

Beneficial Electrification of Transportation

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Part of the *Electrification in the Public Interest Series*



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Table of Contents

About This Series	7
Executive Summary	8
Matching Technology to Transportation Needs	8
Vehicle and Charging Technologies	8
Optimal EV Charging Options Vary by Site and Needs	8
Meeting the Conditions for Beneficial Electrification	9
Consumer Economics	9
Grid Management	9
Energy and Emissions Efficiency	10
Putting Beneficial Electrification Into Action for Transportation	11
Considerations for Safeguarding the Public Interest	11
Strategies to Support Beneficial Electrification	11
Opportunities in a Changing Energy Sector	15
Matching Technology to Transportation Needs	20
Vehicle Technologies	21
Charging Technologies	21
Optimal EV Charging Options Vary by Site and Needs	24
Home Charging With Garage Access	25
Charging for Those in Multi-Family Housing	25
Workplace Charging	26
Charging in Public Places and Transport Corridors	26
Charging for Transit Vehicles	27
Meeting the Conditions for Beneficial Electrification	28
Consumer Economics	29
Factors Affecting Economics	29
Current Economics of Light-Duty EVs	31

Consumer Economics of Electric Buses	33
Grid Management	36
Demand Response	38
Vehicle-to-Grid Services	41
Energy and Emissions Efficiency	43
Emissions Effects of Electric Passenger Vehicles	46
Emissions Effects of Electric Transit Buses	48
Putting Beneficial Electrification Into Action for Transportation	52
Considerations for Safeguarding the Public Interest	53
Equity and Environmental Justice	53
Land Use Management	55
Rural Transportation Needs	56
Strategies to Support Beneficial Electrification	58
Building-Related Standards	58
Standards for Charging Equipment	59
Pilot Programs: First Steps	60
Integrated Planning	62
Energy Efficiency Standards and Programs	64
Decoupling Mechanisms	65
Rate Design	65
Licensing Third-Party Charging Service Providers	70
Conclusion	72
Appendix: Revisiting the Gas Tax	73
Background	73
Spreading the Costs	75
Raising Revenue Equitably	77
Equity and Electric Vehicles	77
Conclusion	78

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Abbreviations

BE	beneficial electrification	IRP	integrated resource planning
BNEF	BloombergNEF	kV	kilovolts
Btu	British thermal unit(s)	kW	kilowatt
CARB	California Air Resources Board	kWh	kilowatt-hour
C&I	commercial and industrial	MPGe	miles per gallon equivalent
CNG	compressed natural gas	NREL	National Renewable Energy Laboratory
CO ₂	carbon dioxide	PG&E	Pacific Gas & Electric Co.
CPUC	California Public Utilities Commission	RMI	Rocky Mountain Institute
DCFC	direct current fast charger	TCO	total cost of ownership
EV	electric vehicle	TOU	time of use
EVSE	electric vehicle supply equipment	UCS	Union of Concerned Scientists
ICE	internal combustion engine	V2G	vehicle to grid

Figures

Figure 1. Plug-In Electric Vehicles as Percentage of Sales in 2017	16
Figure 2. Average Lithium-Ion Battery Prices Have Declined 85 Percent Since 2010	17
Figure 3. Levels of Vehicle Automation	18
Figure 4. EV Charging Infrastructure for Passenger Vehicles	22
Figure 5. Level 2 Charger Load Compared With Other Household Loads	23
Figure 6. Average Household Spending on Gasoline	29
Figure 7. Retail Cost to Charge 1 Mile of EV Range in Different Settings	30
Figure 8. Stakeholder Benefits During the Lifetime of Each Electric Vehicle	31
Figure 9. Total Cost of Vehicle Ownership in Four Regions	32
Figure 10. Total Cost of Vehicle Ownership in US and Europe	33
Figure 11. Battery Electric Vehicles Expected to Reach Cost Parity in Ten Years	33
Figure 12. Projected Cost of Driving Battery Electric Bus vs. Diesel Bus	34
Figure 13. Breakdown of Levelized Cost of Driving in 2020.	34
Figure 14. Total Cost of Ownership for Battery Electric Bus Purchased in 2016	35
Figure 15. Total Cost of Ownership for Electric Buses Decreases as Annual Mileage Increases	36
Figure 16. Electric Vehicles' Low Capacity Utilization Makes Them Potential Grid Resource	37
Figure 17. Shifting Electricity Demand	37
Figure 18. Wind Penetration and Curtailment	38
Figure 19. Utility Interest in Using Demand Response to Integrate Renewable Energy	39
Figure 20. Less Than 1 Percent of Electric Vehicles Require Distribution System Upgrades	39
Figure 21. Growth in Electric Vehicles in California Utility Service Areas	40
Figure 22. Percent of Pacific Gas & Electric Customers With Peak Demand in Each Hour	40
Figure 23. Utility System Costs and Benefits From Electric Vehicle Charging in California	41
Figure 24. US Greenhouse Gas Emissions in 2016 by Economic Sector and Source	44
Figure 25. Life Cycle Stages of Vehicles and Transportation Fuels	45
Figure 26. EVs Produce Lower Greenhouse Gas Emissions Than an Average Gas-Powered Car in Every Grid Region ...	48
Figure 27. Battery Electric Buses Produce Lower Greenhouse Gas Emissions Than Diesel Buses in Every Grid Region ..	51
Figure 28. Rural and Urban Age Trends	56
Figure 29. Poverty Rate Among Elderly by Location and Gender, 2010	56

Figure 30. The Subtransmission System	63
Figure 31. Illustrative Time-of-Use Pricing	66
Figure 32. Customers on Time-of-Use Rates Shift Their EV Charging Away From Peak Periods.	66
Figure 33. Illustrative Non-Coincident Peak Demand Charge	67
Figure 34. Estimated Average Charging Costs Under Current and Proposed PG&E Rate	70
Figure 35. Gasoline Taxes: Combined State and Federal.	74

Tables

Table 1. Specifications of Representative Electric Vehicles.	21
Table 2. Level 2 Charging Is More Efficient Than Level 1 Charging	23
Table 3. Volkswagen Golf Emissions	46
Table 4. Well-to-Tank Emissions in Various Power System Mixes	46
Table 5. Illustrative Electric Sector Carbon Emissions	47
Table 6. Chevrolet Bolt Emissions in Various Power System Mixes.	47
Table 7. Emissions Intensity for Compressed Natural Gas and Diesel Buses	50
Table 8. Proterra Electric Bus Emissions in Various Power System Mixes.	50
Table 9. Illustrative Standard Commercial Rate Design and Impact on Economics of EV Charging	68
Table 10. Illustrative Smart Commercial Rate Design and Impact on Economics of EV Charging	68
Table 11. Illustrative Standard Commercial Rate Design and Impact on Economics of Fast EV Charging.	69
Table 12. Illustrative Smart Commercial Rate Design and Impact on Economics of Fast EV Charging	69
Table 13. User Fee Payments Relative to Allocated Costs	75
Table 14. Illustrative Charges Compared With Roadway Impacts	77
Table 15. Do Different Motor Vehicle Revenue Mechanisms Reflect Roadway Cost Drivers?	77

About This Series

For electrification to be considered beneficial, it must meet one or more of the following conditions without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

The first paper in this series, *Beneficial Electrification: Ensuring Electrification in the Public Interest*, explores policy and regulatory decisions that need to be made to accommodate innovations across the power sector that make it possible to electrify many energy uses currently fueled by oil, propane, and natural gas. The paper makes the case for what RAP calls beneficial electrification—in other words, electrification in the public interest.

The authors offer six principles that will help policymakers and regulators formulate and evaluate their electrification strategies to broadly secure the benefits. Finally, the paper looks at operational elements that states may want to consider as they move ahead with electrification.

This companion paper and two others feature pathways and no-regrets options for regulators to apply these principles specifically to space heating, water heating, and electric vehicles. Each paper lays out initial steps for regulators to establish programs, including standards and metrics to measure success. More specifically, these papers explore issues such as rate design to enable beneficial electrification; program design and implementation; relationships between beneficial electrification and energy efficiency and demand response programs; screening tests for beneficial electrification; and impacts on wholesale markets and vice versa.

Learn more and download the full series at www.raponline.org/BE.

Executive Summary

Technological advances, both in the efficiency of electricity generation and the end uses it fuels, have opened up opportunities for beneficial electrification (BE). Transportation, like space and water heating, is one of these opportunities. The electric vehicle (EV) market is growing rapidly, driven by declining battery costs and improved performance. The development and adoption of autonomous vehicle technologies and the growing demand for shared transportation services are also shaping this market.

In today's changing environment, utility customers are becoming used to the increasing availability and convenience of EVs. These vehicles can convert 60 percent of the energy they draw from the grid into miles traveled, compared with internal combustion engine (ICE) vehicles, which convert only about 20 percent of primary energy to the same purpose. Because of this efficiency, EVs can be significantly less costly and less polluting to operate. Controlled EV charging also can serve as a resource for grid managers.

To ensure that EVs benefit the public, policymakers will need to determine what they want from transportation markets. They will also have to balance some demands of market actors with the public interest. We encourage public utility commissions to find that line in their states and to ask for help from legislatures if existing statutory authority is inadequate.

Matching Technology to Transportation Needs

Vehicle and Charging Technologies

This paper illustrates BE opportunities using passenger vehicles and transit buses as examples. As a representative passenger EV, we use the Chevrolet Bolt with a 60-kilowatt battery, an estimated driving range of 238 miles, and a miles per gallon equivalent of 119 miles. Our representative electric bus, or e-bus, is a Proterra 40-foot Catalyst FC model with

To ensure EVs benefit the public, policymakers will need to determine what they want from transportation markets and balance demands of market actors with the public interest.

a 94-kilowatt battery, a driving range of 33 to 52 miles, and a miles per gallon equivalent of 16.7 to 25.9.

The most common form of charging infrastructure—collectively known as EV supply equipment (EVSE)—utilizes plug-in charging, which varies in cost and grid impact depending on how quickly the vehicle is being charged. Passenger EVs may use any of three broad categories of chargers: a 120-volt Level 1 charger, a 240-volt Level 2 charger, or a Level 3 direct current fast charger using 480 volts or more. Higher-capacity chargers offer shorter charging times but are more costly to install and operate and impose greater demand on the grid. Charger costs also vary significantly with their location. Fast chargers are well-suited for placement in public areas, such as high-traffic commercial locations and major transportation corridors. Level 2 chargers—with relatively lower voltage and capacity than Level 3 but higher efficiency than Level 1—are well-suited for other uses. This includes home charging, where a residential Level 2 charger draws only about twice the energy as an electric clothes dryer.

E-buses can charge by connecting through overhead chargers known as pantographs or wireless inductive charging. As with passenger cars, the greater the e-bus charging speed, the greater the cost and demand on the grid.

Optimal EV Charging Options Vary by Site and Needs

Infrastructure for fueling gasoline- and diesel-powered vehicles is ubiquitous, and most of us take it for granted. EV drivers will need to feel similarly confident that sufficient

infrastructure is in place for them. Investment will need to be targeted to known and prospective charging needs, and each community's needs will differ.

Home charging is convenient for EV drivers, because connecting overnight can recharge a vehicle sufficiently to meet the needs of a typical daily commute. In fact, private charging at homes with access to a garage or carport is the most common type of charging among early adopters of EVs. And because home charging will likely be the most commonly used type of EV charging as the market develops, it will be essential to address the absence of charging infrastructure at multi-unit dwellings, where residents often park in a shared garage or on the street with no dedicated spot.

There is also a risk of low-income and disadvantaged communities being left behind as EVSE is built. States may want to encourage regulated utilities to invest in charging infrastructure in underserved areas unless or until it is determined that private markets do so adequately.

People are more likely to buy an EV if there is access to charging at their workplace; this could serve as the primary charging point for drivers without dedicated home charging. Public charging, including charging in transport corridors, will also be an important feature of the infrastructure landscape. However, the right amount of public charging will vary by state, population density, and the urban or rural setting. Expanding workplace and public charging may require determining the most helpful roles for regulated utilities and private entities.

Meeting the Conditions for Beneficial Electrification

Electrification is beneficial only if it satisfies at least one of the following criteria, without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

In this section we look at how electrified transportation can satisfy these conditions. We conclude that there are circumstances where it will be beneficial in the next several years, if not immediately.

Consumer Economics

The first BE condition is that electrification saves consumers (including public transit operators) money over the long run. Because EVs have higher sticker prices than ICE vehicles, it is important to evaluate their total cost of ownership. Researchers have found that the largest difference in cost between an EV and an ICE vehicle is the expense of the battery. Research has also found that the cost gap is shrinking and can often be offset by lower running costs. Other studies estimate that ownership cost parity between EVs and ICE vehicles will be reached within five to seven years.

The economics of e-buses will be dominated by high upfront costs but also savings opportunities from lower fuel and operating costs. In some jurisdictions, the total cost of ownership for e-buses is already lower than for buses powered by compressed natural gas. Other factors that will affect the ownership costs of e-buses versus fossil-fueled models are the annual distances traveled and whether refueling infrastructure is included.

Grid Management

The second BE condition is that electrification helps in managing the grid. The California Public Utilities Commission identified three characteristics that make EVs potential grid resources. These vehicles:

1. Provide operational flexibility because they offer dual functionality of load (while charging) and generation (while discharging stored energy back to the grid);
2. Have embedded communications and actuation technology because auto manufacturers have built digital controls into the vehicles; and
3. Have low capacity utilization, being idle more than 95 percent of the time and needing to charge only about 10 percent of the time.

EV charging load is controllable through smart charging, time-of-use rate designs, or both, meaning that charging can take advantage of lower-cost electricity and minimize adverse grid effects and investment costs. It can also be moved to times when variable renewable energy resources are more available, helping integrate these resources and reducing the need to curtail them.

Grid management has a lot in common with demand response. This is true not just in the traditional sense of demand response—that is, emergency load shedding—but also in the broader sense of the ability to dynamically shape, shift, and shed energy use at optimal times. Utilities recognize the value of managing demand and can apply that understanding to EVs. The cost of serving this load is low enough, with substantial EV adoption, that it is outweighed by the revenue from EV charging, which creates savings for all ratepayers. Time-of-use rates are the major grid management tool utilities are using. Controlled charging can also be used—and, in the more traditional sense of demand response, chargers can be paused during peak demand or service disruptions.

EVs are also capable of discharging power onto the grid when called upon, a practice known as vehicle to grid (V2G). Using this ability would enable EVs to take power when it is cheaper and discharge it when the power is more valuable, a potential economic benefit to EV owners. Various V2G pilot programs are underway, but deployment is not yet widespread. One of the drawbacks to the development of V2G capabilities is the concern for potential battery degradation and limitations of manufacturer battery warranties. Studies suggest there may be a way to balance strategies designed to maximize return on investment for an EV owner with the need to set limits on the amount of energy traded, making V2G viable and profitable.

Energy and Emissions Efficiency

The third BE condition is that it reduces environmental impacts, such as emissions, in comparison with fossil-fueled options. The transportation sector accounts for a significant portion of US greenhouse gas emissions, roughly 28 percent in 2016. Further, emissions from transportation grew 21 percent between 1990 and 2016, whereas emissions from the electric sector declined 1 percent over the same period. In fact, today's power sector emits the same amount of carbon dioxide as it did a generation ago, although it produces nearly 30 percent more electricity annually. These trends indicate the value of electrifying transportation as part of an overall

Utilities recognize the value of managing demand and can apply that understanding to EVs.

decarbonization policy. Decarbonization opportunities exist throughout the sector, but passenger vehicles, including light-duty cars and trucks, account for roughly 60 percent of transportation emissions.

To determine the emissions effects of different technologies such as EVs, analysts must first define the parameters of a vehicle's life cycle. A “well-to-wheels” analysis, which we use in this paper, includes activities from resource extraction through processing and delivery of fuel to the vehicle, as well as use of the fuel in the vehicle.

Our illustrative ICE vehicle is the 2018 Volkswagen Golf, which we calculate to have well-to-wheels emissions of 0.91 pounds per mile. Our illustrative EV is the 2018 Chevrolet Bolt, whose well-to-wheels emissions depend on the fuel mix of the power system where it is charged. Our calculations find a high of 0.69 pounds per mile in a 100 percent coal system. In other words, a Bolt charged in any US power system will result in lower emissions per mile than a gasoline-powered Golf. This is in line with recent studies that have found that driving an EV in any region of the country produces lower carbon emissions than driving the average new gasoline-powered car.

An analysis of bus testing data found well-to-wheels emissions of 6 to 10.4 pounds per mile for a diesel or compressed natural gas bus, depending on the type of route and number of stops. Our illustrative electric bus, the 40-foot Proterra Catalyst, has lower well-to-wheels emissions even on the highest-carbon power system: 5.3 pounds per mile for a 100 percent coal system.

There are good reasons to conclude that electric transportation meets all three of RAP's BE conditions now or will within several years. As decision-makers consider the opportunities BE presents, we encourage them to apply the three conditions to ensure that electrification proceeds in a manner promoting the public interest.

Putting Beneficial Electrification Into Action for Transportation

This section lays out some considerations for ensuring that transportation electrification is beneficial. We then offer a set of BE-related strategies for states to consider.

Considerations for Safeguarding the Public Interest

Equity and Environmental Justice

Ensuring that the benefits of this new mode of transportation are shared equitably will require states to consider the degree to which all consumers have access to electricity as a transportation fuel, regardless of their economic and geographic circumstances. The development of private, proprietary charging infrastructure raises questions about whether this goal is achievable without policy interventions. Recognizing equity issues in public policy and decision-making processes will ensure more equal sharing of the benefits of electrified transport, or e-transportation. States will also need to work with at-risk communities to identify and develop solutions that deliver on inclusivity goals.

