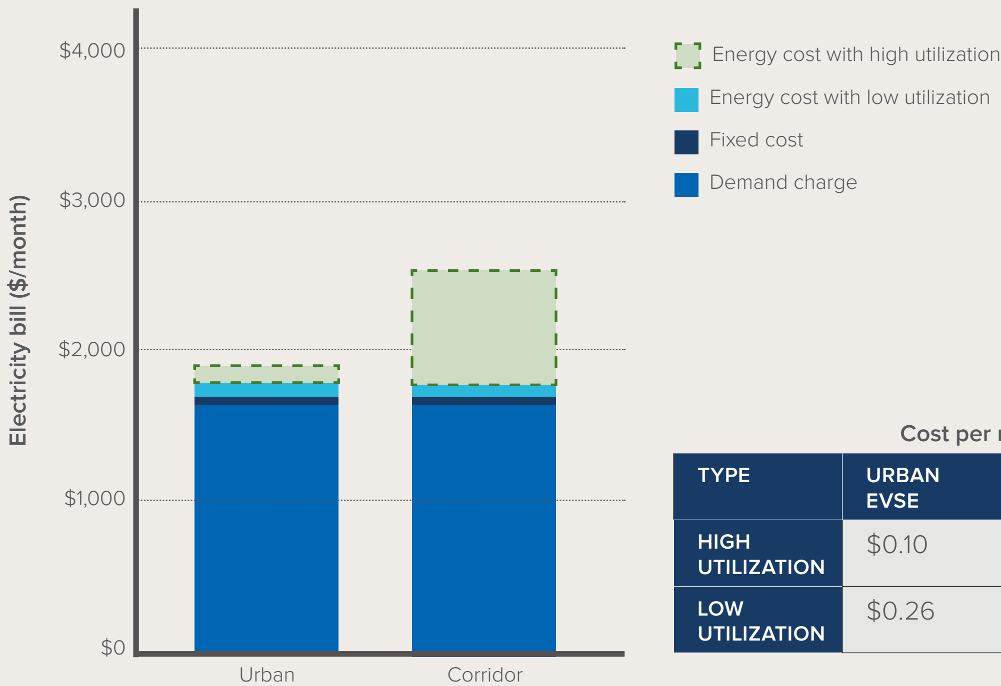


Looking across the various charging options and the price signals they send to the EV owner, we developed a set of hypotheses around these results:

- There isn't much difference between the costs of charging at work, charging at home in an uncontrolled manner, and charging at home in a controlled manner. This will motivate EV drivers to charge when it's convenient for them, not when it's best for the grid.
- All non-fast charging options are significantly cheaper than fueling an ICE vehicle. This suggests that consumers will seek the lower cost of Level 1 or Level 2 charging, which could enable managed charging to provide grid services.
- Charging on a DCFC is costlier per mile than fueling an ICE vehicle in urban locations. As such, non-fleet drivers are likely to view it as a premium option that they'll use infrequently, which does not make it cheaper to own an EV than an ICE.

FIGURE 17

UTILITY BILL FOR A REPRESENTATIVE DCFC IN COLORADO ON THE XCEL GRID



Cost per mile

TYPE	URBAN EVSE	CORRIDOR EVSE	GAS
HIGH UTILIZATION	$0.10	$0.04	$0.10
LOW UTILIZATION	$0.26	$0.08	

This utility bill analysis provides a few key insights into DCFC operation in Colorado:

- In urban locations with low utilization, charging on a DCFC is costlier than fueling an ICE vehicle. In urban locations with high utilization, charging on a DCFC is at parity with fueling an ICE vehicle. In corridor locations, DCFC charging costs less than fueling an ICE vehicle under both low- and high-utilization rates.
- Demand charges make up much of the bill for urban and corridor stations under both high- and low-utilization scenarios, while energy charges vary slightly across scenarios. This results in a high fixed cost of operation that is largely independent of utilization, and will make for challenging economics for DCFC ownership in all but the busiest locations.

OHIO

With EVs comprising 0.15% (6,973 as of May, 2017)[96] of vehicles on the road, Ohio was 16th in the nation in terms of absolute number of EVs, and 32nd in EVs per capita in 2015.[97]

OWNERSHIP

Ohio has a few incentives for EV purchases and related programs, and offers low-interest loans for businesses, nonprofits, public schools, and local governments that want to install charging stations.[98] Of greatest relevance today are three major new programs in the state:

- The Ohio Department of Transportation plans to spend $4 billion over the next two years equipping the state's highways with autonomous-vehicle enabling technology, including "smart mobility corridors" along Interstate 270 around Columbus and on I-90 from Cleveland to the Pennsylvania border.[99]
- The Smart Columbus program, with seed funding of $50 million from the U.S. Department of Transportation and Vulcan, will take an integrated approach to 15 separate elements of smart mobility, including electric autonomous vehicles.[100]
- AEP, a major utility in Ohio, has filed a rate case with the Public Utilities Commission of Ohio (PUCO) seeking to rate-base 1,275 stations over a four-year demonstration period, including 275 public charging stations (of which 25 would be DCFC) and 1,000 residential chargers. The utility would own and operate the charging stations and offer free charging on them. However, the Electric Vehicle Charging Association, a group of commercial charging infrastructure companies, is a party to the case and is negotiating with AEP to ensure the plan fosters competition.[101]

Ohio has a competitive market for electricity generation, although all residents receive their gas and electricity from a single retail energy provider of their choice, which is regulated by PUCO.

SITING STRATEGIES

Electric charging hubs for fleet and commuter vehicles appear to be part of the Smart Columbus plan, which could form the basis for public charging infrastructure across Ohio, radiating out from Columbus. However, the very nascent state of charging infrastructure and electric mobility planning in Ohio leaves plenty of room for the state to change directions. The outcome of AEP's proposal to install, own, and operate charging stations will almost certainly become an important precedent in the state, and indicate which direction the state is likely to go on the question of charging station ownership.

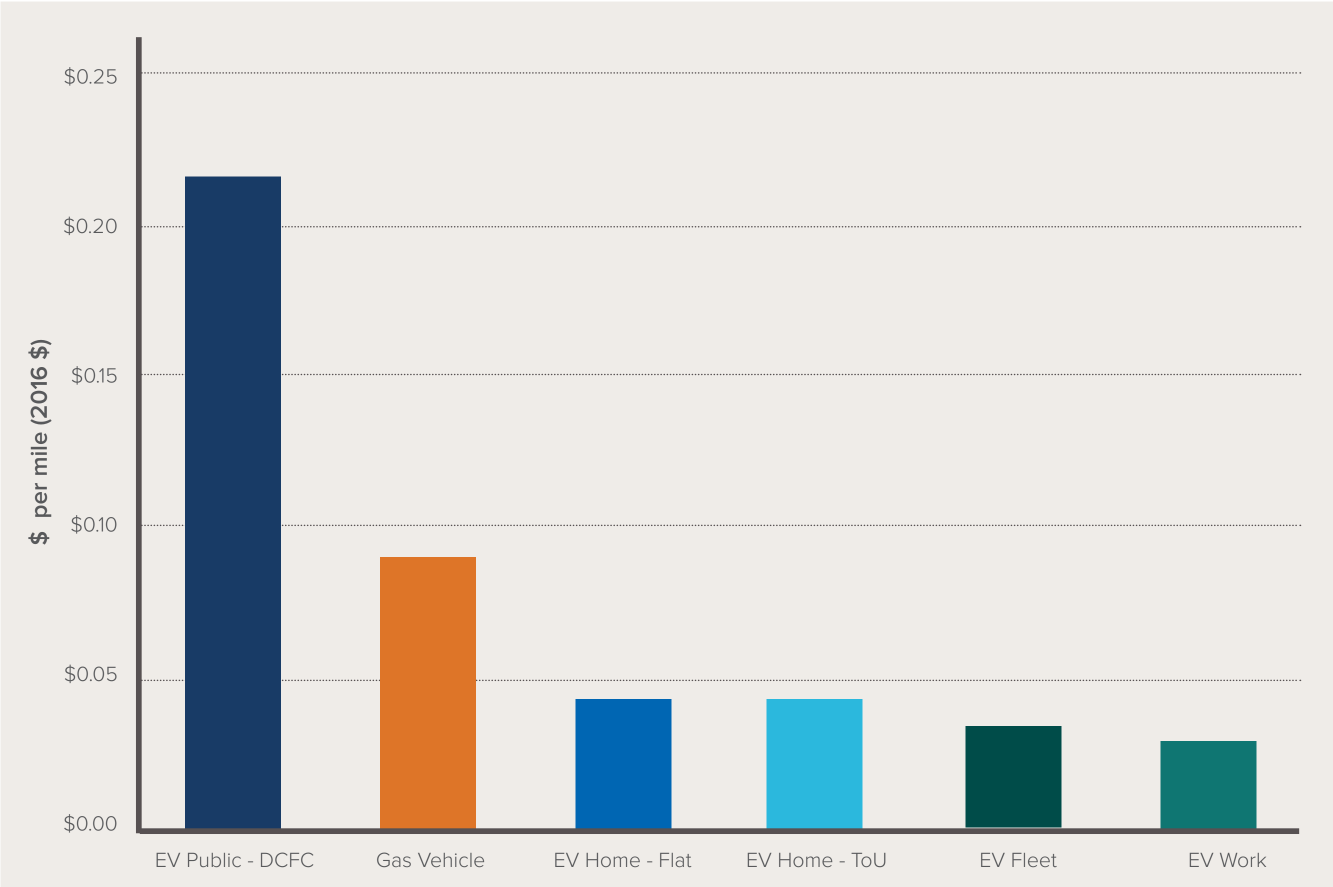
GRID INTEGRATION

With a grid that is mostly powered by coal, has a modest amount of existing wind and solar production, and a relatively small number of EVs on the road, but will potentially have a major expansion of charging infrastructure through AEP and smart mobility infrastructure in Columbus and on Ohio's highways, the state has an excellent opportunity to use its EV infrastructure build-out as a path to accommodating more renewable electricity, displacing coal, and setting good precedents for EV-friendly rate design and managed charging from the ground up.

COST OF CHARGING

The cost of charging an EV in Ohio can be as low as $0.03/mile if charged at work, and as high as $0.22/mile if using a public DCFC.

FIGURE 18:
EV CHARGING COSTS IN OHIO ON THE AEP GRID

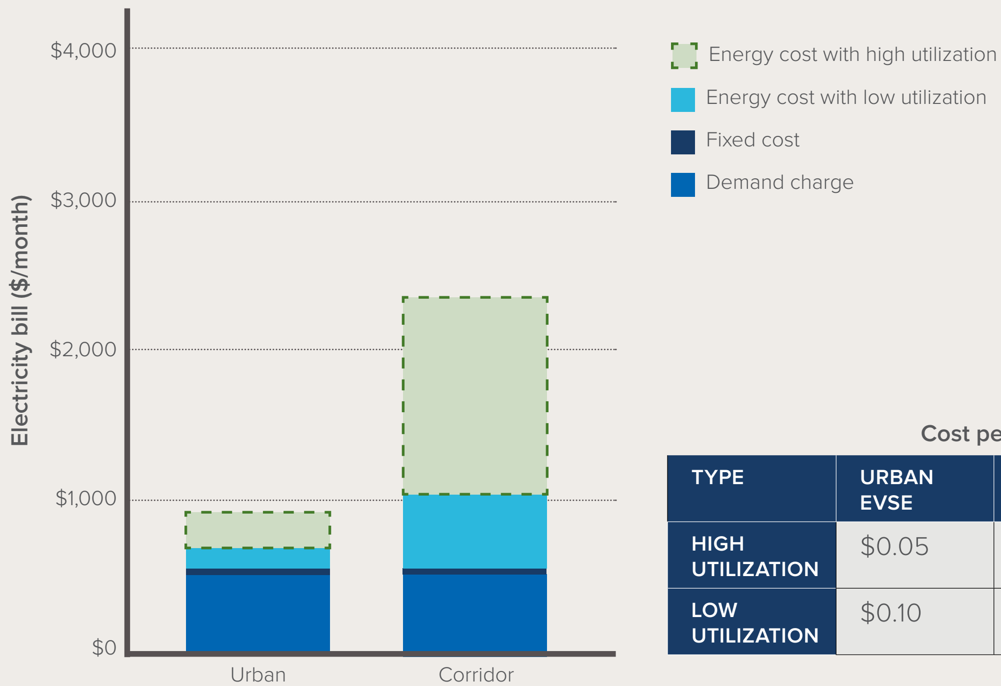


Looking across the various charging options and the price signals they send to the EV owner, we developed a set of hypotheses around these results:

- There is only an 8% difference in cost between uncontrolled and controlled charging while at home. This price differential is insufficient to motivate drivers to charge when grid costs are lowest, and suggests the need for a more differentiated TOU rate.
- Workplace charging is 30% cheaper than home charging. This could be enough to motivate drivers to charge at work more often if workplace chargers were available.
- All non-fast charging options are significantly cheaper than fueling an ICE vehicle. This suggests that consumers will seek the lower cost of Level 1 or Level 2 charging, which could enable managed charging to provide grid services.
- Charging on a DCFC is costlier per mile than fueling an ICE vehicle. As such, nonfleet drivers are likely to view it as a premium option that they'll use infrequently, which does not make it cheaper to own an EV than an ICE.

FIGURE 19

UTILITY BILL FOR A REPRESENTATIVE DCFC IN OHIO ON THE AEP GRID



Cost per mile

TYPE	URBAN EVSE	CORRIDOR EVSE	GAS
HIGH UTILIZATION	$0.05	$0.03	$0.09
LOW UTILIZATION	$0.10	$0.05	

This utility bill analysis provides a few key insights into DCFC operation in Ohio:

- The cost to deliver one mile of charge is lower than the gasoline equivalent in all cases except for the low-utilization scenario in an urban location, where the cost is close to the gasoline equivalent.
- Demand charges are a lesser component of the bill than in other states. This may lead to a more robust network of DCFC where low-utilization stations can operate profitably.
- All non-fast charging options are significantly cheaper than fueling an ICE vehicle. This suggests that consumers will seek the lower cost of Level 1 or Level 2 charging, which could enable managed charging to provide grid services.

TEXAS

With EVs comprising 0.23% (18,930 as of May, 2017)[102] of vehicles on the road, Texas was 6th in the nation in terms of absolute number of EVs, and 28th in EVs per capita in 2015.[103]

OWNERSHIP

The state has numerous incentives for EV purchases and related programs. For example, rebates are available for lower-income households that purchase an EV to replace an older, high-emissions vehicle; certain fleets of state agency vehicles must procure alternative fuel vehicles (including EVs); grants are available to build electrification infrastructure in certain areas; and grants are available to replace diesel fleets with hybrid electric vehicles.[104] Austin Energy, the 8th-largest public utility in the U.S., also has a variety of programs to support EVs in Austin, including rebates (up to $1,500) toward the cost of purchasing and installing a Level 2 charger; a special residential TOU rate for Level 2 chargers; and a plan that offers unlimited charging for $4.17 per month at any of its more than 250 Plug-In EVerywhere stations.[105]

Texas has the most deregulated market in the country, with approximately 85% of the state having a choice of electricity retailer. This might suggest that Texas is inclined toward competitive markets for charging infrastructure, but state law sets a different standard. The Texas Public Utility Regulatory Act requires sellers of electricity to demonstrate that they have "the financial and technical resources to provide continuous and reliable service to customers in the area for which the certification is sought," which has had the effect of barring competitive private charging companies from owning or operating EV charging stations. However, some charging companies have worked around this restriction by partnering with municipal utilities, like Austin Energy, to provide EV charging services.[106] Accordingly, the path of least resistance for private charging companies to increase their deployments in Texas may be through partnerships with municipal utilities, which have a fair amount of latitude to develop EV programs, offer low-cost service that will entice EV drivers, and provide patient capital with low financing costs for a long-term, capital-intensive build-out of charging infrastructure. In areas of Texas served by IOUs, the only two options seem to be either to allow the utilities to build and rate-base charging stations, or to change the law to exempt EV charging stations or their owners and operators from regulations applicable to public utilities, as some 16 states have already done.[107] Whether this state of affairs is by design, or is merely an unintended consequence of old laws, is unclear.