An important facet of equity that policymakers will need to consider is environmental justice. The goal will be to ensure that no group bears a disproportionate share of any negative environmental consequences from the electrification of transportation. Although the growth in EV adoption has the potential to be beneficial across the economy, taking environmental justice into consideration means policymakers first need to understand the effects on at-risk communities before formulating and adopting policy. Second, policymakers need to ensure the mitigation of any negative effects.

Land Use Management

Transportation planning in the broadest sense—shaping what cities and towns will look like—is beyond the scope of this paper. But the development of e-transportation is an opportunity for states to have a larger conversation and revisit their assumptions and transportation planning practices in order to improve how people and goods move around the landscape. Otherwise, we run the risk that e-transportation

will simply produce “e-congestion.” Planning starts with the simple question: Are we going to continue using EVs in the same manner that we have come to use ICE vehicles?

Rural Transportation Needs

Meeting rural transportation needs will be a crucial aspect of electrifying the transportation sector. Rural communities differ in significant ways from cities, and their transportation needs differ as well. One in 5 Americans—about 60 million people—live in rural America, and the percentage of people age 65 or older is both higher and increasing more rapidly in rural areas than in urban ones. Similarly, the poverty rate of rural and small-town populations, especially of elderly women, is higher than the national average.

These numbers suggest that rural residents may be more likely to be physically or financially dependent on shared transit rather than private car ownership. However, the need for rural transit does not eliminate the role of private EVs in meeting the transportation needs of some rural residents, who have more to gain because they drive farther to work, shop, and see a doctor. Because of these added miles, they also have to repair their vehicles more frequently and spend more on gasoline.

Rural communities may be best served by substantial investments in e-buses and EVSE. However, engaging with rural communities is the best way for states to determine residents’ actual transportation needs.

Strategies to Support Beneficial Electrification

Building-Related Standards

Most early adopters of EVs live in detached homes with garages, while apartment dwellers and others often have nowhere to charge. This gap in access is unlikely to change soon without policy intervention. States are responding to this challenge with “right to charge” provisions. Where states do not act, individuals will have to negotiate access with their landlords or homeowners associations.

To improve access to EV charging in existing multi-family housing, a recent report recommended:

1. Education for housing site managers;

2. A tiered state funding program to ensure a workforce trained in EV charging assessment and planning; and
 3. A state capital improvements (cost-sharing) grant program to assist property owners by providing certified assessors to help plan and design EV charging projects in this sector.
- New construction, on the other hand, is an ideal opportunity to deploy EVSE technology more rapidly. Building codes for new construction could include standards for electrical capacity and the necessary wiring to more readily facilitate future installation of charging equipment.

Standards for Charging Equipment

Typical EV charging equipment should allow either the end user, the grid operator, or an aggregator to monitor an EV's state of charge and control charging. Appliance standards could be developed for EV chargers with Wi-Fi or another utility interface, enabling chargers to receive grid signals so operators can tap into EVs as a flexibility resource. It is not clear if the US Department of Energy will recommend EV charging appliance standards, or how the Environmental Protection Agency might further articulate voluntary standards under the Energy Star program. What is clear, however, is that EVs and charging equipment with built-in control systems offer substantial benefits.

Pilot Programs: First Steps

A pilot program is a transitional arrangement between regulators and a utility that allows experimentation under time limits and other constraints. This is an opportunity to test ideas, develop capabilities, learn, and gain experience before committing to, for example, a full-scale EVSE buildout or rate design changes.

Policymakers first need to determine whether a proposed EV pilot clearly articulates its goals and priorities with regard to making electrification beneficial. Will the experiment enhance grid management? Will it create economic benefits? And will it contribute to meeting consumers' wishes or state goals to reduce air pollution?

The next step is ensuring that useful data are obtained from the pilot. Regulators may need to get comfortable with prescribing more extensive reporting requirements than they might otherwise with typical utility programs, particularly with

respect to ensuring openness and access to the data. Examples of metrics may include:

- Program expenses by time period and market segment;
- Charging station deployment;
- Load profiles (when drivers plug in and for how long);
- Charging rates; and
- Estimates of avoided emissions.

Pilot programs should be designed to report these metrics frequently, so the regulator can take meaningful corrective action in a timely manner. In the context of a time-limited pilot, relying on an annual report of metrics makes little sense. Shorter and more streamlined reporting would be useful. In a similar vein, holding regular meetings among stakeholders, utilities, and regulators can ensure that pilot programs receive useful oversight. Finally, program flexibility is important: Policymakers may want to grant some leeway to entities that are implementing EV pilots and meeting program goals, so they can adjust and innovate in response to market conditions.

Integrated Planning

States could adopt a form of integrated resource planning to help envision both the potential for transportation electrification and its effects on the power system. Integrated resource planning is a public process that allows utilities, regulators, and public participants to take an in-depth look at energy demands over an agreed-upon planning horizon, such as ten to 20 years. Accurate forecasts of demand are crucial to this work, and EV deployment scenarios will need to be part of that.

This process also considers available resources and those that need to be acquired to meet projected demand reliably and at the least cost. As states consider their ability to accommodate different types of EV charging needs—especially chargers that require high capacity—it will be useful to first inventory their existing subtransmission resources, especially those that are underused, to determine their hosting capacity.

Energy Efficiency Standards and Programs

The metrics used in state energy efficiency resource standards offer another example of a state policy that may warrant review in light of electrification opportunities. Because many of these standards require energy savings

measured as kilowatt-hour (kWh) reductions, they may discourage the adoption of additional electrified end uses, missing the opportunity to make transportation cleaner. Typical energy efficiency resource standards may also discourage beneficial electrification because a utility's savings obligation increases when its kWh sales increase. This means that the more the utility encourages electrification, the more energy savings it must obtain. Measuring energy savings in terms of primary—or total—energy use or exempting electrification load from such standards are two ways states can address these barriers.

Decoupling Mechanisms

More than half of US states have decoupling mechanisms designed to break the link between electricity sales volumes and utility earnings. These mechanisms have been important in promoting energy efficiency without hurting utility shareholder returns, but they may pose a challenge to electrification. If decoupling mechanisms allow a fixed amount of revenue per customer, but electrification requires modest increases in utility investment in supply and distribution infrastructure, utilities may have no means to recover these costs. This is a simple matter to ameliorate for a narrowly defined set of investments but should not be ignored.

Rate Design

As EV charging load increases demand on our power grids, it is incumbent on utilities and regulators to ensure existing resources are managed to optimize this increased demand and that all ratepayers share equitably in the economic benefits of smart grid management. Providing EV customers with clear price signals through rate design is a key way to do so.

Typical US residential rates consist of a fixed customer charge and a per-kWh energy charge that is the same for all hours of the day. This design does not give clear signals to EV drivers to charge when it is optimal for the grid. Time-varying energy charges are better suited to doing this and can enhance drivers' savings as well as the grid benefits of EVs.

The same holds true for commercial and industrial EV rate design, which affects commercial and workplace charging. Time-varying pricing is already more common in commercial and industrial rates, but those customers generally also pay

Time-varying energy charges can enhance drivers' savings as well as the grid benefits of EVs.

demand charges assessed on their maximum peak demand over the course of a month. Imposing demand charges this way does not necessarily help reduce the overall system peak, a natural target for rate design and a practice that could, in turn, lower overall system costs.

Demand charges may be a high proportion of the overall bill and therefore pose a significant challenge to the economics of EV charging. This creates a deterrent to installing and using charging infrastructure in these settings. For these reasons—and to align with smart rate design principles on cost causation—demand charges that don't align with system peak should be limited to recovering customer-specific costs. We detail rate design improvements that can both address utility costs and encourage EV charging, beginning on Page 65.

Licensing Third-Party Charging Service Providers

In addition to enabling and promoting e-transportation investments by regulated utilities, states should expect third-party entities to want to operate as charging service providers. States will then face the question of whether to regulate these entities. Should businesses engaged in charging vehicles be licensed and regulated like utilities? Or should they be treated like competitive retail service providers, subject to a certification process that reviews their qualifications and conditions for service?

Because utility service requirements are established and enforced under state authority, states have ultimate responsibility for answering these questions. The trend appears to be for state legislatures to exempt third-party charging service providers from typical public utility regulation, although states may conclude that some oversight may be appropriate in the nascent stages of this market development.

Finally, the Appendix to this paper examines the gasoline tax, one of the mechanisms intended to fund the construction and maintenance of roads and bridges. In recent years, this and other taxes have been unable to keep up with those costs. The discussion looks at how transportation infrastructure has

been funded and recommends how states can improve funding to maintain and improve transportation infrastructure as electrified transport options increase.

Advances in the efficiency of electricity generation and the end uses it fuels have opened up opportunities for beneficial electrification. This represents one of the biggest opportunities in the power sector today to connect consumers with more affordable and cleaner resources and to help utilities better manage the grid and reduce harm to the environment and public health. Electrifying transportation is an economical and practical path forward for saving consumers money, improving

flexible management of the power grid, and reducing transportation-related greenhouse gases.

In this paper, the authors apply RAP's three beneficial electrification conditions to two specific opportunities—electrifying passenger vehicles and transit buses—to illustrate that electric transportation benefits are achievable today. As decision-makers consider these opportunities, we encourage them to apply the three BE conditions to ensure that electrification proceeds in a manner promoting the public interest.

Opportunities in a Changing Energy Sector

Reversing the current reliance on direct use of fossil fuels for transportation can benefit consumers, the grid, and the environment.

Technological advances, both in the efficiency of electricity generation and the end uses it fuels, have opened up opportunities for beneficial electrification (BE). Transportation, like space and water heating, is among these opportunities. Beneficial electrification provides one of the biggest opportunities in the power sector today to connect consumers with far more affordable and cleaner resources and to help utilities better manage the grid and reduce harm to the environment and public health.¹ Although the electric power system was once a centralized structure supplied by remote and largely fossil fuel-fired resources, it is becoming cleaner, more distributed, and interconnected, allowing customers to produce, consume, and save energy in numerous ways.

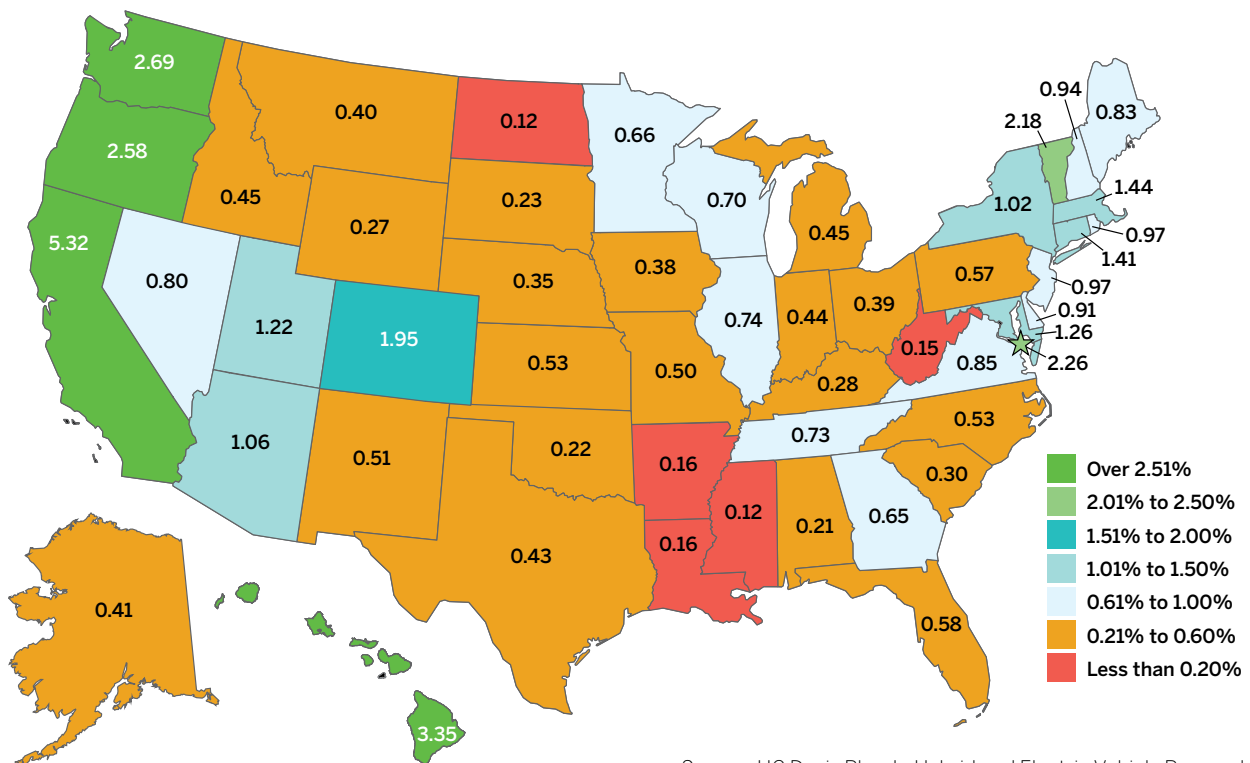
In our paper *Beneficial Electrification: Ensuring Electrification in the Public Interest*, we provide a framework for states to adopt to determine which electrification projects can be beneficial and serve the public interest. For

electrification to be considered beneficial, it must meet at least one of the following conditions without adversely affecting the other two:²

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

In this changing environment, utility customers are getting used to the increasing availability and convenience of electric vehicles (EVs). EVs are far more efficient than internal combustion engine (ICE) vehicles and capable of converting 60 percent of the energy they draw from the grid into miles traveled. Comparable ICE vehicles convert only about 20 percent of primary energy to the same purpose.³ Because of this efficiency, EVs can be significantly less costly and less polluting to operate than ICE vehicles. And because EVs are flexible in when they draw energy, their charging can be controlled and serve as a useful tool for grid managers.

Figure 1. Plug-In Electric Vehicles as Percentage of Sales in 2017



Source: UC Davis Plug-In Hybrid and Electric Vehicle Research Center.

1 Farnsworth, D., Shipley, J., Lazar, J., and Seidman, N. (2018, June). *Beneficial electrification: Ensuring electrification in the public interest*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/beneficial-electrification-ensuring-electrification-public-interest/>

2 Farnsworth et al., 2018.

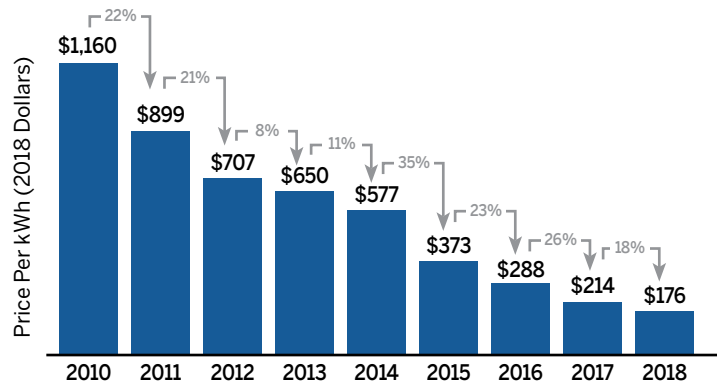
3 "EVs convert about 59%-62% percent of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 17%-21% percent of the energy stored in gasoline to power at the wheels." US Department of Energy, Office of Energy Efficiency & Renewable Energy. *All-electric vehicles* [Webpage]. Retrieved from <https://www.fueleconomy.gov/feg/evtech.shtml>

As illustrated in Figure 1, EV sales are occurring in every state.⁴ This is also a global phenomenon, with a million EVs sold worldwide in 2017.⁵ According to McKinsey and Co., that number is set to more than quadruple. The consulting firm projects that, by 2020, there will be 4.5 million sold—more than 5 percent of the global market. Furthermore, UBS increased its EV sales forecast in 2017, projecting worldwide sales of 14.2 million EVs by 2025.⁶ That would amount to 14 percent of global auto sales. EV market forecasts are not difficult to find. There are many, and they generally project various degrees of market expansion.

Despite uncertainty as to precisely how quickly the US market for EVs is going to grow, there are clear market trends playing a significant role in these changes. The development of battery technology, which is the key cost component of EVs, is helping drive the growth of the EV market.⁷ BloombergNEF (BNEF)—formerly Bloomberg New Energy Finance—reports that average battery prices have declined from roughly \$1,100 per kilowatt-hour (kWh) in 2010 to a weighted average of less than \$200 per kWh in 2018, an 85 percent drop.⁸ Figure 2 illustrates this trend.⁹

Additionally, a Chinese battery manufacturer—Envision Energy, the new owner of Nissan’s battery division—recently

Figure 2. Average Lithium-Ion Battery Prices Have Declined 85 Percent Since 2010



Source: BloombergNEF. (2018). *2018 Battery Price Survey*.

announced its plans to market a battery costing \$100 per kWh by 2020, halving the current average cost per kWh.¹⁰

Along with improvements in the standard lithium-ion battery technology, Volkswagen recently announced it expects to develop product lines using solid-state batteries.¹¹ In addition to being comparatively smaller, solid-state batteries are expected to provide greater range, faster charging, and longer life.