SITING STRATEGIES

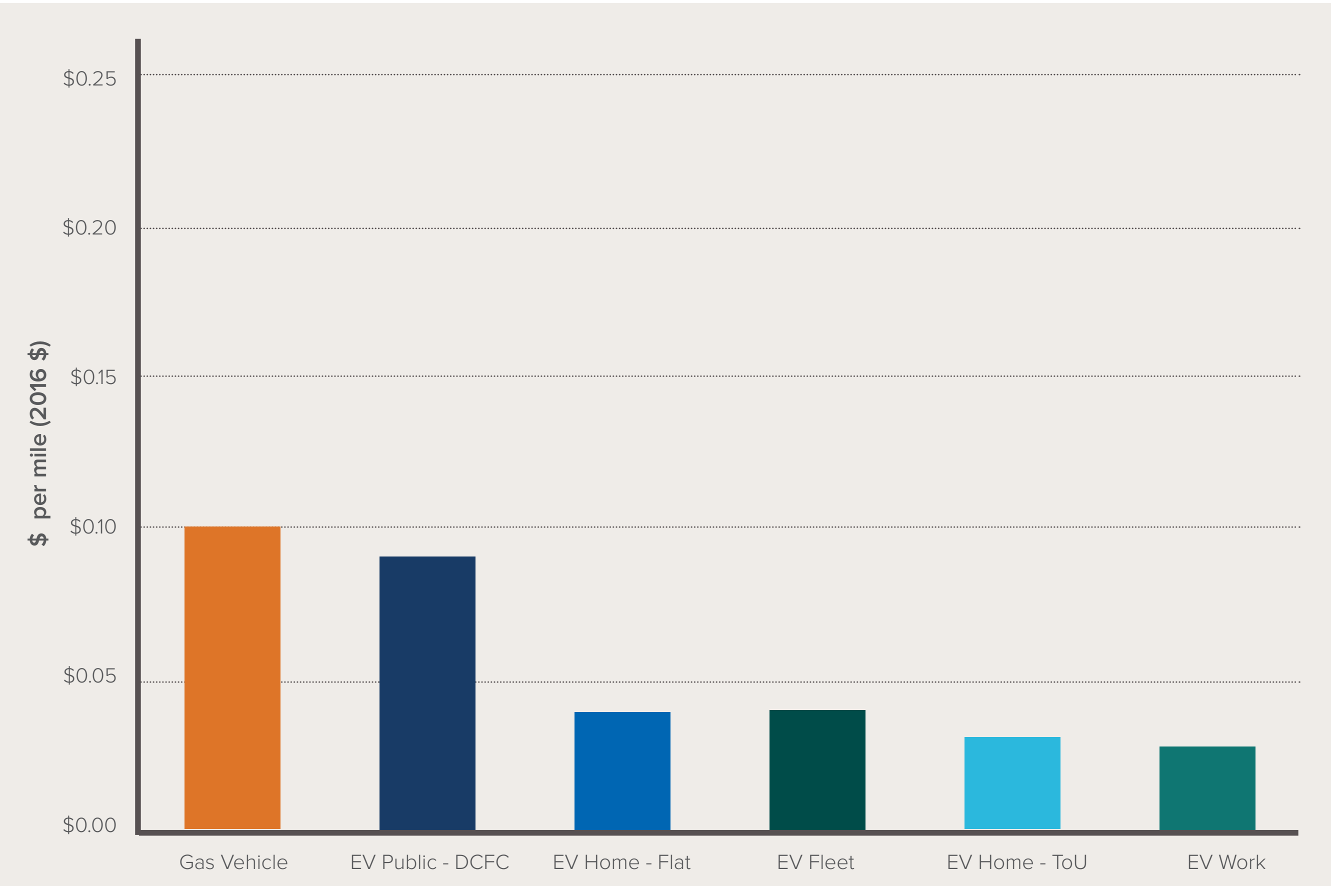
The most useful siting of charging stations in Texas will probably follow similar strategies as in California: high-speed DCFC charging hubs located to serve high-usage fleet and ride-hailing vehicles; and DCFC along high-usage corridors and commuting routes around major cities. And given the relative preponderance of single-family homes with garages, widespread home and workplace charging on Level 2 chargers would offer the best opportunity for using chargers as grid assets. Given the long distances between rest stops on some major highways, it may also be advisable for Texas to deploy DCFC at rest areas and services stops along those routes.

GRID INTEGRATION

Although transmission expansion and market redesign have reduced the incidence of outright wind-power curtailment in Texas in recent years, ERCOT still experiences system-wide negative pricing in the middle of the night due to an oversupply of wind.[108] These negative prices have made it very difficult for merchant generators to survive in ERCOT, and have led to untoward outcomes, such as the bankruptcy of new, highly efficient, low-emissions gas plants like Panda Temple.[109] Instead of reducing the output of zero-carbon generators and forcing low-carbon, efficient generators into bankruptcy, effective use of TOU rates and managed nighttime Level 2 charging by EVs could absorb extra wind power, allow ERCOT to increase the share of wind power on its system, maintain wholesale

FIGURE 20

EV CHARGING COSTS IN TEXAS ON THE AUSTIN ENERGY GRID



pricing that can support new investment, and displace coal power units instead.

COST OF CHARGING

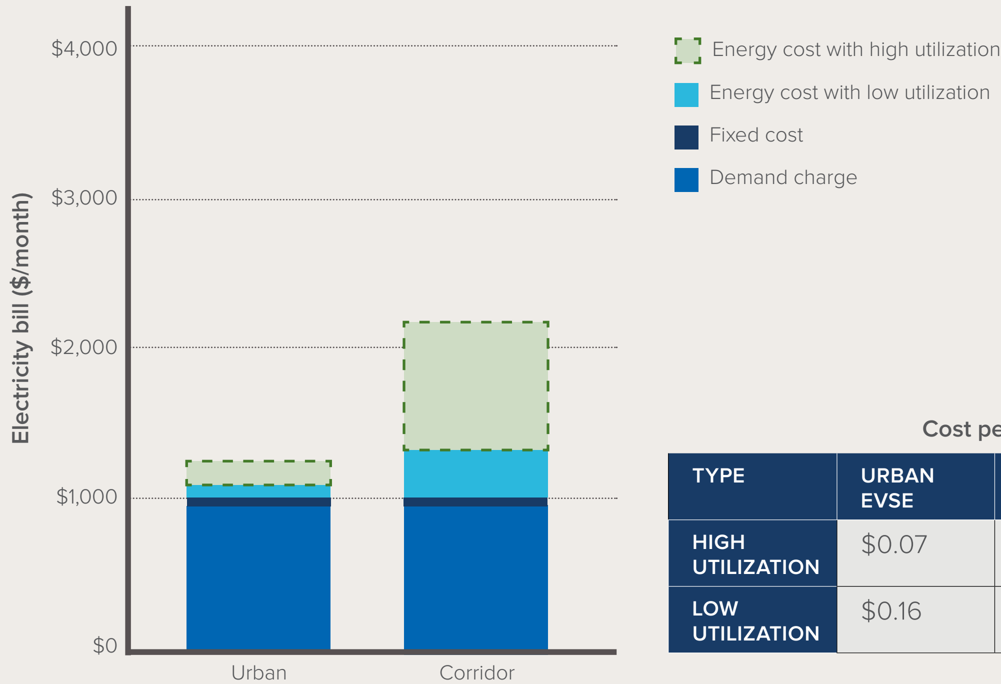
The cost of charging an EV in Austin, Texas, can be as low as $0.03/mile if charged at work, and as high as $0.08/mile if using a public DCFC.

Looking across the various charging options and the price signals they send to the EV owner, we developed a set of hypotheses around these results:

- All EV charging options are lower than the equivalent cost of fueling a gas vehicle. This is largely because of Austin Energy's Plug-in-EVerywhere network, which offers a very inexpensive public charging program for EV owners that includes both Level 2 and DCFC chargers.
- There is a 20% difference in cost between uncontrolled and controlled charging while at home. The price differential of this tariff may be insufficient to substantively shift charging to off-peak periods, and points up an opportunity to use a TOU tariff with a higher differential to help flatten the load profile on the Austin Energy system.
- Workplace charging is 30% cheaper than home charging. This might motivate drivers to charge at work more often if workplace chargers were available.

FIGURE 21

UTILITY BILL FOR A REPRESENTATIVE DCFC IN TEXAS ON THE AUSTIN ENERGY GRID



Cost per mile

TYPE	URBAN EVSE	CORRIDOR EVSE	GAS
HIGH UTILIZATION	$0.07	$0.02	$0.09
LOW UTILIZATION	$0.16	$0.06	

This utility bill analysis provides a few key insights into DCFC operation in Austin, Texas:

- The cost to deliver one mile of charge is lower than the gasoline equivalent in all cases except for the low-utilization scenario in an urban location.
- The demand charge is the largest component of the bill in urban locations under the high-utilization scenario, and ranges from 40%–75% for the corridor locations. This would make it difficult to operate the chargers profitably at very low-utilization charging sites.
- High-utilization corridor charging is very cost-competitive at $0.02/mile.

HAWAII

With EVs comprising 1.2% (6,178 as of May, 2017)[110] of vehicles on its roads, Hawaii was 19th in the nation in terms of absolute number of EVs, but second in EVs per capita (after California) in 2015.[111]

OWNERSHIP

Hawaii has numerous incentives for EV drivers and charging infrastructure. For example, special rebates are available for the Nissan LEAF under a partnership with Nissan;[112] the Hawaiian Electric Company offers TOU rates for residential and commercial EV charging on Oahu, in Maui County, and on the Island of Hawaii; EV drivers have access to high-occupancy vehicle lanes and are exempt from some parking fees; multi-family residential dwellings and townhouses have the explicit right to site charging stations on their premises; public parking facilities that have at least 100 parking spaces must designate at least one parking space specifically for PEVs; and PEVs top the list of eligible vehicles that state and county agencies must purchase. Other programs are under consideration, including a request by the Hawaii Senate to adopt rules that encourage the use of EVs for taxis at Honolulu International Airport. The state also intends to embrace EVs as part of its strategy to meet 100% of its energy needs from energy-efficient and renewable sources by 2045—a goal that implicitly rules out reliance on petroleum fuels.[113]

Hawaii has a fully regulated electricity market, in which Hawaiian Electric is the primary regulated monopoly. But the island state has also embraced private ownership of charging infrastructure and has a well-developed ecosystem of charging networks providing service in the state.[114] Charging station owners are exempted from rules that apply to public utilities. State agencies and advocates are largely aligned on the need for vehicle electrification, although the funding model for deploying additional chargers remains a subject of debate.

SITING STRATEGIES

The size of the Hawaiian Islands makes it possible to make nearly all normal trips within the 30- to 60-mile range of most EVs. Even the longest numbered highway in Hawaii, state route 11 on the Big Island, is within the range of a single Chevy Bolt charge, at 122 miles. Accordingly, Level 2 charging is adequate for most purposes in Hawaii, and Level 2 chargers constitute the bulk of the state's 250+ charging stations. The need for DCFC is primarily limited to high-traffic shopping areas and tourist destinations. As a result, Hawaii will be able to provide ubiquitous charging infrastructure at a relatively low cost, while also having an excellent opportunity to manage charging stations to provide grid services.

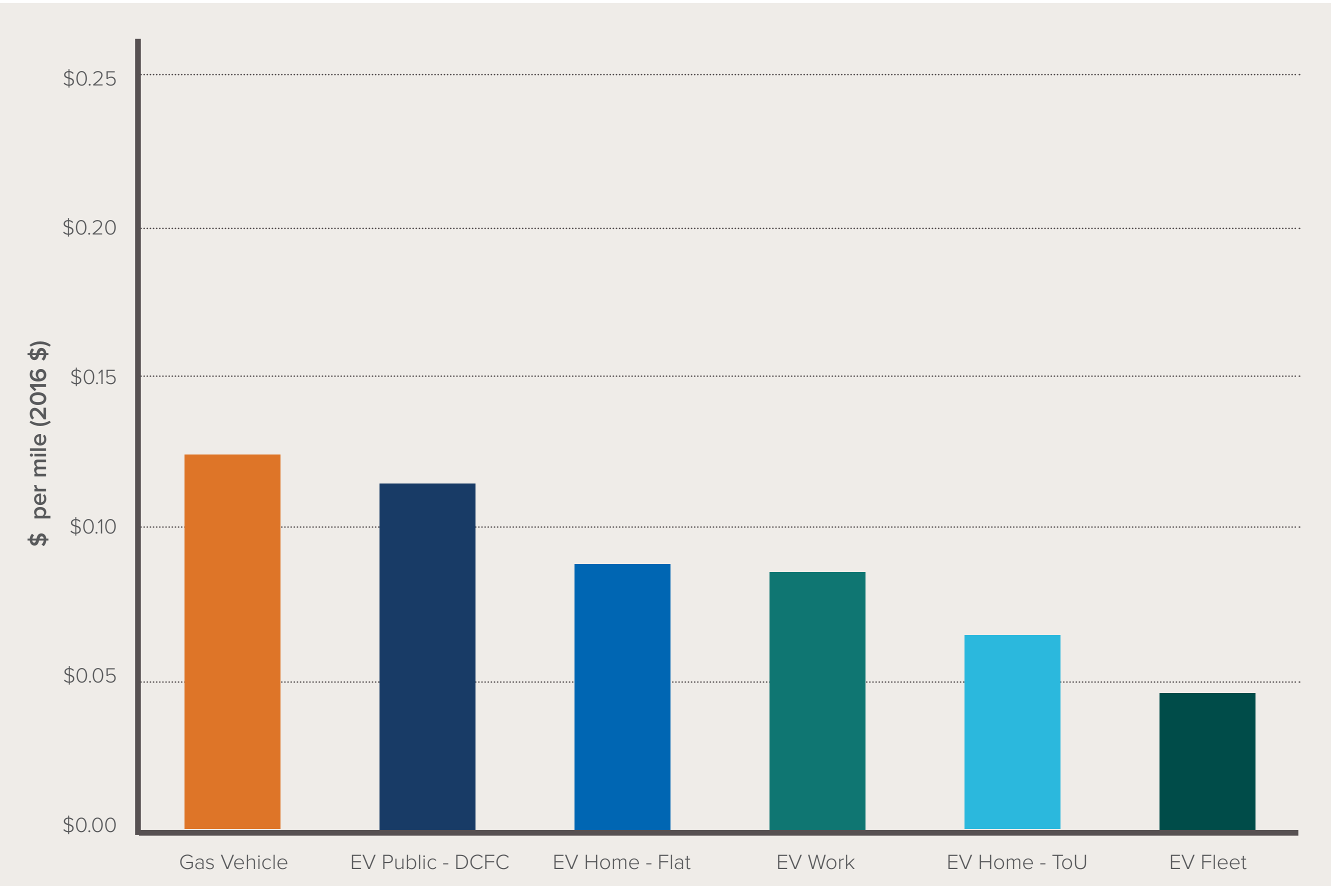
GRID INTEGRATION

With a grid that is 73% powered by petroleum, Hawaii has the highest residential electricity prices in the nation (29.6 cents/kWh in 2015)[115] and the most urgent need of any state to switch its grid power from expensive petroleum to cheap and abundant local renewable electricity. Unlike all the other states, vehicle electrification in Hawaii can displace petroleum twice: once in the vehicles, and once in the grid power supply. Hawaii has the third-highest solar capacity per capita,[116] but it also experiences substantial curtailment of its solar and wind output due to oversupply in low load periods, and balancing challenges such as maintaining frequency and stability which arise from having small balancing areas on each island with limited interconnection.