Not only are battery prices improving, so is the average

4 UC Davis Plug-In Hybrid and Electric Vehicle Research Center. *Percent plug-in electric vehicle sales in US vehicle market in 2017*. Retrieved from <https://phev.ucdavis.edu/zemap/>

5 Hertzke, P., Müller, N., Schenk, S., and Wu, T. (2018, May). *The global electric-vehicle market is amped up and on the rise*. McKinsey & Co. Retrieved from <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise>

6 UBS. (2017, May). *UBS Evidence Lab electric car teardown—Disruption ahead?* Zurich, Switzerland: Author. Retrieved from <https://neo.ubs.com/shared/d1wkuDIEbYPjF/>

7 Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L., and Mai, T. (2017). *Electrification futures study: End-use electric technology cost and performance projections through 2050* (NREL/TP-6A20-70485). Golden, CO: National Renewable Energy Laboratory. Retrieved from www.nrel.gov/docs/fy18osti/70485.pdf. The study cautions that projections for lower battery costs should not be considered predictive of plug-in electric vehicle growth. However, it also notes that historically observed technology cost and performance improvements, especially battery cost reductions, have increased market opportunities for transportation electrification. Others consider greater battery production volume to be “a key determinant to increasing electric vehicles’ competitiveness with conventional vehicles over time.” See Slowik, P., Pavlenko, N., and Lutsey, N. (2016). *Assessment of next-generation electric vehicle technologies*, p. 10. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/Next%20Gen%20EV%20Tech_white-paper_ICCT_31102016.pdf

8 See McKerracher, C. *Electric vehicle outlook: 2018—Setting the scene*, p. 2. BloombergNEF. Retrieved from <https://bnef.turtl.co/story/evo2018>. The company’s 2018 Battery Price Survey includes updated numbers. See BloombergNEF. (2018, December 19). *Lithium-ion battery price survey results: Volume-weighted average*. Retrieved from <https://www.facebook.com/BloombergNEF/videos/our-2018-battery-price-survey-has-found-that-the-volume-weighted-average-price-of-2243145969343197/>. BNEF projects that these costs will continue to decline, estimating prices of \$70 per kWh for lithium-ion batteries by 2030. See Morsey, S. *Electric vehicle outlook: 2018—Global sales outlook*, p. 3. BNEF. Retrieved from <https://bnef.turtl.co/story/evo2018>

9 BloombergNEF. (2018). *2018 Battery price survey*.

10 Envision Energy reports that its analysts realized they could achieve these goals after the company purchased Nissan’s battery division in 2018 and further predict that battery prices will drop to \$50 per kWh by 2025. McMahon, J. (2018, December 4). *Chinese company says it will soon cross \$100 battery threshold, slaying the gasoline car*. Forbes. Retrieved from <https://www.forbes.com/sites/jeffmcmahon/2018/12/04/chinese-company-says-it-will-soon-cross-100-battery-threshold-slay-the-internal-combustion-engine/amp/>

11 Solid-state technology replaces the polymer gel electrolyte currently used in lithium-ion cells. Halvorson, B. (2018, October 5). VW confirms it’s planning for solid-state batteries by 2025. *Green Car Reports*. Retrieved from https://www.greencarreports.com/news/1119182_vw-confirms-its-planning-for-solid-state-batteries-by-2025. Additionally, Audi, BMW, and Toyota all have announced plans to produce vehicles with solid-state batteries.

energy density of EV batteries, an increase of approximately 5 to 7 percent a year, according to BNEF.¹² Energy density is the amount of energy stored by volume. Increased density can extend the mileage of an EV or lower the cost of a battery able to reach a certain range.

Improvements in battery cost and energy density are an important trend for EV market growth and will become key factors in managing the power grid.¹³

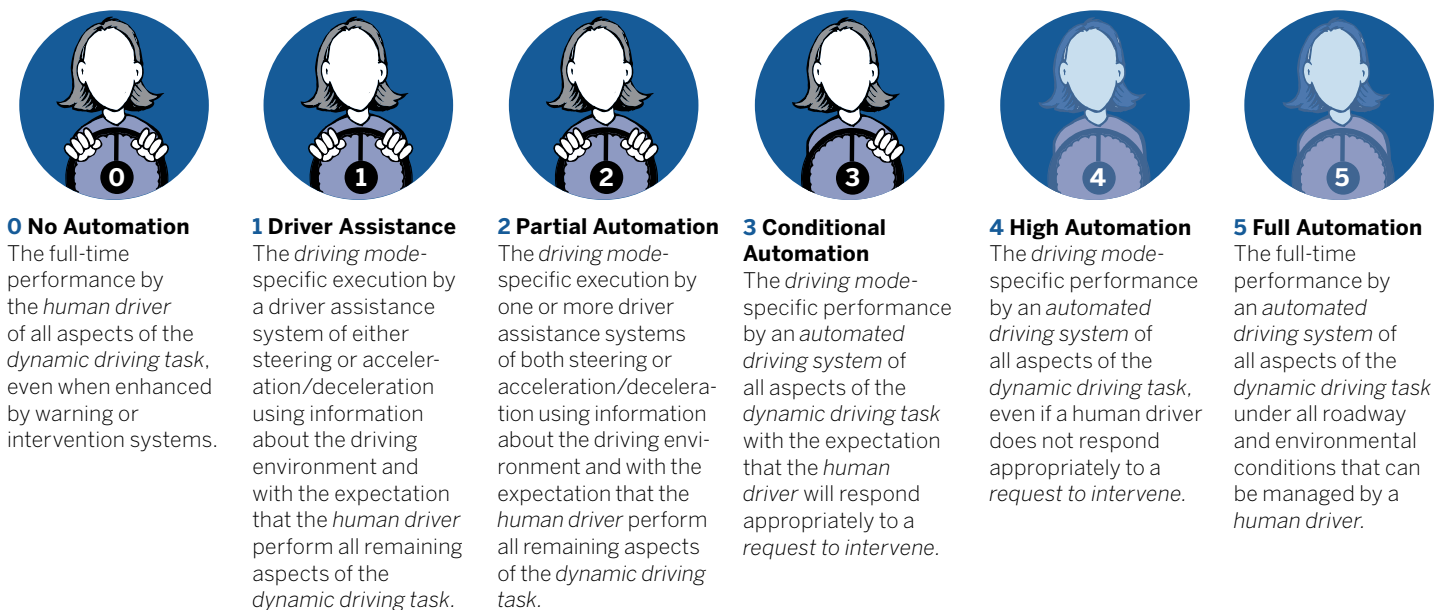
The development of and investment in technology enabling advanced driver assistance systems represents another significant market trend in electrified transport, or e-transportation. These systems are based on radar, cameras, and ultrasonic sensors.¹⁴ Figure 3 illustrates levels of automation and driver assistance.¹⁵ It is not clear how quickly to expect the adoption of these innovations that would give over human control through driver assistance

Improvements in battery cost and energy density are an important trend for EV market growth and will become key factors in managing the grid.

and anti-collision systems, or how soon they will become standard equipment in EVs. Proponents assert that increased automation will minimize human error and reduce auto accidents. Furthermore, they contend that advanced driver assistance systems can help organize traffic flow and reduce congestion—for example, by improving the overall function of city taxi and other fleet traffic.¹⁶

Tesla has a system called Autopilot that it describes as “the hardware needed for full self-driving capability at a safety level substantially greater than that of a human driver.”¹⁷ In 2017,

Figure 3. Levels of Vehicle Automation



Source: US Department of Transportation. (2018, October). *Preparing for the Future of Transportation: Automated Vehicles 3.0*.

12 See McKerracher. Energy density is one of the key properties of a battery, along with power density, cost, and lifetime. Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., and Van Mierlo, J. (2017, September 1). Cost projection of state of the art lithium-ion batteries for electric vehicles up to 2030. *Energies*, 10(9), 1314. Retrieved from <https://doi.org/10.3390/en10091314>

13 See the discussion of grid management beginning on Page 36.

14 Shuiyiu, J. (2018, February 15). Self-driving car technology gives a cutting edge. *The Telegraph*. Retrieved from <https://www.telegraph.co.uk/news/world/china-watch/technology/self-driving-car-technology/>

15 US Department of Transportation. (2018, October). *Preparing for the future of transportation: Automated vehicles 3.0*. Washington, DC: Author. Retrieved from <https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf>

16 Thompson, A. (2017, January 2). A mere algorithm could make NYC taxis four times more efficient. *Popular Mechanics*. Retrieved from <https://www.popularmechanics.com/cars/car-technology/a24567/mit-taxi-algorithm/>

17 Tesla. *Full self-driving hardware on all cars* [Webpage]. Retrieved from <https://www.tesla.com/AUTOPILOT>

Intel Corp. spent more than \$15 billion on Mobileye, an autonomous vehicle technology that will put the company into the business, along with others,¹⁸ of developing driverless systems for other automakers.¹⁹ In 2016, Goldman Sachs projected autonomous vehicle market growth from about \$3 billion in 2015 to \$96 billion in 2025 and \$290 billion in 2035.²⁰

One other significant trend that will likely shape the development of the EV market is the growth of shared transportation.²¹ As the term suggests, shared transportation implies a move away from the individual automobile to a model based on multiple users. It is an expansion of the on-demand model of vehicle use available for centuries through cabs, but more recently employed by Zipcar, Uber, and Lyft.²² Zipcar's pitch line "Own the trip, not the car" captures the idea of on-demand access to cars and the hourly or daily payment for their use.²³ BNEF predicts that the "global shared mobility fleet will swell from just under 5 million vehicles today to more than 20 million by 2040. By then, over 90 percent of these cars will be electric, due to lower operating costs. Highly autonomous vehicles will account for 40 percent of the shared mobility fleet."²⁴

These trends illustrate some of the ways the transportation sector is changing. Growing consumer interest in these new technologies and in reducing pollution and saving money can be expected to further spur demand for EVs—and for the electricity that fuels them. How the market grows, however, will depend on how well the power system adapts.

This means government will have to make choices. It will need to decide what it wants from transportation markets and precisely what benefits are worth trying to secure. Regulators will also have to balance some demands of market

actors with the public interest. This paper is intended to help energy regulators in that work. We encourage public utility commissions to find that line for their states, and to ask for help from legislatures if existing statutory authority is inadequate.

In this paper, we apply the three beneficial electrification conditions described above to the current market for EVs in the United States. We also explore topics that regulators are likely to confront as transportation electrification develops in their jurisdictions and as they are asked to review related proposals. Regulatory commissions should have a good sense of alternatives that a utility might have considered in making its investment decisions, in order to avoid being put into a situation in which the regulator sees no choice but to approve proposals to recover costs related to e-transportation.

In the next section, we look at technical considerations related to e-transportation, focusing on personal vehicles and transit buses. We also explore related charging equipment.

The third section of this paper considers necessary conditions for the beneficial electrification of the transportation sector and concludes there are numerous instances where BE can proceed today.

In the last section, we discuss considerations and strategies to help ensure that the e-transportation market develops in a manner consistent with the public interest. Like the electric sector, transportation underlies the structure and function of our economy. Changes to this sector will be far-reaching.

Finally, in the Appendix, we review how transportation infrastructure is funded in the US. We recommend ways that states can effectively fund this sector in a future where electrification plays a greater part.

18 Nvidia Corp. and Qualcomm Inc. have announced similar efforts.

19 Mobileye is taking an initial step by developing mapping technology to support the development of future driver assistance systems. Cohen, T. and Scheer, S. (2017, May 3). *Mobileye sees income from maps before self-driving cars launch*. Reuters. Retrieved from <https://ca.reuters.com/article/businessNews/idCAKBN17Z1CC-OCABS>

20 Cohen and Scheer, 2017.

21 Keating, M. (2018, July 25). Shared electric vehicles are the key to transforming the future of transport. *Intelligent Transport*. Retrieved from

<https://www.intelligenttransport.com/transport-articles/70014/shared-electric-vehicles-transform/>

22 Hawkins, A. (2018, June 19). Uber will start paying some drivers to switch to electric cars. *The Verge*. Retrieved from <https://www.theverge.com/2018/6/19/17480044/uber-electric-vehicle-ev-driver-cash-incentive>

23 Zipcar [Website]. Retrieved from <https://www.zipcar.com/>

24 BloombergNEF. (2018, May 21). E-buses to surge even faster than EVs as conventional vehicles fade [Blog post]. Retrieved from <https://about.bnef.com/blog/e-buses-surge-even-faster-evs-conventional-vehicles-fade/>

Matching Technology to Transportation Needs

Adoption of electric cars and transit buses depends in part on the availability, location, and speed of charging infrastructure—factors that vary based on customer and power system needs.

In our paper *Beneficial Electrification: Ensuring Electrification in the Public Interest*,²⁵ we make the case that, for electrification to be considered beneficial, it must satisfy at least one of the following conditions without adversely affecting the other two:

- 1. Saves consumers money over the long run;
- 2. Enables better grid management; and
- 3. Reduces negative environmental impacts.

The electrification of transportation is an opportunity for consumers to save money and decrease their environmental footprint and for utilities to better manage their power grids. Later in this paper we explore these three conditions and strategies for achieving them. First, however, we provide an overview of the relevant technologies and how they can be used as this market matures.

Vehicle Technologies

Beneficial electrification seeks to take advantage of technology trends to benefit consumers, grid operations, and the environment. In the case of transportation, this means analyzing the suitability of replacing ICE vehicles with EVs.

This paper focuses on the BE opportunities associated with passenger vehicles and transit buses. For purposes of analysis, we have chosen representative vehicles to illustrate technological capability and cost. The Chevrolet Bolt serves as a representative²⁶ electric passenger vehicle, while the Proterra 40-foot Catalyst FC model with a ProDrive drivetrain serves as a representative²⁷ electric bus, or e-bus. Table 1 details their

Electrification is an opportunity for consumers to save money and decrease their environmental footprint and for utilities to better manage the grid.

battery sizes, estimated driving range, and fuel efficiency expressed as miles per gallon equivalent (MPGe).^{28, 29}

Charging Technologies

Technology considerations in the EV context extend beyond the vehicles themselves to charging equipment and infrastructure. The major considerations regulators should expect to encounter will involve charging. Different technologies exist for charging EVs and e-buses; they are generally known as EV supply equipment (EVSE).³⁰ Charging more quickly requires higher-capacity EVSE. This has implications both for grid management and cost. The most common EVSE plug-in units fall into three broad categories or levels, illustrated in Figure 4 on the next page.³¹ Level 3 chargers are more commonly called direct current fast chargers (DCFCs).

Table 1. Specifications of Representative Electric Vehicles

	Battery size (kWhs)	Estimated driving range (miles)	Miles per gallon equivalent
Chevrolet Bolt	60	238	119
Proterra Catalyst FC	94	33 to 52	16.7 to 25.9

Sources: Car and Driver; Proterra; and US Department of Energy, Office of Energy Efficiency & Renewable Energy.

25 Farnsworth et al., 2018.

26 See UBS, 2017. While choosing only several examples of EVs for our discussion, we note that electric transportation includes a large number of both on-road (e.g., semi-trucks and pickup trucks) and off-road vehicles (e.g., freight yard forklifts and tractors, and gantry cranes used to move shipping containers) that we are not discussing.

27 The Proterra buses have been used as models in other research. See Jadun et al., 2017, p. 23. Further, performance information is available for an earlier (perhaps less efficient) Proterra model. An earlier, less advanced model from Proterra was evaluated for its in-use performance in California. See Eudy, L., Prohaska, R., Kelly, K., and Post, M. (2016, January). *Foothill transit battery electric bus demonstration results* (NREL/TP-5400-65274). Golden, CO: National Renewable Energy Laboratory. Retrieved from <https://www.nrel.gov/docs/fy16osti/65274.pdf>

28 Car and Driver. *Chevrolet Bolt EV* [Webpage]. Retrieved from <https://www.caranddriver.com/chevrolet/bolt-ev/specs#specifications>. The US Department of Energy estimates the 2018 Bolt’s miles per gallon equivalent as 128 in the city and 110 on the highway for a combined 119. See US Department

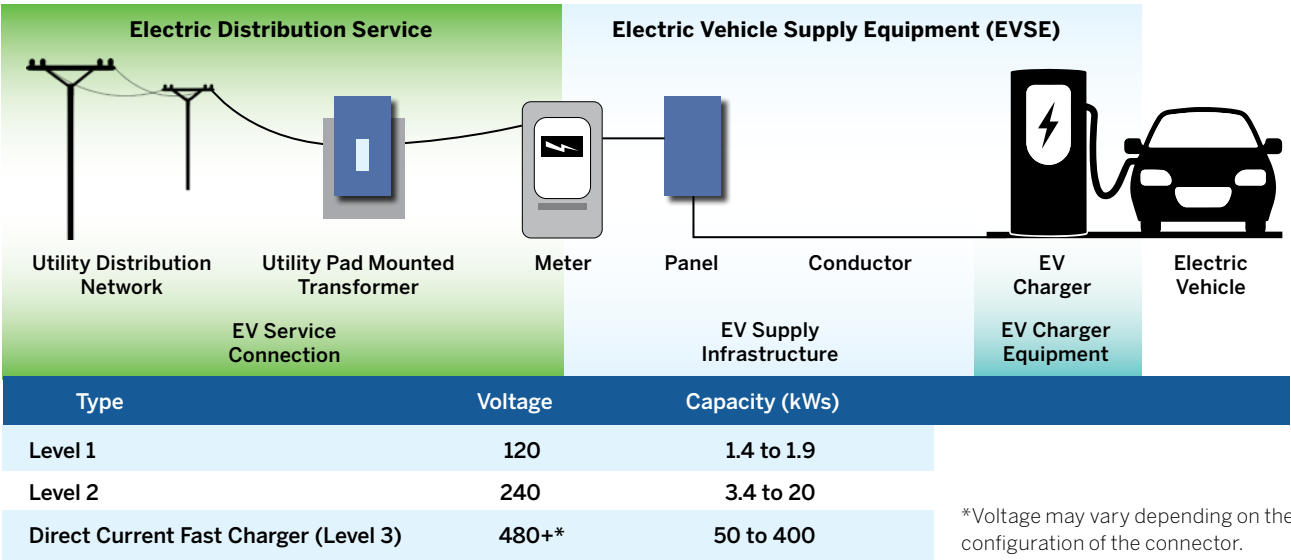
of Energy, Office of Energy Efficiency & Renewable Energy. *2018 Chevrolet Bolt EV* [Webpage]. Retrieved from <https://www.fueleconomy.gov/feg/noframes/39786.shtml>

29 Proterra. (2018, March). *Catalyst: 40 foot bus performance specifications*. Retrieved from <https://www.proterra.com/wp-content/uploads/2018/05/Catalyst-40-ft-Spec-Sheet-Sept-2018.pdf>

30 The term “EVSE” typically refers to the apparatus like a wall charger or charging station used to deliver energy to charge a vehicle. In this paper, we use the terms “EVSE” and “EV charging infrastructure” more broadly to include the plant required to connect the charging apparatus to the grid.