A comprehensive build-out of Level 2 charging stations on Hawaii with smart TOU rate design and managed charging could radically improve Hawaii's energy and fiscal balance by absorbing more solar and wind instead of curtailing it, and by displacing petroleum. It would also gradually lead to a lower unit cost for wind and solar, because in Hawaii the cost of curtailment is built into the price of fixed-price contracts, rather than via direct compensation.[117] Deploying more charging infrastructure would lead naturally to a virtuous cycle in which more chargers beget more EVs, which displace

FIGURE 22

EV CHARGING COSTS IN HAWAII ON THE HAWAIIAN ELECTRIC GRID



more petroleum, which reduces the cost of driving and grid power simultaneously, which makes vehicle electrification even more financially attractive, and which enables the absorption of more wind and solar with zero marginal cost.

COST OF CHARGING

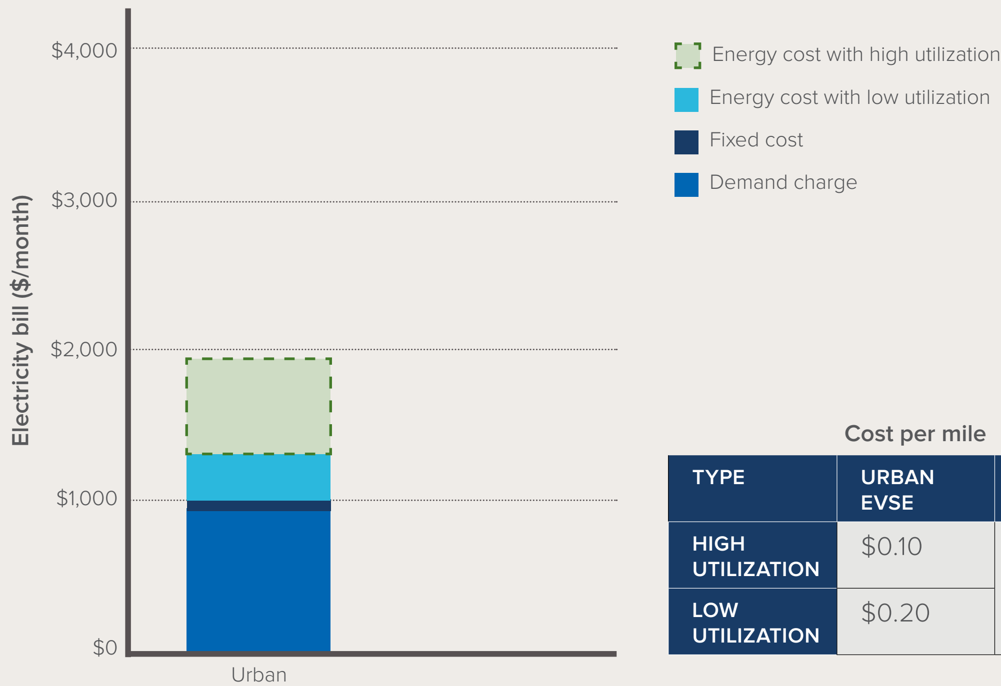
The cost of charging an EV in Hawaii can be as low as $0.05/mile for fleets; $0.06/mile if personally owned and charged at home; and as high as $0.011/mile if using a public DCFC.

Looking across the various charging options and the price signals they send to the EV owner, we developed a set of hypotheses around these results:

- All EV charging options are lower than the equivalent cost of fueling an ICE vehicle. This is largely because of Hawaiian Electric's EV-U pilot tariff, which offers fixed-fee DCFC access, and Hawaii's high cost of gasoline.
- There is a 27% difference in cost between uncontrolled and controlled home charging, which offers a moderately persuasive price signal to drivers to charge during off-peak periods.
- Workplace charging is more expensive than controlled home charging, and only slightly less expensive than uncontrolled home charging. This price differential would not be particularly effective at motivating

FIGURE 23

UTILITY BILL FOR A REPRESENTATIVE DCFC IN HAWAII ON THE HAWAIIAN ELECTRIC GRID[ii]



Cost per mile

TYPE	URBAN EVSE	GAS
HIGH UTILIZATION	$0.10	$0.12
LOW UTILIZATION	$0.20	

workplace charging, but daytime workplace charging is what the Hawaiian grid needs to avoid midday solar curtailment.

This utility bill analysis provides a few key insights into DCFC operation in Hawaii:

- Urban charging is costlier than gasoline fueling for nearly all utilization levels evaluated.
- High energy costs make the economics of EV charging more challenging in low-utilization scenarios.

[ii] Corridor charging is not applicable to the Hawaii case study due to the unique driving patterns and distances traveled on the Hawaiian Islands, and was therefore not included in this analysis.

04 LET'S GET MOVING

eTourEurope, courtesy of Werner Hillebrand-Hansen

LET'S GET MOVING

The time for debating the equitability of vehicle electrification, and waffling over whether or not to make investments in it, is behind us. Electric vehicles of all sizes, shapes, and applications are coming quickly, and utilities and their regulators need to be prepared to implement programs now that will transform the mobility marketplace, lest they find themselves uncomfortably behind the curve and suddenly facing the need to install expensive peaking generation or to upgrade a large number of distribution transformers. The rapid and unplanned adoption of air conditioning 50 years ago put grid operators in just such a position, and it could happen again now, only at a much larger scale and a much higher cost. It is absolutely critical to get right the methods and infrastructure for vehicle electrification from the start, with appropriate tariffs, well-planned charging infrastructure, and the ability to manage chargers either directly or through aggregators.

With careful planning and early intervention, the electric vehicle revolution can help optimize the grid and reduce the unit cost of electricity, while increasing the share of renewable electricity and reducing emissions

THE ROLE OF PILOTS AND DEMONSTRATIONS FOR EXPANDING EV INFRASTRUCTURE

In many parts of the U.S., EV adoption remains low and there is a dearth of data to inform EV charging infrastructure deployments and related policy decisions. Where this is the case, pilots and demonstrations offer an important opportunity to quickly build evidence that can inform future infrastructure deployments. Pilots also offer an opportunity to make lower-risk investments while rapidly deploying much-needed infrastructure.

However, pilots and demonstrations are not a panacea and they have their limitations. When used ineffectively or unnecessarily, pilots can delay important infrastructure investments or system enhancements, and yield little insight that would support scaling.

RMI recently investigated the best practices for utility pilots and demonstrations and shared our findings in our report *Pathways for Innovation: The Role of Pilots and Demonstrations in Reinventing the Utility Business Model.*[118] We identified the following best practices for utility pilots and demonstrations:

- Strategic Planning: Embrace a strategy for energy system transformation and craft a complementary road map for innovation.
- Design to scale: Design pilots and demonstrations to maximize learning and prepare for full-scale deployment.
- Organization: Create leadership support and accountability, dedicated resources, and cross-functional collaboration within the utility for effective innovation.
- Stakeholder engagement: Collaborate effectively across industry stakeholder groups to design and execute meaningful pilots.
- Cross-utility collaboration: Share best practices and lessons learned among utilities to accelerate effective innovation.

Each of these best practices is relevant to rapidly scaling the deployment of EV charging infrastructure to support an electrified transportation future. If pilots and demonstrations are designed well, the industry can test a range of promising and innovative approaches to integrating EV charging infrastructure for the benefit of customers, utilities, and the environment.

in both the electricity and transportation sectors. Without it, we could wind up with a lot of inefficient and expensive generation capacity with low load factors, a network of chargers that doesn't provide cost-effective and accessible support for EVs, higher costs, and unnecessary strife in regulatory proceedings as utilities, interveners, and regulators struggle to catch up to the challenge.

As we have demonstrated in this report, there is no single best approach to preparing for electric vehicles. Each U.S. state will have to answer key questions for itself, including:

- Who will guide charging infrastructure deployment: a market, central planners, public/private partnerships, or a legislature
- Who should install and own charging infrastructure
- What the role of regulators should be in guiding the infrastructure build-out
- How much of the total cost should be paid by drivers and private sector companies directly, and how much should be socialized
- How to design tariffs to reward charging behavior that provides grid services and absorbs low-carbon power generation
- Where to site charging stations so that they will be well used and produce enough revenue to more than cover their own costs, while still remaining useful as society eventually transitions away from personal vehicle ownership and toward ridesharing services.

One thing that all areas have in common, however, is that they need to start installing charging stations, and making sure that they do it in a well-planned, coordinated fashion. If your state or municipality is just beginning to install public charging stations, then well-designed pilot installations and demonstration projects are a low-risk way to get started. If your community has already done some pilot projects and collected some data to help identify the stations that will get the most use, then turn those insights into a more comprehensive plan and starting building charging stations in earnest. Look at the various types of site hosts—commuting rest stops, single-family homes, multiunit dwellings, workplaces, shopping areas—and understand how each one will have a different use pattern and will play a different role on the grid when the loads of charging stations are carefully managed. And for every charging station that is deployed, ensure that useful data can be gathered on it to help decision makers understand the value/risk proposition of vehicle electrification in their communities. By starting with pilot projects, gathering data as the charging network scales up, and using that data to guide subsequent deployments, we can plot a path toward a fully optimized system that serves the needs of the entire community, not just early EV drivers.

GL

GLOSSARY

B1 all-electric sport utility truck © Bollinger Motors, LLC

GLOSSARY

BEV	battery electric vehicle
DCFC	DC fast charging
EVSE	electric vehicle supply equipment (charging equipment)
G2V	grid-to-vehicle
GHG	greenhouse gas
IOU	investor-owned utility
PEV	plug-in electric vehicle
POV	personally owned vehicle
PHEV	plug-in hybrid electric vehicle
RIM	ratepayer impact measure
TCO	total cost of ownership
V2G	vehicle-to-grid
SAEV	shared autonomous electric vehicle

AP

APPENDIX: ANALYSIS METHODOLOGIES

image © Rocky Mountain Institute

APPENDIX: ANALYSIS METHODOLOGIES

FLEET TOTAL COST OF OWNERSHIP

We calculated the total cost of ownership (TCO) for a fleet of 30 vehicles, operated for five years, driving 25,000 miles per year, for both internal combustion and electric vehicles. Resale value was not included, and an end-of-life value of $0 was assumed for both vehicle classes. The fleet TCO included capital costs, financing costs, insurance, fuel, maintenance, oil, and federal- and state-level tax incentives. Detailed assumptions are shown in Table 4.

TABLE 4

FLEET TOTAL COST OF OWNERSHIP ASSUMPTIONS

ASSUMPTION / CALCULATION	VALUE	UNIT
FLEET SIZE	30	vehicles
ANNUAL MILES DRIVEN	25,000	miles
EFFECTIVE ELECTRICITY COST – INCLUSIVE OF FIXED, DEMAND, VOLUMETRIC, AND DELIVERY FEES		
Xcel	$0.15	$/kWh
AEP	$0.14	$/kWh
Austin Energy	$0.16	$/kWh
Hawaiian Electric	$0.18	$/kWh
SCE	$0.20	$/kWh
GASOLINE PRICE		
Colorado	$2.30	$/gallon
Ohio	$2.18	$/gallon
Texas	$2.14	$/gallon
Hawaii	$2.98	$/gallon
California	$3.03	$/gallon
STATE TAX CREDIT		
Colorado	$5,000	$/vehicle
Ohio	$0	$/vehicle
Texas	$500	$/vehicle
Hawaii	$0	$/vehicle
California	$2,500	$/vehicle
ICE PURCHASE PRICE	$25,670	$/mile
EV PURCHASE PRICE	$36,500	$/mile
OIL (ICE ONLY)	$0.006	$/mile
TIRES	$0.004	$/mile
MAINTENANCE COSTS	$0.016	$/mile
DISCOUNT RATE	10%	%

COST OF CHARGING BY CHARGER TYPE

We calculated the cost (to the homeowner, employer, or DCFC site host) of charging an electric vehicle at home, at work, or on a public DCFC network, using the applicable tariff from Table 6 (residential for home, commercial for workplace, and retail or utility programs for DCFC). We then derived the equivalent cost per mile based on the assumptions listed in Table 5.

The homeowner's cost assumes that charging is conducted using a Level 2 wall-mounted charger on a separate meter.

The employer's cost assumes that workplace charging is conducted using a shared and managed bank of 25 Level 2 chargers on a separate meter with an aggregate maximum charge rate of 20 kW. We determined the maximum managed power by assuming that 15% of the daily miles driven per EV were charged at work, on average, and were distributed non-uniformly throughout the workday, based on state-specific TOU rates where applicable. Unmanaged workplace charging would result in a significant increase in peak demand and is not modeled here.

The EV owner's cost of fast public charging assumes that it is conducted on a 50 kW DCFC unit and is based on the available retail DCFC program in that area as described in Table 6. Retail rates for DCFC in states without a utility-specific DCFC program are based on EVgo's Flex charging program.

TABLE 5

ELECTRIC VEHICLE CHARGING ASSUMPTIONS

ASSUMPTION / CALCULATION	VALUE	UNIT
WORKPLACE AGGREGATED PEAK CHARGING RATE	20	kW
HOME PEAK CHARGING RATE	7.7	kW
DCFC PEAK CHARGING RATE	50	kW
CHARGING BREAKDOWN		
Home	80%	% of daily charging needs
Workplace	15%	% of daily charging needs
DCFC	5%	% of daily charging needs
On-peak charging (workplace and home) on TOU rate	5%	% of on-peak charging
Annual vehicles miles traveled	13,000	miles/year
EV fuel efficiency	3.5	miles/kWh
Vehicle battery capacity	60	kWh
ICE fuel efficiency	24	mpg

TABLE 6
UTILITY TARIFF SUMMARY

STATE	UTILITY	FLEET	WORKPLACE	RESIDENTIAL TOU	PUBLIC DCFC
California	SCE	TOU EV-4	TOU EV-4	TOU EV-1	EVgo Flex plan
Colorado	Xcel	Secondary General	Secondary General	Residential TOU Pricing	EVgo Flex plan
Hawaii	HECO	TOU J	EV-F	Schedule R TOU	EV-U pilot
Ohio	AEP	GS3	GS3	Residential ToD	EVgo Flex plan
Texas	Austin Energy	AE Secondary V2	AE Secondary V2	EV 360	Plug in Everywhere

COST OF CHARGING FOR PUBLIC DCFC SITE HOSTS

We developed two host-site DCFC utilization profiles, urban and corridor, and for each profile we created a low- and high-utilization scenario.