31 Illustration based on California Public Utilities Commission, Application 15-02-009, Proposed Decision of ALJ Farrar, mailed November 14, 2016, p. 8. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M171/K213/171213824.PDF>. Table based on Fitzgerald, G., and Nelder, C. (2017). *From gas to grid: Building charging infrastructure to power electric vehicle demand*. Boulder, CO: Rocky Mountain Institute. Retrieved from https://www.rmi.org/insight/from_gas_to_grid/

Figure 4. EV Charging Infrastructure for Passenger Vehicles



Sources: Illustration based on California Public Utilities Commission, Application 15-02-009, Proposed Decision of ALJ Farrar, Mailed November 14, 2016.
Table based on Fitzgerald, G., and Nelder, C. (2017). *From Gas to Grid: Building Charging Infrastructure to Power Electric Vehicle Demand*.

A Level 1 charger typically comes included with a passenger EV and uses a standard American 120-volt plug, connecting to a wall outlet as does a toaster or clothes iron. Depending on a variety of factors, a Level 1 charger might easily take more than ten hours to charge an EV. In addition, Level 1 chargers cannot be remotely controlled to charge during certain times (that is, to enable smart charging).³² This is unlike most Level 2 and Level 3 chargers, which can also connect to a telecommunications network, recognize customer charging patterns, and enable services like billing.

Higher-level chargers offer shorter charging times but are costlier to install and operate.³³ These costs vary significantly with the charger location; consider, for instance, that installing a charger in a parking lot may require trenching through pavement. The high costs of Level 3 chargers make them well-suited for placement in public areas, such as high-traffic

commercial locations and along major transportation corridors. The moderate costs and grid demand of Level 2 chargers make them well-suited for other uses, including charging at home. A residential Level 2 charger draws only about twice the energy of an electric clothes dryer, as illustrated in Figure 5.³⁴

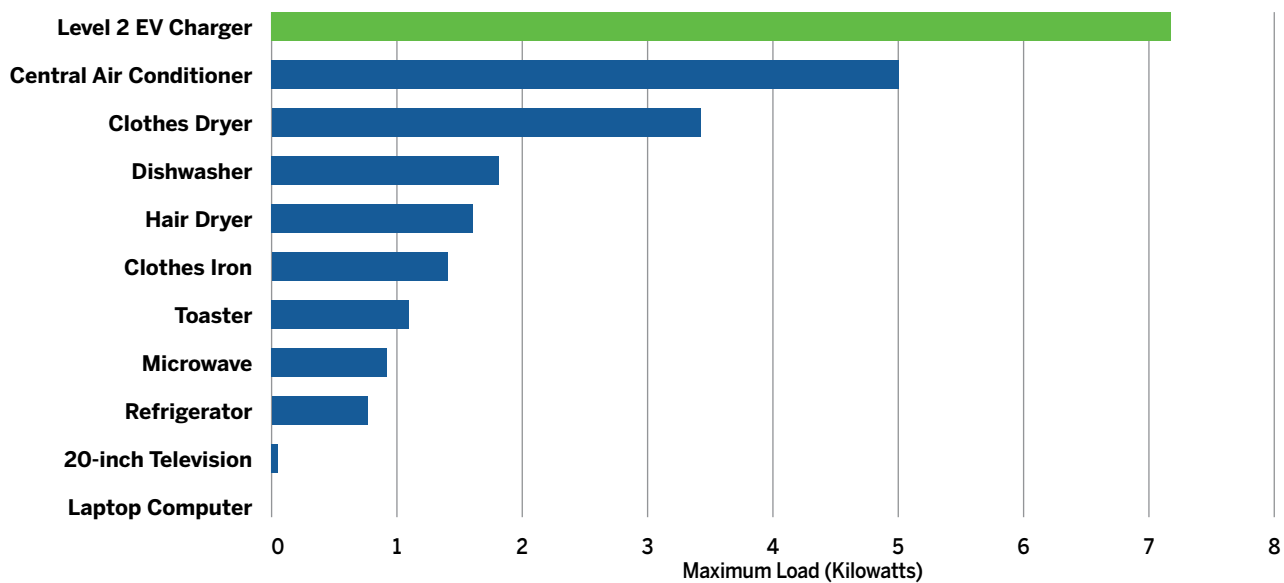
The manner in which EVs are charged has significant implications for grid management. We discuss this in detail beginning on Page 36. It is important to remember that EV chargers are electrical end uses, after all, and relevant energy efficiency considerations apply to EVSE as they do to any other electrical appliance.

Charging level is important, because variations in efficiency can have implications for the overall load on the electric grid. In 2013, Vermont Energy Investment Corp. studied the relative efficiency of chargers and found that a Level 2 charger is more efficient than the Level 1 charger that

32 It should be noted, however, that most EVs have communications and actuation technology built into their systems that may still allow for some degree of control of charging with Level 1 chargers. Langton, A., and Crisostomo, N. (2013, October). *Vehicle-grid integration: A vision for zero-emission transportation interconnected throughout California's electricity system*. California Public Utilities Commission. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K975/81975482.pdf>. This flexibility allows drivers to shift charging to different times of the day to minimize their costs and maximize benefits to the grid.

33 Tesla has indicated it will be producing a 1,000-kilowatt semi-truck charger. See Tesla. (2017, November 17). *Close-up look at the Tesla Semi "Megacharger" charging port*. Retrieved from <https://www.teslarati.com/tesla-semi-megacharger-charging-port-close-up-look/>

34 Allison, A., and Whited, M. (2017, March 2). *A plug for effective EV rates*. Cambridge, MA: Synapse Energy Economics. Retrieved from <http://www.synapse-energy.com/sites/default/files/A-Plug-for-Effective-EV-Rates-S66-020.pdf>

Figure 5. Level 2 Charger Load Compared With Other Household Loads

Source: Allison, A., and Whited, M. (2017, March 2). *A Plug for Effective EV Rates*.

is typically provided as standard equipment with EVs.³⁵ When more than 2 kWhs are drawn (a “high energy” charge event), a Level 2 charger provides an average 2.3 percent efficiency

Table 2. Level 2 Charging Is More Efficient Than Level 1 Charging

Charging sessions	Average Level 2 charge efficiency	Average Level 1 charge efficiency	Efficiency gain of Level 2 charging
Low energy (<2 kWhs drawn)	83.5%	70.7%	12.8%
High energy (>2 kWhs drawn)	86.5%	84.2%	2.3%
All	86.4%	83.7%	2.7%

Source: Forward, E., Glitman, K., and Roberts, D. (2013, March). *An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency*.

gain over a Level 1 charger. When the energy drawn falls below 2 kWhs (a “low energy” charge event³⁶), a Level 2 charger provides a 12.8 percent efficiency gain over a Level 1 charger.³⁷ Table 2 summarizes these findings.³⁸

Recognizing these benefits, the Washington Utilities and Transportation Commission allowed Puget Sound Energy to recover pilot program costs through its conservation rider due to the “incremental efficiency benefits associated with Level 2 chargers over Level 1 chargers, and the potential avoidance of new generation resources.”³⁹ This is one illustration of how charging programs, wholly apart from grid management purposes, can produce greater efficiencies through identifying and promoting more efficient charging equipment.

E-buses may power up through plug-in charging as well as through other methods called pantograph charging and

35 Forward, E., Glitman, K., and Roberts, D. (2013, March). *An assessment of Level 1 and Level 2 electric vehicle charging efficiency: To investigate potential applications of efficiency measures to various electric vehicles and their supply equipment*, Table 1, p. 9. Burlington, VT: Vermont Energy Investment Corp. Retrieved from <https://www.veic.org/docs/Transportation/20130320-EVT-NRA-Final-Report.pdf>

36 A “low-energy” charge event is probably as common an occurrence as an EV owner using a 6.6-kilowatt charging station for 15 minutes while parked and running an errand.

37 Forward et al., 2013, note 9, citing FleetCarma. (2012, December). *An investigation of Level 1 vs. Level 2 charging events in plug-in vehicles*. Unpublished manuscript.

38 Forward et al., 2013.

39 See Washington Utilities and Transportation Commission, Docket UE-160799, Draft Policy and Interpretive Statement on January 13, 2017, paragraph 5, citing Docket UE-131585, and paragraph 69. Retrieved by docket number from https://www.utc.wa.gov/_layouts/15/CasesPublicWebsite/GetDocument.ashx?docID=94&year=2016&docketNumber=160799. Puget Sound Energy’s electric vehicle charger incentive went into effect May 1, 2014. Through its Schedule 120 Conservation Service Rider tariff, the utility offered a \$500 rebate for customers who purchased their own Level 2 electric vehicle charger.

inductive charging.⁴⁰ A pantograph is an overhead connection such as those found on subways or streetcars. Inductive or wireless charging involves positioning the e-bus over EVSE embedded in the pavement. For wireless bus charging, half a transformer is located on the ground and the other half in the bus. When the bus is in place and the charger turned on, the current in the ground-mounted unit activates the vehicle-mounted unit.

As is the case for passenger car charging, EVSE for e-buses may offer greater speed in exchange for greater grid demand and higher costs. In general, the range of e-bus charging times extends from about five hours through a slow connection to 30 minutes or less with a high-voltage direct current connection and can be broken down into various increments.⁴¹

Optimal EV Charging Options Vary by Site and Needs

The availability, functionality, and convenience of vehicle charging infrastructure is an essential element of a transition to electric mobility. Infrastructure for fueling gasoline- and diesel-powered transportation is ubiquitous; many of us likely take for granted that we will be able to make it to one of the country's 150,000 filling stations when we need to.⁴² EV operators will need to feel similarly sure they will be able to keep their vehicles fueled.

Although there seems to be agreement that expanded access to charging is essential for accelerating EV adoption, no consensus exists on the optimal number or type of charging points. The National Renewable Energy Laboratory (NREL), part of the US Department of Energy, analyzed what it would

To expand the EV market beyond single-family homes, it's essential to address the lack of charging opportunities at multi-unit dwellings.

take to support 15 million plug-in vehicles in the US and found that 600,000 non-residential Level 2 chargers and 8,500 direct current fast charging stations were needed.⁴³ A statistical analysis of the connection between EV uptake and number of charging stations found that 275 public charging points per million residents is a benchmark number for leading US markets.⁴⁴ NREL also found that EV uptake correlated with availability of fast charging and workplace charging. Because EVSE capabilities and drivers' charging needs vary widely, the right number and type of charging stations will vary by region, state, city, and neighborhood based on factors such as the types of trips drivers need to take and the population density of a particular location.

Data show that early adopters of EVs are generally educated, middle-aged, married men who live in single-family homes and have higher incomes than non-adopters.⁴⁵ Transforming the market for charging infrastructure to reach prospective consumers beyond the early adopters is necessary to develop a broader market for e-transportation. Targeting investments to known charging needs can most cost-effectively give more people access to electric transportation.⁴⁶ Next we describe several EVSE market segments and their importance in the larger e-transportation market.

40 Prescient & Strategic Intelligence. (2018, September). *US electric bus charging station market report*. Retrieved from <https://www.psmarketresearch.com/market-analysis/us-electric-bus-charging-station-market>

41 Prescient & Strategic Intelligence, 2018. One report describes a fast charger that can fully charge a bus in less than 10 minutes. See Eudy et al., 2016.

42 American Petroleum Institute. (2017). *Service station FAQs* [Webpage]. Retrieved from <https://www.api.org/oil-and-natural-gas/consumer-information/consumer-resources/service-station-faqs>

43 Wood, E., Rames, C., Muratori, M., Raghavan, S., and Melaina, M. (2017, September). *National plug-in electric vehicle infrastructure analysis*. Washington, DC: US Department of Energy, Office of Energy Efficiency & Renewable Energy. Retrieved from <https://www.nrel.gov/docs/fy17osti/69031.pdf>

44 Slowik, P., and Lutsey, N. (2017, July). *Expanding the electric vehicle market in U.S. cities*. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

45 Slowik, P., and Nicholas, M. (2017, December). *Expanding access to electric mobility in the United States*. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/Expanding-access-electric-mobility_ICCT-Briefing_06122017_vF.pdf

46 The economics of EV charging stations—that is, whether installation makes economic sense in a given area or circumstance—will partly depend on the utilization rate of the station. We discuss this more fully in the sections on consumer economics and rate design.

Home Charging With Garage Access

Private charging at homes with access to a garage or carport is the most common type among early adopters of EVs. Most vehicles are sold ready to plug into standard (120-volt) wall sockets and with the ability to charge with a Level 2 charger (240 volts), so barriers to charging are lower for drivers in this market segment. Plugging in overnight at home can recharge an EV sufficiently to meet the needs of a typical daily commute.⁴⁷

As EV adoption grows, it will be important for more home vehicle charging to be done with higher-efficiency Level 2 chargers with timers or internet connectivity. These more advanced chargers cost more than Level 1 chargers but will enable faster charging and the ability to control its timing. We discuss the importance of the enhanced functionality of controllable Level 2 charging in greater detail in the section on grid management, beginning on Page 36.

Charging for Those in Multi-Family Housing

Roughly 30 percent of US housing stock is in structures with three or more dwelling units.⁴⁸ In urban areas, this percentage can be much higher. To expand the EV market beyond single-family homes, it will be essential to address the lack of EVSE at multi-unit dwellings, where residents often park in a shared garage or on the street with no dedicated spot.⁴⁹

One option for getting charging infrastructure to this segment of the market is to add charge points to a certain number of parking spaces in existing garages—although the costs of installing charging stations for multi-family dwellings can be high. One California study estimated installation costs of \$5,400 per Level 2 charge point added in such settings.⁵⁰ The costs and uncertainty about usage rates may discourage

landlords or charging providers from investing in this infrastructure. Even where tenants have the desire and ability to cover the costs of installation and use of a charging station in a dedicated parking spot, they may not have the authority to sign off on construction. Some states have passed “right to charge” laws, which make it harder for a property management entity to prevent residents from installing charging stations when certain conditions are met.⁵¹

Low-income and otherwise disadvantaged communities are at risk of being left behind as EV charging infrastructure is built. States may find it appropriate to allow or require regulated utilities to invest in charging infrastructure in these more difficult or underserved areas unless or until the private market does so adequately. Other efforts may prove effective at making electric mobility more accessible to low-income communities and residents of multi-unit dwellings. Increasing access to public and workplace charging options could be a key enabler for these market segments—in particular, installing public curbside charging stations in the areas where multi-family buildings are common. We further discuss considerations for equitable access to electric mobility beginning on Page 53.

Sustained efforts are needed to make EV charging, or other types of electric mobility, available to communities in ways that can best meet their needs. This could mean expanding services like car-sharing and public transit, in addition to strategic placement of private vehicle charging options. EV car-sharing is a way to expand electric mobility to communities that may not need or desire private vehicle ownership. Some programs offer discounted use rates to low-income users.⁵² Expanding the use of e-buses in public transit fleets can also bring the cost-saving and environmental benefits of electrified transportation to a broader resident population.

47 A Brookings Institution study found that the US metro area with the longest average commute is Atlanta, Georgia, with a typical one-way commute of 12.8 miles. Kneebone, E., and Holmes, N. (2015, March). *The growing distance between people and jobs in metropolitan America*. Washington, DC: Metropolitan Policy Program at Brookings. Retrieved from https://www.brookings.edu/wp-content/uploads/2016/07/Srvy_JobsProximity.pdf

48 US Census Bureau. *2012-2016 American Community Survey five-year estimates*. Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_5YR_DP04&src=pt

49 Single-family houses with no dedicated parking—which are common in cities—pose some of the same challenges articulated here.

50 Turek, A., DeShazo, G.M., Siembab, W., and Baum, A. (2017, January). *Assessing the multi-unit dwelling barrier to plug-in electric vehicle adoption in the South Bay*. Sacramento, CA: California Energy Commission. Retrieved from http://southbaycities.org/sites/default/files/ARV-14-035%20ZEV%20MUD%20-%20Final-Draft%20Rpt_0.pdf

51 California, Ontario, Florida, Colorado, and Oregon are examples of jurisdictions that have adopted “right to charge” laws.

52 Los Angeles provides an example. See Spacek, R. (2017, June 9). New L.A. car-sharing service aims to serve low-income neighborhoods. *Los Angeles Times*. Retrieved from <https://www.latimes.com/business/la-fi-bluela-20170609-story.html>

Workplace Charging

The ability to plug in while at work may prove a critical piece of the EVSE development challenge. Research has shown that people are 20 times more likely to buy an EV if there is access to charging at their workplace.⁵³ The workplace conceivably could serve as the primary charging point for drivers without dedicated home charging. It may make sense to consider incentives for workplace charging as a way to support EV adoption by people living in multi-unit dwellings.

Workplace charging could also help integrate larger amounts of midday variable energy resources, particularly solar. As the penetration of solar on the grid continues to grow, EVs represent an opportunity to take advantage of low-cost, low-emissions power.⁵⁴ These benefits could be important considerations when identifying goals for EVSE charging pilot programs and rollout plans.⁵⁵

As with the challenge of developing charging infrastructure for multi-unit dwellings, a challenge for expanding workplace charging may be determining the most appropriate roles for regulated utilities and private entities. In one program design that is being successfully employed, utilities focus on installing EVSE from the distribution transformer up to the charging station but do not own or operate the charging station itself. This approach, referred to as make-ready, has been approved in cases in California and Massachusetts.

Charging in Public Places and Transport Corridors

The right amount of public charging infrastructure will vary by state, population density, the urban or rural setting, and the access drivers have to other types of

The right amount of public charging infrastructure will vary by state, population density, the urban or rural setting, and access to other charging.

charging infrastructure. The International Council on Clean Transportation found that the relationship between public charger availability and EV adoption follows a clear pattern around the world. In cities with a lower rate of private garage ownership, such as Amsterdam and Beijing, the ratio of EVs to each public charge point is lower (in the range of 3 to 5 EVs per charger). In California cities, where residents have greater access to workplace and private home charging, the ratio of EVs to public chargers is higher (25 to 30 vehicles per charger). This is in line with findings from NREL's simulations regarding non-residential charging stations necessary to support widespread adoption of plug-in vehicles.⁵⁶ NREL found that the amount of charging assumed to happen at residential locations is strongly correlated with non-residential infrastructure requirements. In fact, a decrease in the amount of home charging is a determinant of public charging infrastructure needs, even more so than an increase in the total number of electric vehicles on the road.⁵⁷

To date, public charging infrastructure development in the US has been supported by federal, state, and local programs and funding. Volkswagen, under a settlement with the US Environmental Protection Agency, will invest \$2 billion in charging infrastructure over ten years, which will result in several thousand more charge points across the country.⁵⁸ Utilities likely also can play an important role in deploying

53 Olexsak, S. (2014, November 18). *Survey says: Workplace charging is growing in popularity and impact*. US Department of Energy, Office of Energy Efficiency & Renewable Energy. Retrieved from <https://energy.gov/eere/articles/survey-says-workplace-charging-growing-popularity-and-impact>

54 For example, the California Independent System Operator "duck curve," showing the significant drop in net load during the daytime hours on its system, illustrates how much excess solar power could be usefully employed to charge vehicles with cheap, clean power.

55 Significant electricity rate design changes will be needed to support workplace charging to avoid the imposition of demand charges on the portion of charging that occurs during low-cost, low-stress periods. See the rate design discussion beginning on Page 65.

56 Wood et al., 2017.

57 Wood et al., 2017.

58 Trust funds were developed in a settlement with the Environmental Protection Agency because Volkswagen was selling cars in the US with a "defeat device" (or software) in diesel engines that could detect when they were being tested, changing the performance to improve results. Hotten, R. (2015, December 10). *Volkswagen: The scandal explained*. BBC News. Retrieved from <https://www.bbc.com/news/business-34324772>

charging infrastructure that can provide benefits to all rate-payers. California's large investor-owned utilities are deploying various programs and pilots that include public Level 2 and fast charging.⁵⁹ Utilities and regulators in other states are also considering the costs and benefits of ratepayer investments in transportation electrification.

As public charging infrastructure is deployed more widely and EV adoption grows, it will also be important to streamline the user experience of charging. An EV driver today needs to maintain multiple memberships and accounts to access public charging infrastructure operated by different entities. Interoperability would enable drivers to charge at any station with a single payment method, and their usage information could be communicated to the correct entity, similar to the way that roaming charges are included in mobile phone rates.⁶⁰

Charging for Transit Vehicles

EVSE for e-buses will also need to be deployed in a way that recognizes the varying needs of transit users and operators. Bus routes may play a significant role in the siting of

EVSE, because charging at the start or end of a route will be least disruptive to passengers.⁶¹ Further complicating siting is the preference to use buses interchangeably among routes, in part because of the need to comply with federal funding requirements.⁶² Similarly, the type of route may influence the type of EVSE needed: Fast charging may be necessary for short loop routes, such as downtown circulators, where the buses need to run frequently and have comparatively little downtime. In contrast, overnight charging may be adequate for longer routes, where the buses run less often and can spend longer periods charging. These decisions have implications for both the power system and the transit system.

Burlington Electric Department in Vermont, for example, has proposed to charge its electric buses overnight.⁶³ Furthermore, it intends to automate and synchronize the process so that as one bus stops charging, the next one immediately begins.⁶⁴

Collaboration between local transit agencies and the utilities that serve them can identify potential constraints and solutions that work for both the power and transit systems.

59 For more information on California utilities' transportation electrification activities, see California Public Utilities Commission. *Transportation electrification activities pursuant to Senate Bill 350* [Webpage]. Retrieved from <http://www.cpuc.ca.gov/sb350te/>

60 A coalition of the three largest charging networks in the US (Blink, ChargePoint, and NRG eVgo), along with two of the largest EV manufacturers (BMW and Nissan), is endeavoring to address this issue. Their group is called ROEV and aims to create a universal network that lets someone with a charging card from any member network charge at any other network location. They liken this to bank cards allowing users to withdraw money from any ATM. Electrify America is also working with EV Connect, Greenlots, and SemaConnect to enable network sharing among all of its members. See Descant, S. (2018, October 30). EV charging infrastructure moves toward interoperability. *FutureStructure*. Retrieved from <http://www.govtech.com/fs/transportation/EV-Charging-Infrastructure-Moves-Toward-Interoperability.html>

61 Based on personal communication with Geoffrey Hobin, Transit Authority of River City, December 19, 2018, and with Carrie Butler, Lextran, November 19, 2018.

62 To comply with federal funding requirements, such as Title VI of the Civil Rights Act, public transit agencies may seek to rotate buses between routes so as to ensure older, more polluting buses are not disproportionately used in disadvantaged communities. See Federal Transit Administration. *Title VI of the Civil Rights Act of 1964* [Webpage]. Retrieved from <https://www.transit.dot.gov/title6>

63 Lyle, T. (2018). *A pathway to decarbonizing public transit*, p. 6-10. Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from <https://aceee.org/files/proceedings/2018/#/paper/event-data/p188>

64 This strategy of charging vehicles in sequence rather than all at once, if feasible for a transit agency, may offer a way to avoid paying more significant demand charges. We explore issues of rate design beginning on Page 65.

Meeting the Conditions for Beneficial Electrification

Electrified transportation has the ability to save consumers money, make the grid more flexible, and reduce carbon emissions.

As noted previously, electrification is beneficial only if it satisfies at least one of the following criteria without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

In this section, we look at the circumstances under which the adoption of passenger vehicles and electric buses meets these conditions.

Consumer Economics

The first of the three conditions of BE is that it benefits consumers economically. This means that end-use consumers—such as individuals, municipal transit companies, or companies with a fleet of trucks—will save money over the lifetime of an investment as compared with the alternative they would otherwise use. Whether electrification will be beneficial from a consumer cost-effectiveness standpoint depends on the situation.

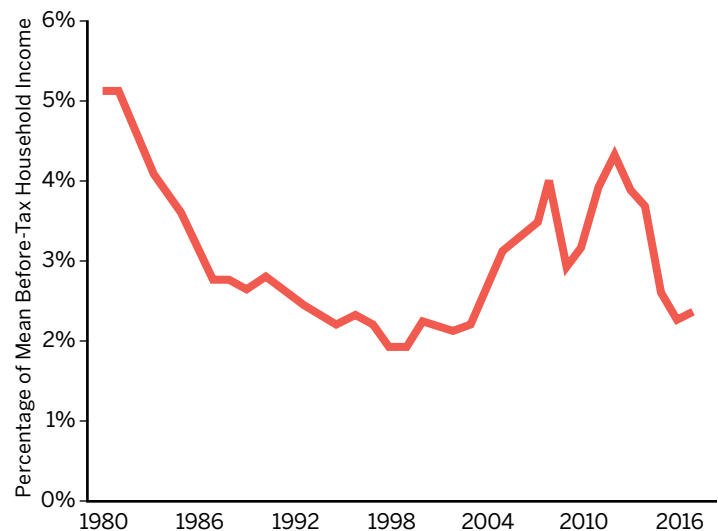
Factors Affecting Economics

Although EVs are a promising means of cost-effective transportation, a number of factors affect the suitability of their adoption. Before looking at consumer costs for EVs, we describe some of the factors driving the economics of consumer decisions to switch from internal combustion engine vehicles to EVs.

1. **Housing type** can influence the decision to purchase an EV. Without a place to charge it, a consumer will face a significant barrier to switching to an EV.
2. **Installed cost of EVSE** may be a fraction of the overall cost of an EV, but it could strongly influence consumer adoption. If an EV costs more than an ICE alternative, in order for the economics to work consumers will need to save money on operating costs and maintenance over its

Although EVs are a promising means of cost-effective transportation, a number of factors affect the suitability of their adoption.

Figure 6. Average Household Spending on Gasoline



Source: US Energy Information Administration. (2017, October 6). *U.S. Household Spending for Gasoline is Expected to Remain Below \$2,000 in 2017*.

lifetime, including the life of the charging equipment.

The incremental difference in cost between an EV (including the charger) and the alternative will also affect the reasonableness and ability of utility programs to provide incentives to overcome price differentials.

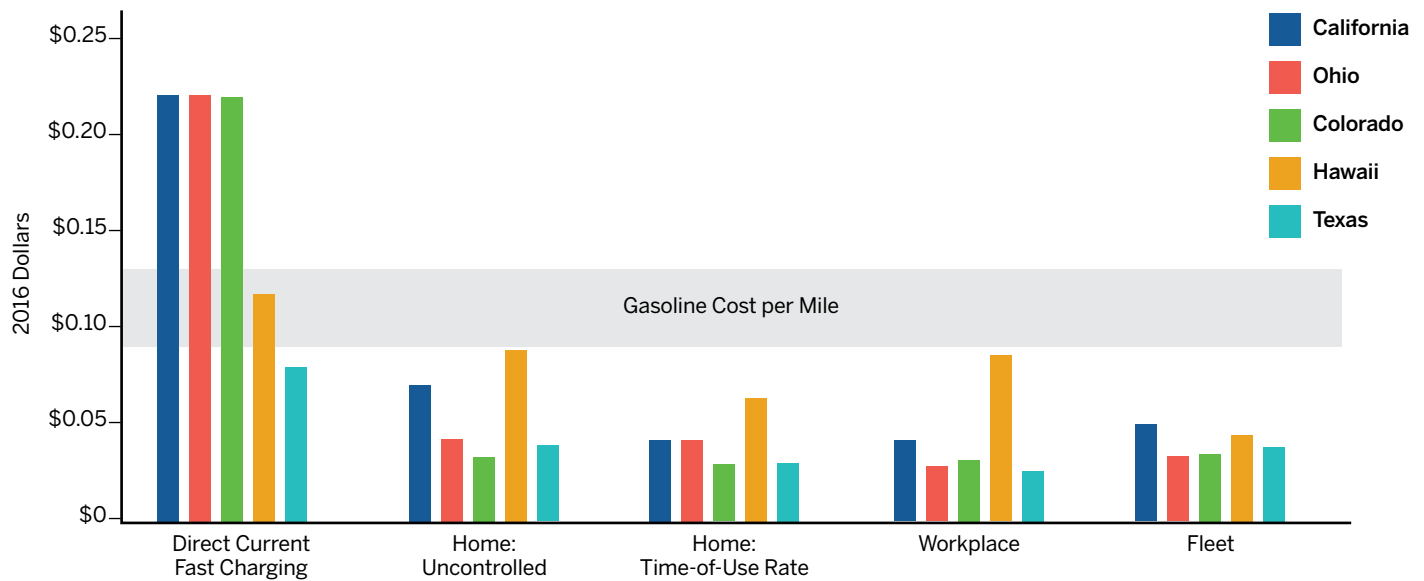
3. **The cost of energy** generally affects whether electrification, whatever the context, makes sense for consumers.⁶⁵ As illustrated in Figure 6, households in 2016 on average spent between 2 and 3 percent of their pretax income on gasoline.⁶⁶

According to the Union of Concerned Scientists (UCS), broader transportation-related costs constitute the second largest expense for many Americans.⁶⁷ While a typical

65 The Environmental Protection Agency assumes that one gallon of gas contains 115,000 Btu of energy and that it equates to 33.7 kilowatt-hours. See US Environmental Protection Agency. Technology: Learn more about technology assumptions in the Choose a Path tool. *Green Vehicle Guide*. Retrieved from <https://www.epa.gov/greenvehicles/technology-learn-more-about-technology-assumptions-choose-path-tool>

66 US Energy Information Administration. (2017, October 6). US household spending for gasoline is expected to remain below \$2,000 in 2017. *Today in Energy*. Retrieved from <https://www.eia.gov/todayinenergy/detail.php?id=33232>

67 Goldman, J. (2017). *Fuel efficiency, consumers, and income*. Cambridge, MA: Union of Concerned Scientists. Retrieved from https://www.ucsusa.org/clean-vehicles/electric-vehicles/fuel-economy-low-income#.W_K-2ug3k2w

Figure 7. Retail Cost to Charge 1 Mile of EV Range in Different Settings

Source: Fitzgerald, G., and Nelder, C. (2017). *From Gas to Grid: Building Charging Infrastructure to Power Electric Vehicle Demand*.

middle-income household might spend about 20 percent of its income on transportation, low-income consumers spend about 30 percent of their total income on the same thing.⁶⁸ UCS also notes that low-income households spend more on fuel than on vehicle purchases, meaning that any fuel savings would be more significant for them.

EV owners, unlike ICE vehicle owners, have various options in how they fuel up. Where a car is charged, at what time of day, under what specific electricity rate, and with what type of charger will affect how much the owner pays. Rocky Mountain Institute (RMI) looked at charging costs in five states: California, Colorado, Hawaii, Ohio, and Texas. It found that the cost to charge an EV can be as high as 22 cents per mile and as low as 3 cents per mile, “while the cost of fueling a gasoline vehicle varies in a much narrower band” between 9 and 13 cents per mile.⁶⁹ Figure 7 illustrates these findings.⁷⁰ In addition to energy costs at the time of purchase, projected changes in costs of electricity and other fuels over the life of the vehicle are useful when considering the total costs of ownership for

different options. But these projections, by their nature, are uncertain.

4. **Imperfect information** hinders the ability to make sound economic decisions. The value of some benefits of EVs is difficult to determine precisely, and this can make it harder for a consumer to understand the full costs and benefits. For example, given their superior efficiency, EVs should produce fuel savings, but exactly how much will depend on the ICE vehicle miles being avoided and the electricity cost of charging.⁷¹ RMI posits a number of benefits in addition to fuel cost savings, as illustrated in Figure 8.⁷²

There is a similar challenge related to maintenance costs. EVs share many similar parts with ICE vehicles, such as suspension and tires. But because EVs have dramatically fewer drivetrain parts, they have fewer components to break down. They are, therefore, less likely to need as much maintenance as ICE vehicles, which have components like the engine, transmission, radiator, and timing belt. We know that we pay for maintenance of our ICE vehicles, but exactly how much is hard to estimate.

68 Goldman, 2017.

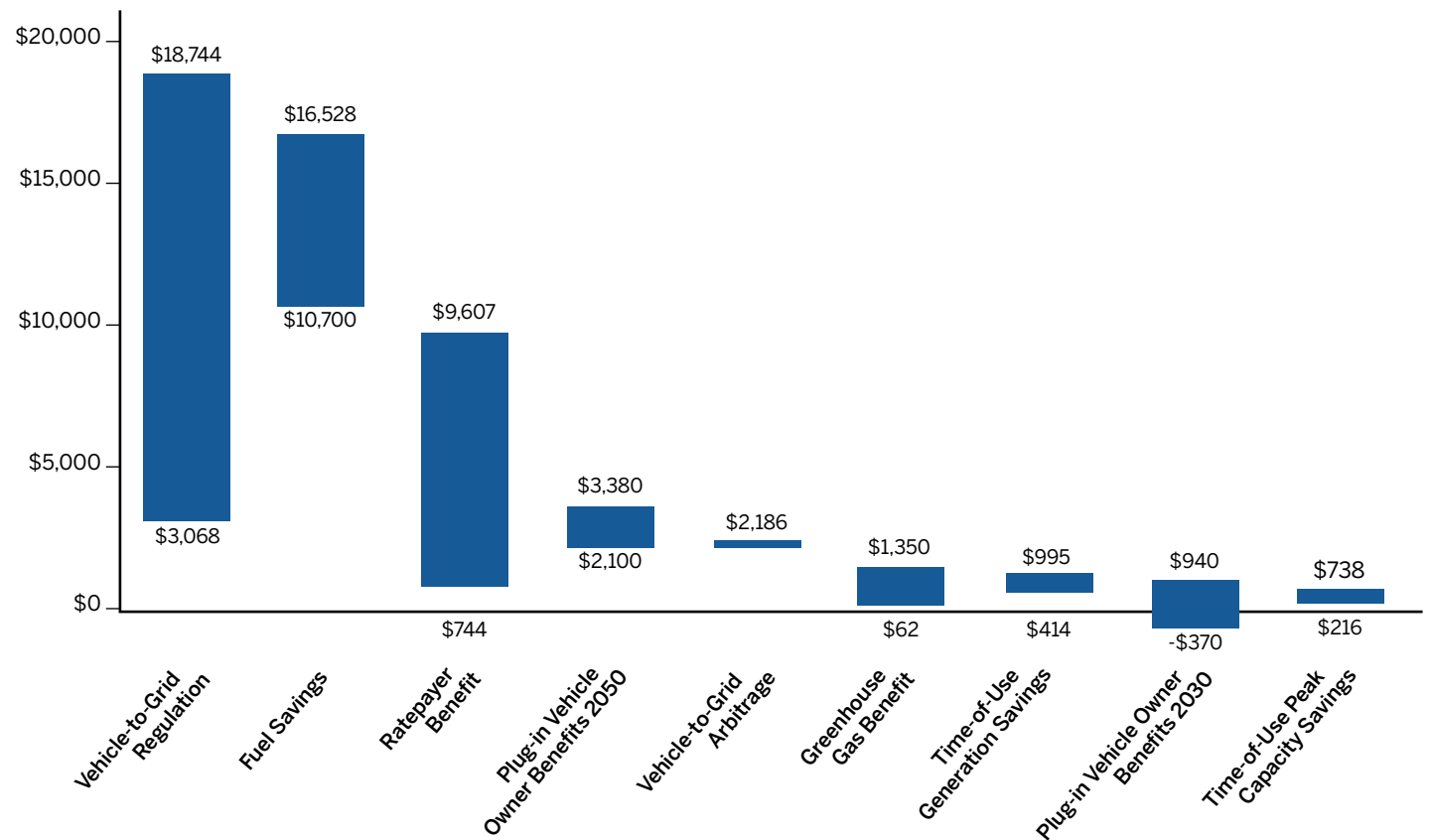
69 Fitzgerald and Nelder, 2017.