The urban site profile was derived from real DCFC utilization data in California on the EVgo fast charging network. Details are available in our report, *EVgo Fleet and Tariff Analysis*.[119]

The corridor site profile was created to represent the expected utilization that a highway DCFC network would achieve if the network were ubiquitous and EV owners refueled under the same refueling behaviors as ICE drivers do along highway corridors. It is important to note that the corridor utilization profile is theoretical and somewhat optimistic, because it is unlikely that this type of charging behavior would be realized without both a robust and ubiquitous corridor charging network and EVs with a standard 240-mile range.

CORRIDOR DCFC LOAD PROFILE

Figure 24 shows the low- and high-utilization scenarios for the corridor DCFC load profile. Vehicles are assumed to have a 60 kWh battery that begins each charging event with a 25% charge and ends with a 90% charge.

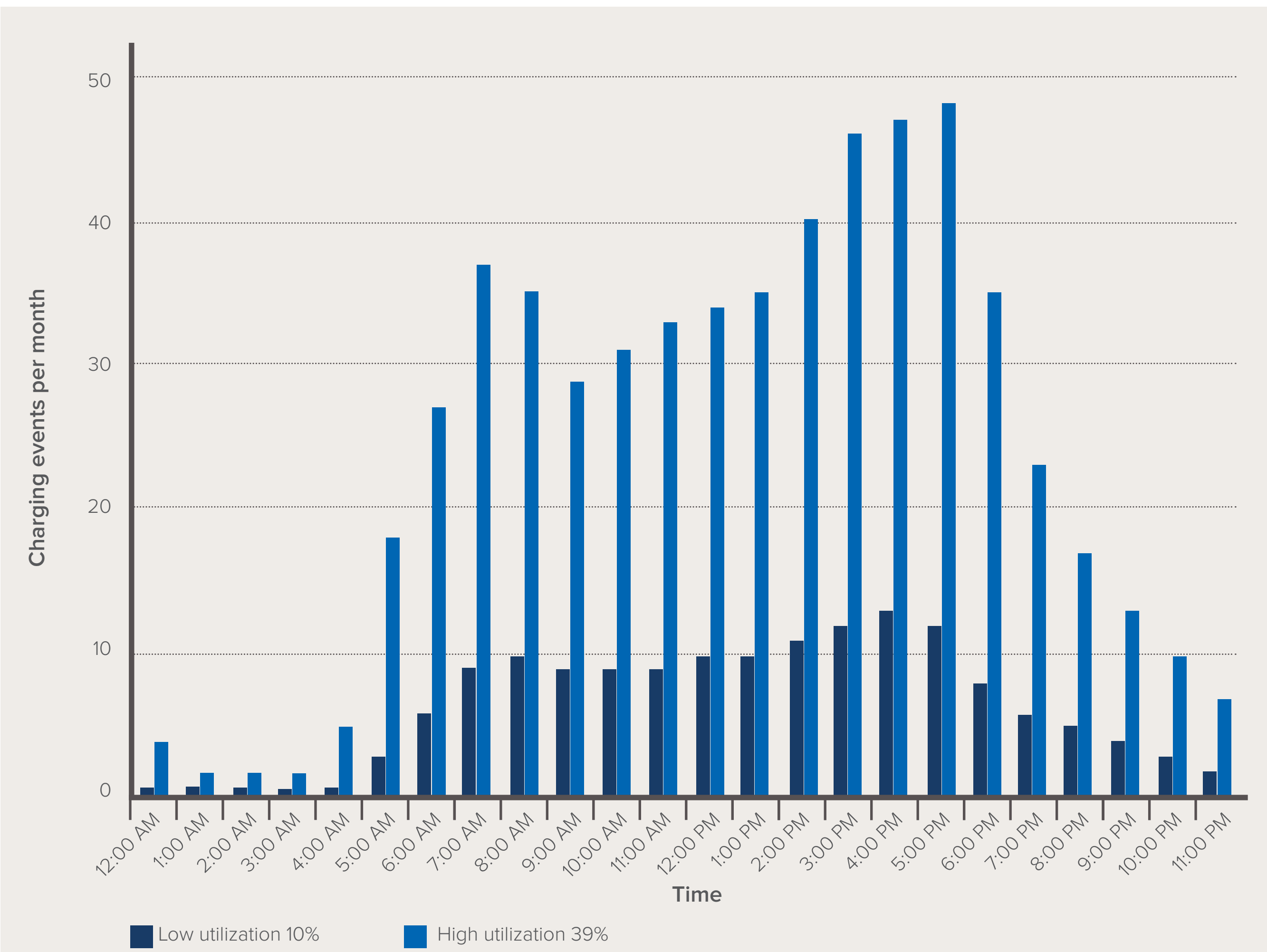
The low-utilization scenario assumes 156 charging events per month, with a total delivered energy of 5,938 kWh per month, representing a 10% utilization factor.

The high-utilization scenario assumes 580 charging events per month, with 22,539 kWh of energy delivered per month, representing a 39% utilization factor.

We calculated the timing and frequency of charging events using an idealized model based on actual volumetric traffic flows along interstates 91 and 95 in Massachusetts, with I-91 representing the low-utilization scenario and I-95 the high-utilization scenario. We assumed that a bank of DCFC chargers was available every 100 miles along each corridor, and that 1% of vehicles on the road were EVs.

FIGURE 24

CORRIDOR DCFC UTILIZATION PROFILE



URBAN DCFC LOAD PROFILE

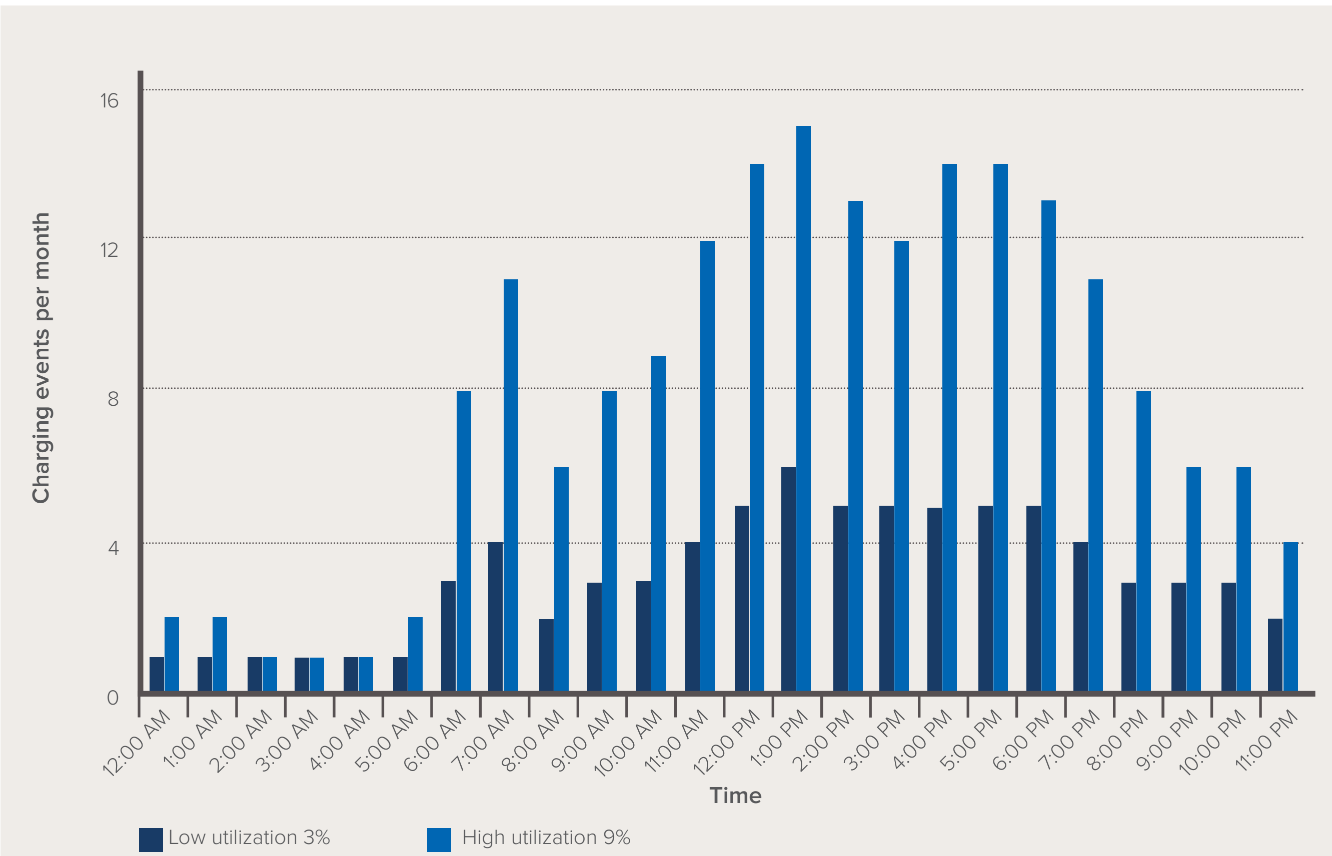
Figure 25 shows the low- and high-utilization scenarios for the urban load profile. The profiles were derived from our *EVgo Fleet and Tariff Analysis* report. Vehicles are assumed to have a 60 kWh battery that begins each charging event with a 40% charge and ends with an 85% charge.