70 Fitzgerald and Nelder, 2017.

71 US Department of Energy. (2015, September 16). *Saving money with electric vehicles* [Webpage]. Retrieved from <https://www.energy.gov/energysaver/articles/saving-money-electric-vehicles>

72 Fitzgerald and Nelder, 2017.

Figure 8. Stakeholder Benefits During the Lifetime of Each Electric Vehicle



Source: Fitzgerald, G., and Nelder, C. (2017). *From Gas to Grid: Building Charging Infrastructure to Power Electric Vehicle Demand*.

Current Economics of Light-Duty EVs

To calculate the cost-effectiveness of EVs, it is important to evaluate the total cost of ownership (TCO), as it is an important economic criterion for consumers. A TCO calculation gathers direct and indirect costs a consumer will pay over the lifetime of a good or service, illustrating its true cost. Comparing the TCO of an EV versus an ICE vehicle requires a comparison of the costs of capital, maintenance, and fuel; residual value; and other values.⁷³ TCO provides a useful perspective because it endeavors to clarify all costs, not just the sticker price.⁷⁴

In 2015, researchers from the University of Leeds in

England tracked the TCO of selected low-emissions vehicles between 1997 and 2015 in Japan, the UK, California, and Texas.⁷⁵ They looked at examples of hybrid electric vehicles, plug-in hybrid EVs, battery electric vehicles, and ICE vehicles. The TCO assessment in the Leeds study includes the vehicle’s initial cost; depreciation; annual fuel cost; annual mileage; fuel efficiency; and annual maintenance, insurance, taxes, and subsidies.⁷⁶ The study concluded that the largest difference in TCO between an electric vehicle and a fossil-fueled vehicle is the cost of a battery. Figure 9 on the next page illustrates the breakdown of costs the study found.⁷⁷

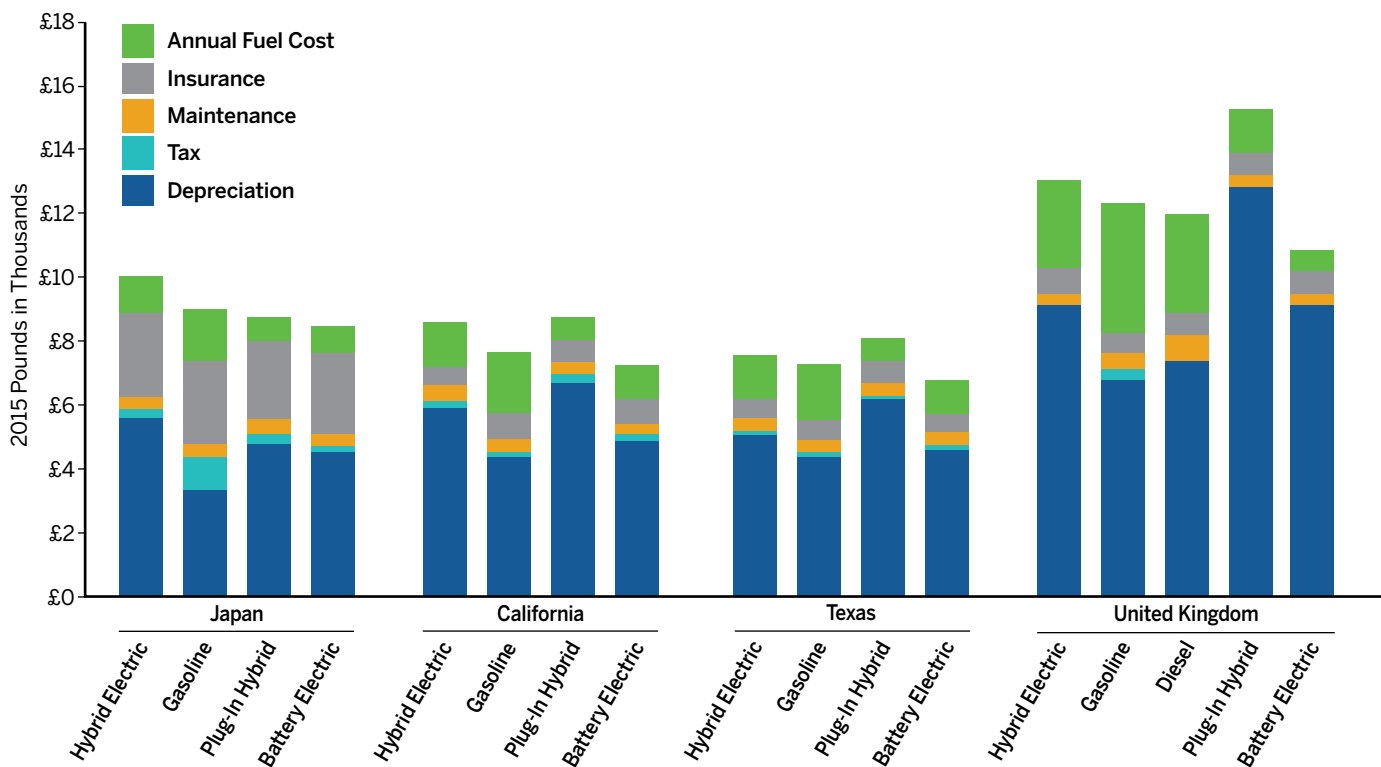
73 Palmer, K., Tate, J., Wadud, Z., and Nellthorp, J. (2018, January 1). Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. *Applied Energy*, 209, 108-119. Retrieved from <https://www.sciencedirect.com/science/article/pii/S030626191731526X?via%3Dihub>

74 Ellram, L. (1995, October). Total cost of ownership: An analysis approach for purchasing. *International Journal of Physical Distribution and Logistics Management*, 25(8), 4-23. Retrieved from https://www.researchgate.net/publication/235292888_Total_Cost_of_Ownership_An_Analysis_Approach_for_Purchasing

75 Palmer et al., 2018.

76 Palmer et al., 2018. TCO was also calculated assuming the following average annual mileage for each of the four regions: 6,213 miles for Japan, 10,400 for the UK, 11,071 for California, and 15,641 for Texas.

77 Palmer et al., 2018.

Figure 9. Total Cost of Vehicle Ownership in Four Regions

Source: Palmer, K., Tate, J.E., Wadud, Z., and Nellthorp, J. (2018, January). *Total Cost of Ownership and Market Share for Hybrid and Electric Vehicles in the UK, US and Japan.*

The Leeds study found that in all four regions surveyed, the incremental cost of hybrid and battery electric vehicles over internal combustion vehicles declined between the year each car was introduced and 2015. This was due, in large part, to fuel and operating costs as well as savings on taxes and maintenance.

Although EVs have higher sticker prices than ICE vehicles, the study found that the price premium of these new technologies “can often be offset by lower running costs.”⁷⁸ The study also found that, in 2015, battery electric vehicles were cheaper than ICE alternatives due to fuel costs and policy supports in all four regions. However, due to the continued need for traditional fuel and the receipt of less policy support, hybrid EVs in all regions still had a higher

TCO than internal combustion vehicles.

In 2017, UBS estimated TCO parity between electric and internal combustion vehicles in the United States and the EU, using the Chevrolet Bolt and Volkswagen Golf as proxies.⁷⁹ Due primarily to higher fuel prices in Europe, UBS estimated that parity there had already been reached, but not yet in the US (see Figure 10).⁸⁰

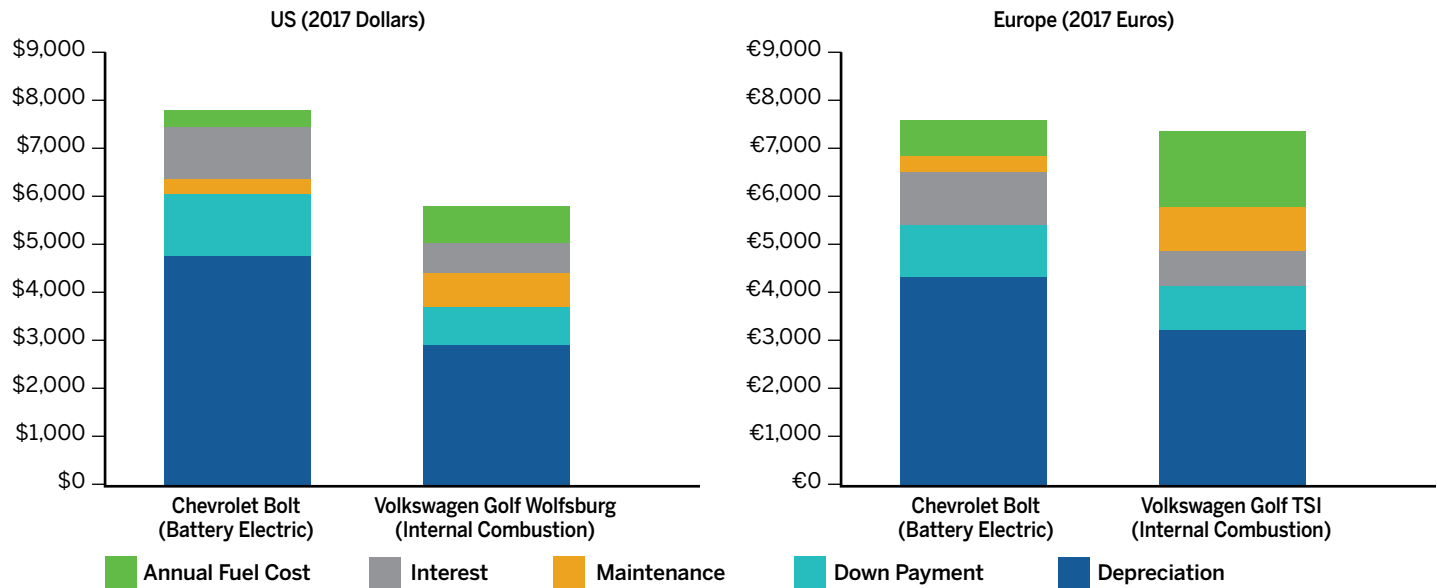
UBS uses the term “true cost parity” to describe the point at which the manufacturer, such as General Motors, also earns a 5 percent margin before interest and taxes. To project the year when true cost parity occurs, UBS tied the Bolt’s sticker price to the annual expected decline in the cost for General Motors to produce it.⁸¹

78 Palmer et al., 2018, abstract.

79 TCO parity estimates exclude any EV purchase incentives or other subsidies. UBS, 2017. For a further definition of total cost of ownership, see UBS, 2017, p. 10 and Appendix.

80 UBS, 2017, p. 10, Figures 16 and 17.

81 UBS, 2017. The expected decline in production costs is based on UBS’ forecast of 2025 prices for Bolt components, including batteries. The projected cost decline is about \$1,100 a year. As the Bolt’s costs drop due to manufacturing improvements, General Motors’ profits will increase and at some point will reach 5 percent. For the Volkswagen Golf, UBS assumes inflation of 0.5 percent and a 2 percent increase in fuel efficiency per year.

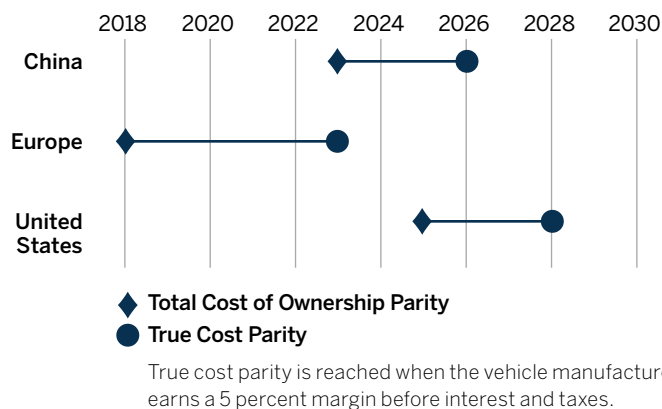
Figure 10. Total Cost of Vehicle Ownership in US and Europe

Source: UBS Evidence Lab Electric Car Teardown—Disruption Ahead? © UBS 2018. All rights reserved. Reproduced with permission.

UBS estimated that true cost parity between the two vehicles will be reached in 2023 in Europe, 2026 in China, and 2028 in the US, as illustrated by Figure 11.⁸² When characterizing cost parity without regard for manufacturer profit margin, UBS projected that TCO parity would occur sooner: in 2018 in Europe, 2023 in China, and 2025 in the US.

These two studies examining the economics of EVs versus ICE vehicles point to common factors including component

costs, fuel costs, and policy-related incentives. The Leeds study found the potential for lower running costs to offset the price premium of EVs. UBS' conclusions about TCO parity, under both its definitions, are likewise contingent on component and fuel costs and assumptions about the effects of inflation and improved fuel efficiency of ICE vehicles. It is also worth remembering that infrastructure costs in this new market will initially be shared by relatively few EV owners but will be spread more broadly as the market grows. That means the per-unit cost of charging will go down as the e-transportation market develops.

Figure 11. Battery Electric Vehicles Expected to Reach Cost Parity in Ten Years

Source: Adapted from UBS Evidence Lab Electric Car Teardown—Disruption Ahead? © UBS 2018. All rights reserved. Reproduced with permission.

Consumer Economics of Electric Buses

The available data suggest that the consumer economics of e-buses will be dominated by high upfront costs but also savings opportunities from lower operating costs. For example, in its *Electrification Futures Study*, NREL develops projections for the e-bus subsector based in part on estimates from manufacturer Proterra and on analyses developed by the California Air Resources Board (CARB). In its “moderate advancement” scenario,⁸³ NREL assumes a bus with a 330-kWh battery and a 238-mile range.⁸⁴ NREL also assumes that a DCFC capable of

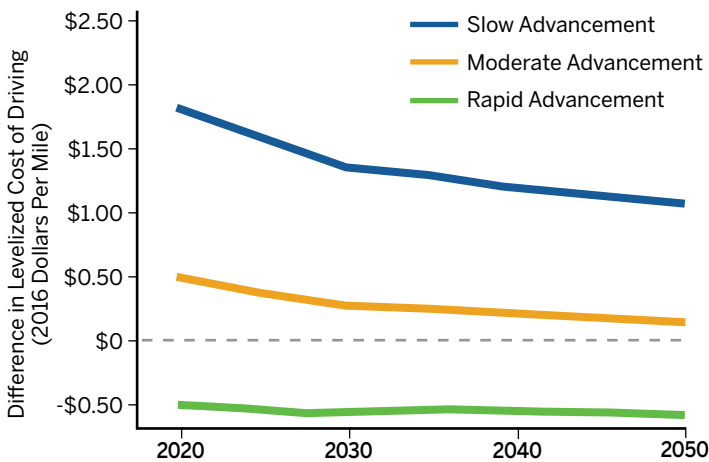
82 Adapted from UBS, 2017, Figure 4.

beyond what is assumed in the “slow advancement” case.

83 NREL’s “moderate advancement” sensitivity analysis assumes a moderate amount of additional research and development and technology innovation,

84 Jadun et al., 2017, Table 7.

Figure 12. Projected Cost of Driving Battery Electric Bus vs. Diesel Bus



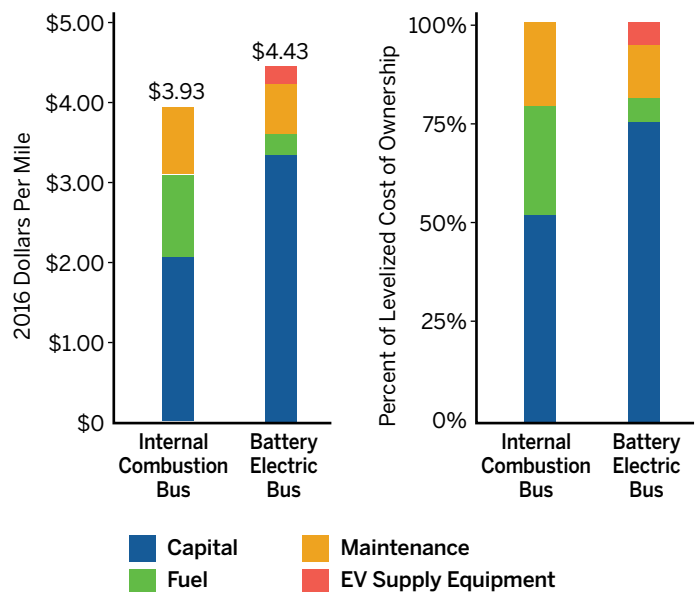
Source: Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L., and Mai, T. (2017). *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections Through 2050*.

350 kilowatts (kW) is required to support the duty cycles expected for buses. As shown in Figure 12,⁸⁵ the levelized cost of driving for buses does not go below that of a comparable diesel vehicle by 2035 in the moderate advancement case, although it does under the “rapid advancement” case.⁸⁶

Figure 13⁸⁷ depicting NREL’s assessment of the levelized cost of driving for an e-bus demonstrates that upfront cost is by far the largest component (75 percent) and is likely to be the central investment challenge. However, while only a quarter of e-bus cost is associated with fuel and maintenance, these two components account for 50 percent of ICE bus costs. Given that these elements represent a larger portion of overall ICE bus costs, any uncertainties (such as oil price volatility or the effects of future carbon regulation) would have a far greater effect on the future cost of ICE buses.

Moreover, according to CARB data, maintenance costs for electric buses are lower than for diesel buses: 19 cents a mile less for battery electric models and 11 cents less for hybrids.⁸⁸ New CARB maintenance data that weren’t available for inclusion in NREL’s *Electrification Futures Study* illustrate significant

Figure 13. Breakdown of Levelized Cost of Driving in 2020



Note: Costs are calculated based on moderate technology advancement as defined in source material.

Source: Based on Jadun, P., McMillan, C., Steinberg, D., Muratori, M., Vimmerstedt, L., and Mai, T. (2017). *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050*.

differences in overall cost per mile for different buses: 18 cents (electric), 32 cents (diesel hybrid), and 44 cents (diesel).⁸⁹

To determine fuel use and greenhouse gas emissions for different bus technologies and fuel types, CARB has also established an estimated energy efficiency ratio for buses. Recent tests show that the efficiency of battery electric vehicles is considerably higher than that of conventional vehicles for different weight classes, vehicle types, and duty cycles. The data show a vehicle efficiency about 3.5 times that of conventional diesel vehicles at highway speeds, and efficiencies 5 to 6 times that of diesel when operated at lower-speed duty cycles where idling and coasting losses from conventional engines are highest.⁹⁰

CARB characterized TCO for e-buses purchased in 2016, relying on data from buses manufactured by Build Your Dreams with onboard charging, a 12-year battery warranty, and Low

85 Based on Jadun et al., 2017, Figure 16.

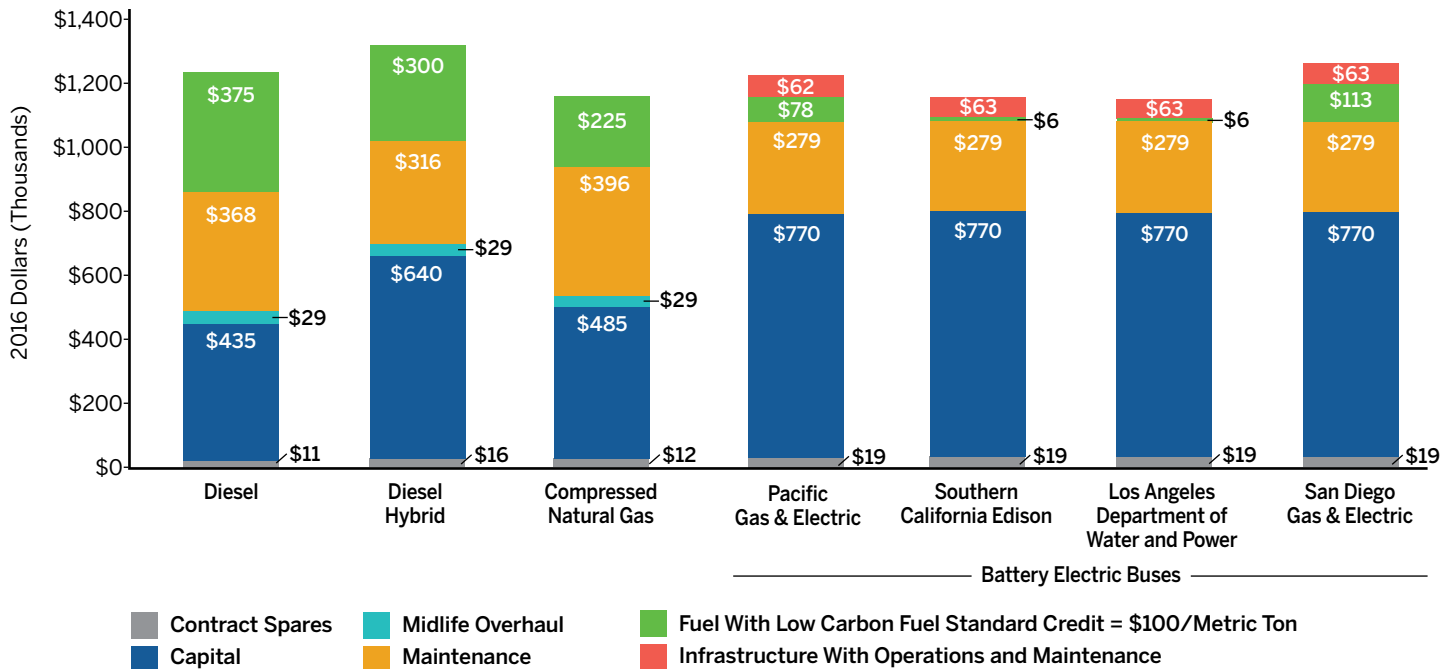
86 The “rapid advancement” case assumes specifications based on the E2 Max model from Proterra. Jadun, et al., 2017, citing Proterra. (2017). *Proterra Catalyst 40-foot transit vehicle*. NREL also explains that the rapid advancement projections “are consistent with futures in which public and private research and development (R&D) investment in electric technologies spurs technology innovations, manufacturing scale-up increases production efficiencies, and consumer demand and public policy yields technology learning.” Jadun et al., 2017, p. 3.

87 Based on Jadun et al., 2017, Figure 13.

88 California Air Resources Board. (2017, June 26). *5th Innovative Clean Transit workgroup meeting* [Presentation]. Retrieved from https://arb.ca.gov/msprog/ict/meeting/mt170626/170626_wg_pres.pdf

89 California Air Resources Board, 2017.

90 California Air Resources Board. (2017, April 24). Discussion draft, cited in CARB, 2017, June.

Figure 14. Total Cost of Ownership for Battery Electric Bus Purchased in 2016

Source: Based on California Air Resources Board. (2017, June 26). *5th Innovative Clean Transit Workgroup Meeting*.

Carbon Fuel Standard credits.⁹¹ Figure 14 illustrates the findings for the four California utility service areas examined.⁹² E-buses in two of the four areas already had lower TCOs than the buses fueled by compressed natural gas (CNG) that were analyzed. E-buses in three of the four areas had lower TCOs than the diesel buses used for comparison. And e-buses in all four areas had lower TCOs than the diesel hybrid buses analyzed.

BNEF also analyzed the TCO of e-buses in 2018, and its report acknowledges that many factors affect the analysis.⁹³ When comparing e-buses with those fueled by diesel or CNG, BNEF notes that the result will be heavily dependent on whether refueling infrastructure is part of the calculation. Where new

diesel or CNG refueling infrastructure is included, BNEF assumes per-bus costs of \$91,600 for diesel and \$40,000 for CNG.⁹⁴ The analysis also assumes three driving distances that correspond to a small, medium, or large city. For a diesel bus traveling 30,000, 60,000, or 80,000 kilometers a year, the cost per kilometer would be \$1.80, \$1.16, and 99 cents, respectively. For a CNG bus it would be \$1.93, \$1.23, and \$1.06 per kilometer.⁹⁵

In characterizing efficiencies, BNEF models three types of e-bus⁹⁶ and assumes various charging configurations.⁹⁷ As illustrated in Figure 15 on the next page, the TCO for e-buses used in the analysis decreases more rapidly than for diesel buses in proportion to the distances traveled.⁹⁸

91 The Low Carbon Fuel Standard is designed to encourage the use of cleaner low-carbon fuels in California, foster their production, and, therefore, reduce greenhouse gas emissions. California Air Resources Board. (2018, November 26). *Low carbon fuel standard* [Webpage]. Retrieved from <https://www.arb.ca.gov/fuels/lcfs/lcfs.htm>

92 Based on California Air Resources Board, 2017, June, p. 40.

93 BloombergNEF. (2018, March 29). *Electric buses in cities driving towards cleaner air and lower CO₂*. Retrieved from <https://about.bnef.com/blog/electric-buses-cities-driving-towards-cleaner-air-lower-co2/>

94 For the diesel refueling infrastructure cost assumptions, the report cites the AFLEET Tool 2016, Argonne National Laboratory. CNG refueling infrastructure

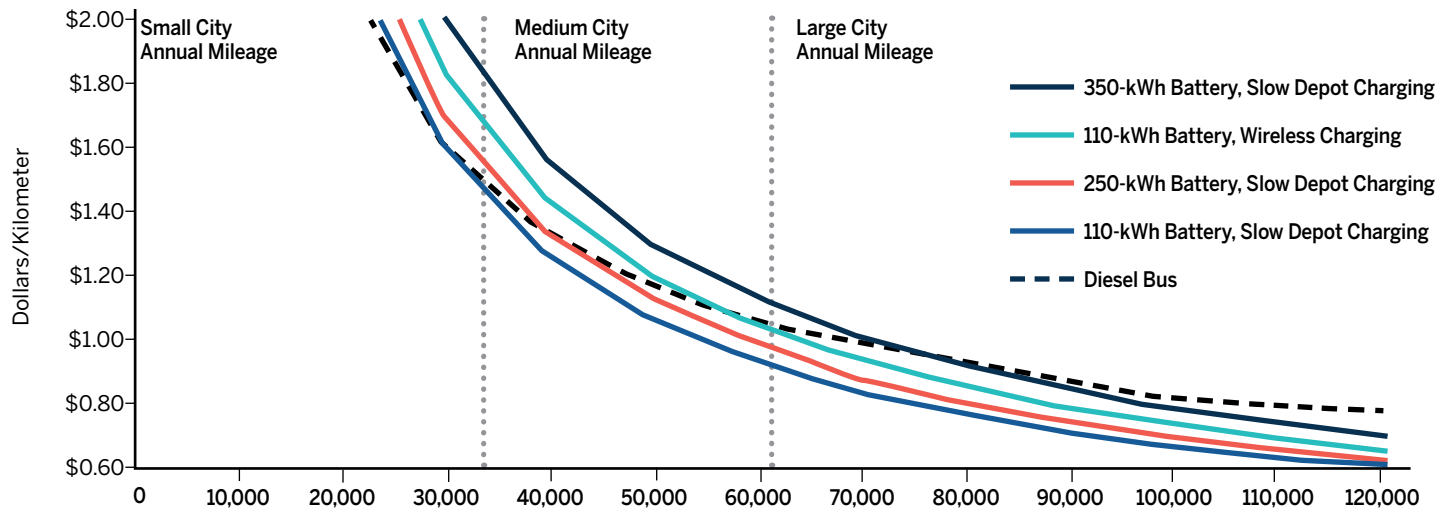
cost assumptions are attributed to CARB.

95 BloombergNEF, 2018, March, p. 33.

96 They are a 350-kWh e-bus, 0.48 miles per kWh, upfront cost of \$700,000; a 250-kWh e-bus, 0.50 miles per kWh, upfront cost of \$570,000; and a 110-kWh e-bus, 0.52 miles per kWh, upfront cost of \$530,000.

97 Slow depot charging at \$50,000 per charger; fast terminal charging at \$110,000; pantograph charging at \$230,000 per pantograph; and wireless charging at a bus stop at \$400,000.

98 BloombergNEF, 2018, March.

Figure 15. Total Cost of Ownership for Electric Buses Decreases as Annual Mileage Increases

Notes: Diesel price at \$0.66/liter (\$2.50/gallon), electricity price at \$0.10/kWh, annual kilometers traveled — variable.
Bus route length will not always correspond with city size.

Source: Based on BloombergNEF. (2018, March 29). *Electric Buses in Cities Driving Towards Cleaner Air and Lower CO₂*.

BNEF found that the TCO of several e-buses drops below that of diesel and CNG buses when the annual distance traveled increases to 60,000 kilometers. Large cities with high bus mileage have the greatest flexibility to choose from a number of e-bus options, all of which are cheaper than diesel and CNG buses. The report notes:

In a megacity, where buses travel at least 220km/day, using even the most expensive 350-kWh e-bus instead of a CNG bus could bring around \$130,000 in operational costs savings over the 15-year lifetime of a bus.⁹⁹

Although adopting EVs may not be immediately feasible or even economically suitable in all circumstances, such evidence suggests there are many scenarios under which these investments can yield economic benefits. As discussed here, it is important to understand the TCO as well as other factors that can affect one's investment choices when making the case for

The cost of ownership for several e-buses drops below that of diesel and compressed natural gas buses when the annual distance traveled increases.

economic investment in EVs. For e-buses, although the upfront cost challenge will continue to be significant compared with ICE vehicles, their operational savings should be a key factor in determining their TCO economics.

Grid Management

The second BE condition is that electrification helps in managing the grid. EV charging demand can be controlled—through smart charging, time-of-use (TOU) pricing,¹⁰⁰ or a combination of both—meaning it can become an important tool and add flexibility to the grid.^{101, 102} The charging of individual

99 BloombergNEF, 2018, March.

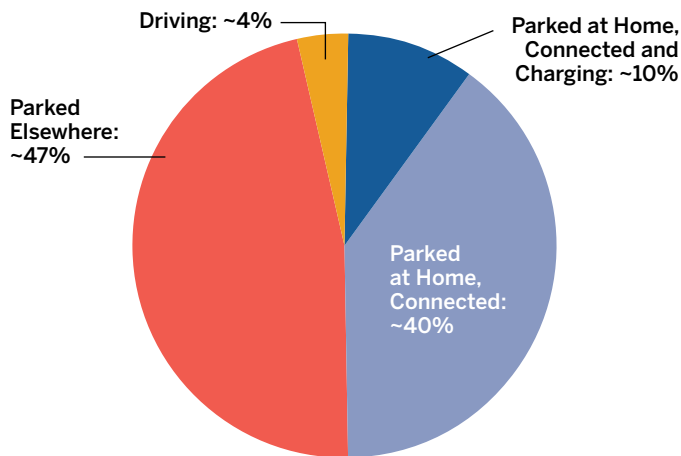
100 Another key to grid management is rate design, discussed beginning on Page 65.

101 Flex EV load can help reduce peak demand and, as a result, the need for investment in incremental generation, transmission, and distribution resources. Stern, F. (2013). Peak demand and time-differentiated energy savings cross-cutting protocols. In *The Uniform Methods Project: Methods for determining energy efficiency savings for specific measures* (NREL/SR-

7A30-53827). Golden CO: National Renewable Energy Laboratory. Retrieved from <https://www.energy.gov/sites/prod/files/2013/05/10/53827-10.pdf>

102 The various ways that EVs can provide grid services are sometimes referred to using the expression "vehicle-grid integration." For further information, see California Independent System Operator Corp. (2014, February). *California vehicle-grid integration (VGI) roadmap: Enabling vehicle-based grid services*. Folsom, CA: Author. Retrieved from <https://www.caiso.com/Documents/Vehicle-GridIntegrationRoadmap.pdf>

Figure 16. Electric Vehicles' Low Capacity Utilization Makes Them Potential Grid Resource



Source: Langton, A., and Crisostomo, N. (2013, October). *Vehicle-Grid Integration: A Vision for Zero-Emission Transportation Interconnected Throughout California's Electricity System*.

EVs or fleets of them can be optimized to avoid or minimize adverse grid effects and investment costs and to take advantage of lower-cost and cleaner production times for electricity.

Electricity grids utilize various flexibility tools to ensure the system can respond to variations in load. EVs can be included on that list. The California Public Utilities Commission (CPUC) identified three characteristics that make EVs potential grid resources.¹⁰³ These vehicles:

1. Provide operational flexibility because they possess a dual

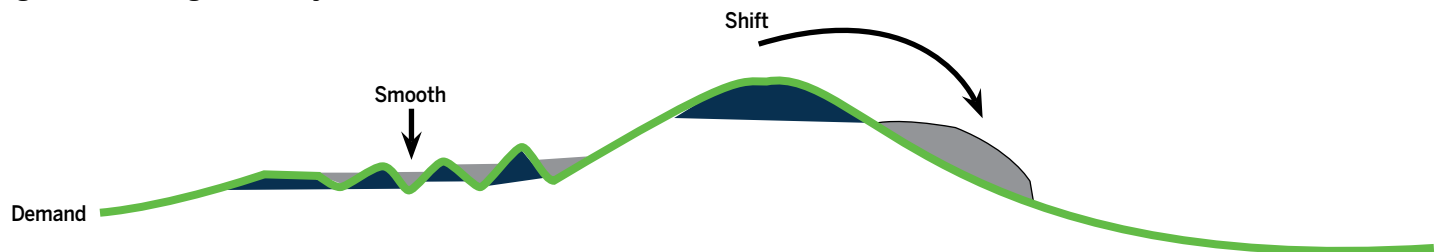
functionality of load (while charging) and generation (while discharging stored energy back to the grid);

2. Have embedded communications and actuation technology because auto manufacturers have built digital controls into vehicles; and
3. Have low capacity utilization, being idle more than 95 percent of the time and needing to charge only about 10 percent of the time. Figure 16 illustrates this quality.¹⁰⁴

An EV's load is inherently flexible because capacity utilization is low and charging does not need to occur at the same time the vehicle is being used. This allows for the shaping (that is, smoothing) and shifting of that load to meet grid conditions. This is illustrated in Figure 17 by moving load from peaks to times of lower demand.¹⁰⁵ EVs are also capable of responding quickly to a signal.¹⁰⁶ So, not only are they flexible over the course of the day but also within minutes and seconds.¹⁰⁷

As noted above, the growing percentage of variable energy resources like solar and wind generation on the grid means that system operators increasingly need to focus on meeting net load—the difference between forecast load and the amount of load met by intermittent resources.¹⁰⁸ Just as EV load can be shifted away from system peaks to cheaper hours, it can also be moved to times when variable renewable energy resources are more available. This can reduce the need to curtail renewables, increase the use of non-carbon

Figure 17. Shifting Electricity Demand



Source: © E Source, adapted from Integral Analytics Inc.

¹⁰³ Langton and Crisostomo, 2013.

¹⁰⁴ Langton and Crisostomo, 2013, Figure 2.

¹⁰⁵ Podorson, D. (2014, September). *Battery killers: How water heaters have evolved into grid-scale energy-storage devices*. E Source. Retrieved from <https://www.esource.com/ES-WP-18/GIWHs>

¹⁰⁶ EVs and their batteries are particularly good at providing fast-response services to discharge stored electricity into the grid.