The low-utilization scenario assumes 76 charging events per month, with 1,718 kWh of energy delivered per month, representing a 3% utilization factor.

The high-utilization scenario assumes 183 charging events per month, with 4,934 kWh of energy delivered per month, representing a 9% utilization factor.

FIGURE 25

URBAN DCFC UTILIZATION PROFILE



We calculated the cost (to the DCFC site hosts) of providing charging using the load profiles shown in Figure 25 and the applicable commercial tariff structures from Table 6. We assumed that each DCFC station had two ports, with a peak capacity of 100 kW per station. We assumed that each station is separately metered and draws a peak demand of 100 kW. Based on the monthly utility bill and number of miles charged in each scenario, we calculated the cost (to the site host) for delivering one mile of EV range. This cost represents the cost to the DCFC host site for electricity service only, and does not include other operational site costs.

SUMMARY OF COSTS AND BENEFITS FROM LITERATURE

FIGURE 26

DETAIL OF STAKEHOLDER BENEFITS FOR EVS FROM THE LITERATURE

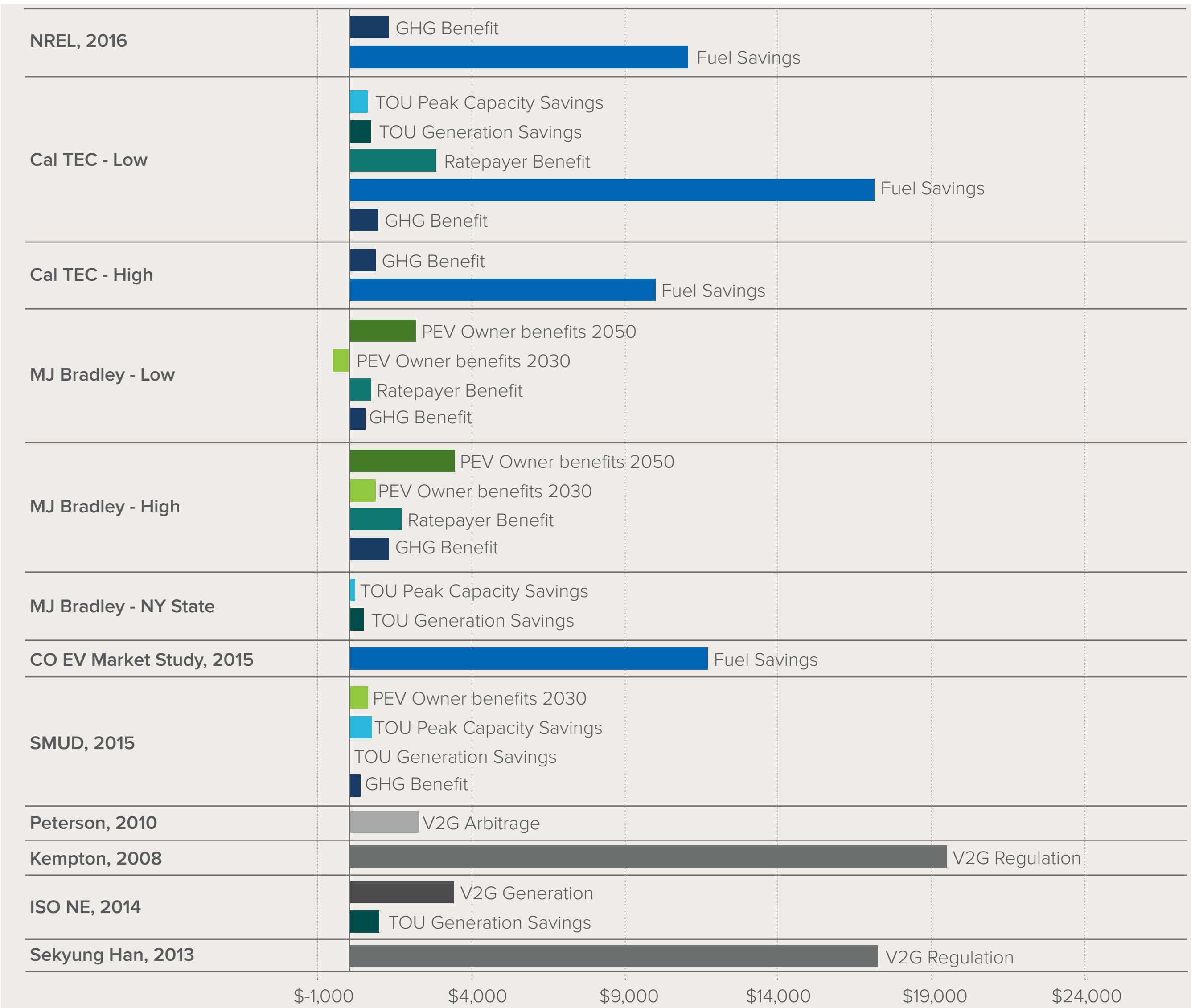


TABLE 7

TABULATED EV STAKEHOLDER BENEFITS FROM THE LITERATURE

	NREL, 2016	CAL TEC - LOW	CAL TEC - HIGH	MJ BRADLEY - LOW	MJ BRADLEY - HIGH	MJ BRADLEY - NY STATE	CO EV MARKET STUDY	SMUD, 2015	PETERSON, 2010	KEMPTON, 2008	ISO NE, 2014	ISO NE, 2014
GHG BENEFIT	$1,350	$1,033		$611	$1,294			$62				
FUEL SAVINGS	$10,700	$16,528					$11,249					
RATEPAYER BENEFIT		$2,788	$9,607	$744	$1,692							
TOU GENERATION SAVINGS		$764	$878			$477		$414			$995	
TOU PEAK CAPACITY SAVINGS		$661				$216		$738				
V2G REGULATION										$18,744	$3,068	$16,590
V2G ARBITRAGE									$2,186			
PEV OWNER BENEFITS *2030				-$370	$940			$697				
PEV OWNER BENEFITS *2050				$2,100	$3,380							

EN

ENDNOTES

image © Rocky Mountain Institute

ENDNOTES

[1] Assumes U.S. EV sales growth of 32% per year, 13,500 miles/year, 3.5 mi/kWh, and $0.132/kWh.

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22830 Two Rivers Road
Basalt, CO 81621
www.rmi.org