¹⁰⁷ Fitzgerald, G., Nelder, C., and Newcomb, J. (2016, June). *Electric vehicles as distributed energy resources*. Boulder, CO: Rocky Mountain Institute. Retrieved from http://www.rmi.org/pdf_evs_as_DERs

¹⁰⁸ Colburn, K. (2017, January 24). Beneficial electrification: A key to better grid management [Blog post]. Regulatory Assistance Project. Retrieved from <https://www.raponline.org/blog/beneficial-electrification-a-key-to-better-grid-management/>. Grid operators now recognize that active efforts on the demand side can help meet today's balancing challenges. Colburn, K. (2017, February 1). Beneficial electrification: A growth opportunity [Blog post]. Regulatory Assistance Project. Retrieved from <https://www.raponline.org/blog/beneficial-electrification-a-growth-opportunity/>

resources, and save consumers money while still ensuring that their EV is adequately charged when they need it.

Increased amounts of renewable energy are being produced across the country but are often curtailed.¹⁰⁹ Figure 18 illustrates these trends.¹¹⁰ In 2016, the Electric Reliability Council of Texas curtailed more than 800 gigawatt-hours of wind energy, or about 1.6 percent of its total potential wind generation. In the same year, the Midcontinent Independent System Operator curtailed more than 2,000 gigawatt-hours of wind power, or about 4.3 percent of its total wind energy potential.¹¹¹

By moving EV charging to times and locations associated with renewable energy curtailment, grid managers can help reduce the thousands of gigawatt-hours of electricity from existing variable energy resources that are being wasted.

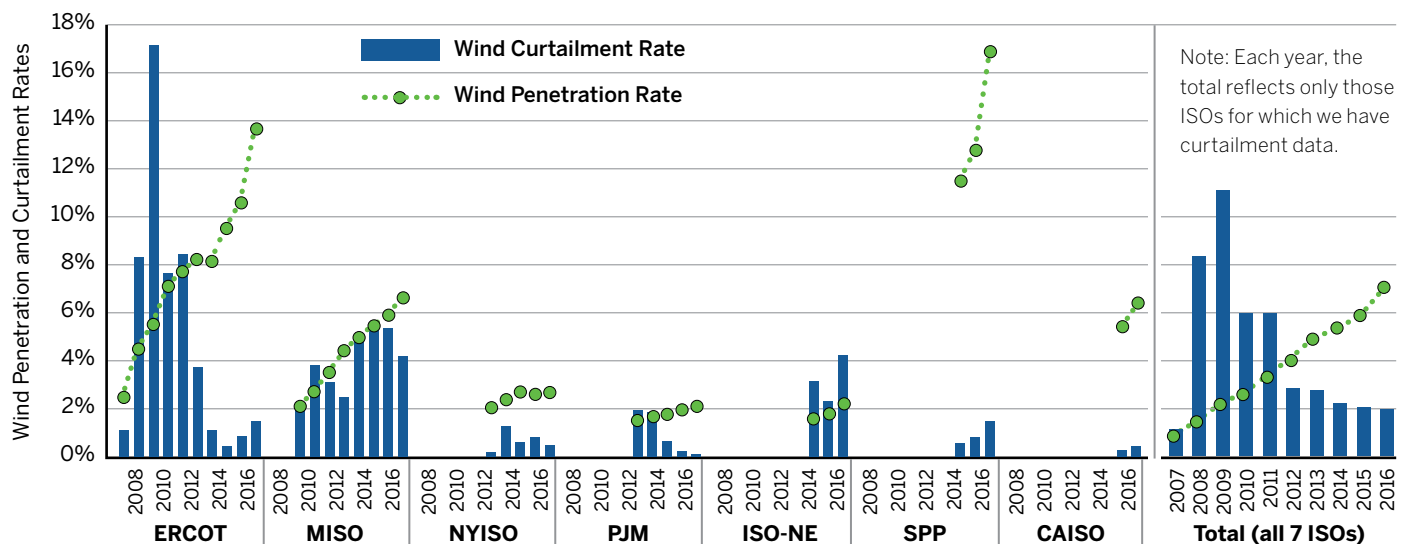
Just as EV load can be shifted from system peaks to cheaper hours, it can also be moved to times when variable renewable energy resources are more available.

Demand Response

When one considers the potential grid management support that EVs can provide, the usual definitions of smart charging and demand response blur slightly. What we refer to as grid management has much in common with smart charging, which Dale Hall and Nic Lutsey define as any “program that manages electric vehicle charging to promote grid stability or more efficient resource usage.”¹¹²

Grid management also has a lot in common with demand response—not just the traditional view of demand response

Figure 18. Wind Penetration and Curtailment



Note: All curtailment percentages shown represent both forced and economic curtailment.

PJM's 2012 curtailment estimate is for June through December only.

Source: Wiser, R., and Bolinger, M. (2017). *2016 Wind Technologies Market Report*.

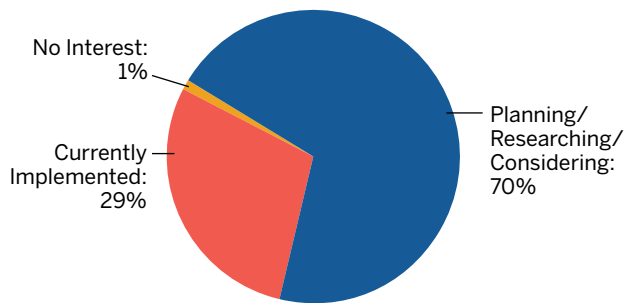
109 "Curtailment of wind project output happens because of transmission inadequacy and other forms of grid and generator inflexibility. For example, over-generation can occur when wind generation is high but transmission capacity is insufficient to move excess generation to other load centers, or thermal generators cannot feasibly ramp down any further or quickly enough." Wiser, R., and Bolinger, M. (2017). *2016 Wind technologies market report*, p. 37. Washington, DC: US Department of Energy, Office of Energy Efficiency & Renewable Energy. Retrieved from https://energy.gov/sites/prod/files/2017/10/f37/2016_Wind_Technologies_Market_Report_101317.pdf

110 Wiser and Bolinger, 2017.

111 Wiser and Bolinger, 2017. Wind is not the only renewable resource affected; in 2016, the California Independent System Operator curtailed more than 308,000 megawatt-hours of wind and solar generation combined. California Independent System Operator Corp. (2017). *Impacts of renewable energy on grid operations*. Folsom, CA: Author. Retrieved from <https://www.aiso.com/Documents/CurtailmentFastFacts.pdf>

112 Hall, D., and Lutsey, N. (2017). *Literature review on power utility best practices regarding electric vehicles*. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/Power-utility-best-practices-EVs_whitepaper_14022017_vF.pdf

Figure 19. Utility Interest in Using Demand Response to Integrate Renewable Energy



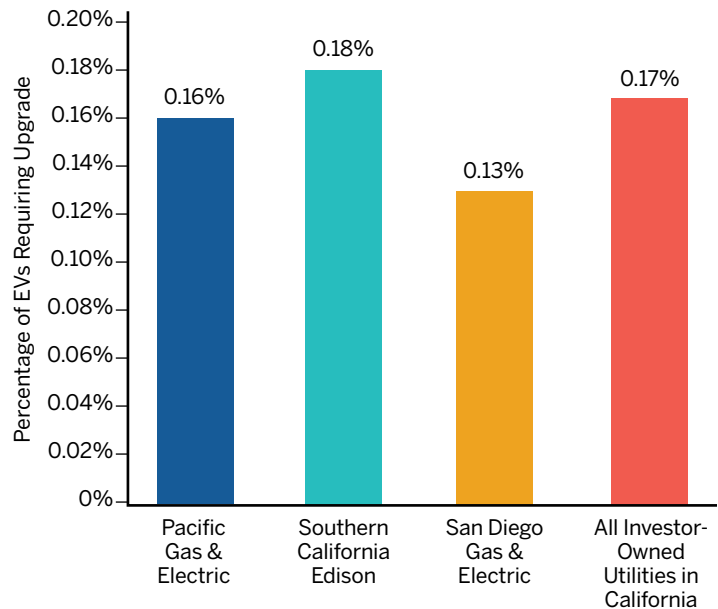
Source: Based on Smart Electric Power Alliance. (2017, October). *2017 Utility Demand Response Market Snapshot*.

as emergency load shedding, but also the broader and more fluid conception that recognizes the ability of electricity users to reduce or to shape, shift, and shed their energy use with relative ease.¹¹³ Definitions aside, recognizing the capabilities of EVs and the role they can play for the grid is the first step in managing them.

Utilities recognize the value of managing demand and can apply that understanding to EVs.¹¹⁴ Smart Electric Power Alliance reports that nearly 70 percent of utility survey respondents indicate they are planning, researching, or considering using demand response as a means of managing greater adoption of renewable resources—that is, variable energy resources—while nearly 30 percent have already done so. Figure 19 illustrates these responses.¹¹⁵

Several studies of EV deployment in California illustrate these grid management benefits. In a 2018 paper for the

Figure 20. Less Than 1 Percent of Electric Vehicles Require Distribution System Upgrades



Source: Allison, A., and Whited, M. (2018, March). *Electric Vehicles Still Not Crashing the Grid: Updates from California*.

Natural Resources Defense Council, Synapse Energy Economics writes, “Over the past six years, fewer than 0.2 percent of EVs have resulted in a distribution system or service line upgrade.”¹¹⁶ Figure 20 shows the percentage by utility.¹¹⁷

In 2017, these utilities collectively spent about \$500,000 on EV-related upgrades out of a combined distribution capital budget of more than \$5 billion—an outlay of “about *one hundredth of one percent* of total distribution capital expenditures.”¹¹⁸ Especially when one considers the increase in

113 The *2025 California Demand Response Potential Study* identifies four categories of demand response services: (1) “Shape” captures demand response that reshapes customer load profiles; (2) “shift” represents demand response that encourages the movement of energy consumption from times of high demand to times of day when there is a surplus of renewable generation; (3) “shed” describes loads that can be curtailed to provide peak capacity and support the system in emergency or contingency events; and (4) “shimmy” involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and disturbances at time scales ranging from seconds up to an hour. See Alstone, P., Potter, J., Piette, M.A., Schwartz, P., Berger, M., Dunn, L.N., et al. (2017). *2025 California demand response potential study—Charting California’s demand response future: Final report on Phase 2 results* (LBNL 2001113). Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from <http://eta-publications.lbl.gov/sites/default/files/lbnl-2001113.pdf>

114 Although this paper does not go into detail on this topic, we should note that not only utilities are well-positioned to take advantage of these innovations,

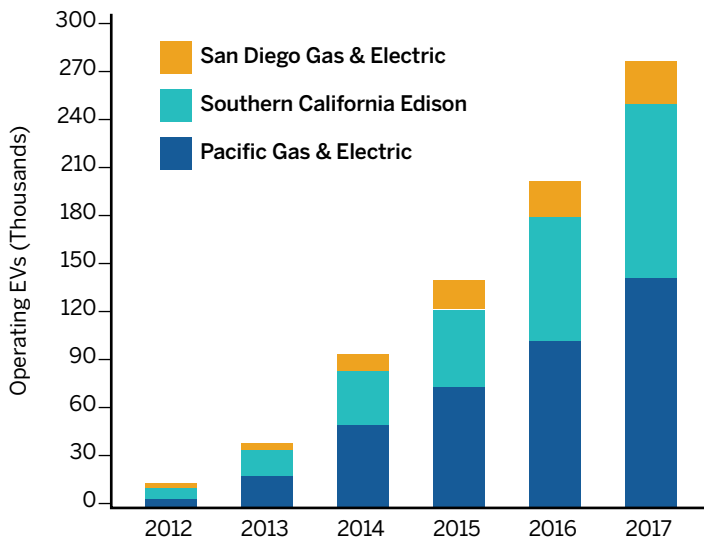
but so are other independent commercial entities—that is, aggregators. See California Public Utilities Commission. *Consumer FAQ on DR providers (also known as aggregators)* [Webpage]. Retrieved from <http://www.cpuc.ca.gov/General.aspx?id=6306>

115 Chew, B., Feldman, B., Esch, N., and Lynch, M. (2017, October). *2017 Utility demand response market snapshot*. Washington, DC: Smart Electric Power Alliance. Retrieved from <https://sepapower.org/resource/2017-utility-demand-response-market-snapshot/>

116 Allison, A., and Whited, M. (2018, March). *Electric vehicles still not crashing the grid: Updates from California*. Cambridge, MA: Synapse Energy Economics. Retrieved from <http://www.synapse-energy.com/sites/default/files/EV-Not-Crashing-Grid-17-025.pdf>

117 Allison and Whited, 2018.

118 Allison and Whited, 2018.

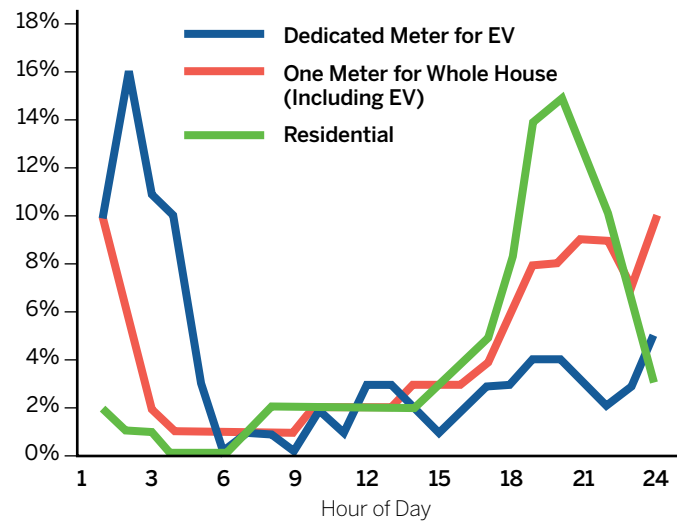
Figure 21. Growth in Electric Vehicles in California Utility Service Areas

Source: Allison, A., and Whited, M. (2018, March). *Electric Vehicles Still Not Crashing the Grid: Updates from California*.

adoption of EVs in California over this time (a tripling between 2014 and 2017),¹¹⁹ it is remarkable that this amount of growth has been accommodated as readily as it has (see Figure 21).¹²⁰

Synapse also reports that TOU rates are the major management tool the utilities are using, as illustrated in Figure 22.¹²¹ Instead of charging on peak, EV owners in the territory of Pacific Gas & Electric Co. (PG&E), for example, are choosing to charge late at night (10 p.m. to 2 a.m.) when there is little demand for electricity and prices are much lower.

This strategy is a way for the utility to make greater use of its assets and increase the return on them.¹²² It is also a way for consumers to save money in “fueling” their EVs. These management strategies can also lower the average

Figure 22. Percent of Pacific Gas & Electric Customers With Peak Demand in Each Hour

Source: Allison, A., and Whited, M. (2018, March). *Electric Vehicles Still Not Crashing the Grid: Updates from California*.

cost to serve all customers, as found in a 2016 analysis of EV adoption scenarios in California by Energy and Environmental Economics.¹²³ Figure 23 illustrates these costs and benefits.¹²⁴

The analysis determined that with substantial EV adoption, the utilities’ cost of serving this load is low enough that it is outweighed by the revenue from EV charging. This reduces the cost of electricity to all ratepayers, not just EV drivers.¹²⁵

Demand response in its traditional and more limited form (that is, curtailing load) is already being applied in the EV charging context. Utilities can simply pause charging at peak times or when supply is disrupted. This approach can help stabilize the grid and avoid the dispatch of often more expensive and dirtier peaking generation resources.

119 Today, California has more than 490,000 EVs on the road. See Veloz. *Sales dashboard* [Webpage]. Retrieved from <http://www.veloz.org/sales-dashboard/>

120 Allison and Whited, 2018.

121 Allison and Whited, 2018.

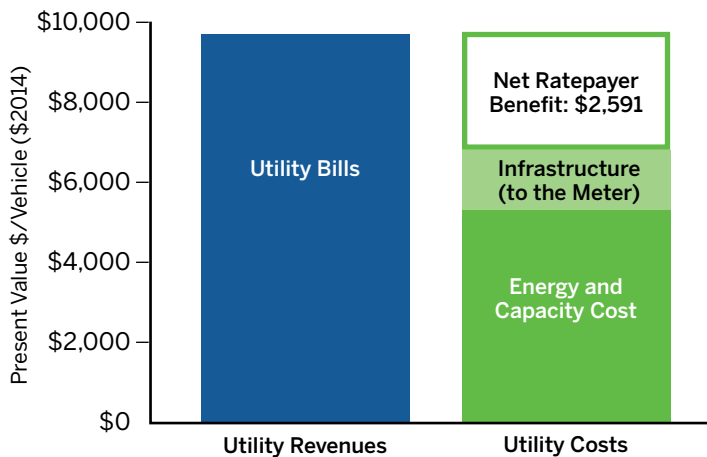
122 For an analysis of how existing distribution network grids are largely underutilized and how the unused network capacity could be used for charging electric vehicles with little or no need for additional capacity, see Hogan, M., Kolokathis, C., and Jahn, A. (2018, January). *Treasure hiding in plain sight: Launching electric transport with the grid we already have*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/treasure-hiding-in-plain-sight-launching-electric-transport-with-the-grid-we-already-have/>

123 They found “a net benefit to all ratepayers, not just EV drivers, in this case an average of \$2,591 per vehicle in present value terms over the life of the 2.2 million EVs.” Ryan, N., and McKenzie, L. (2016, April). *Utilities’ role in transport electrification: Capturing benefits for all ratepayers*. *Fortnightly Magazine*. Retrieved from <https://www.fortnightly.com/fortnightly/2016/04/utilities-role-transport-electrification-capturing-benefits-all-ratepayers>

124 Ryan and McKenzie, 2016.

125 “Even with rapid adoption in California (seven million EVs in 2030), the present value of EV-driven upgrades projected through 2030 represents slightly less than one percent of the California utilities’ 2012 revenue requirement for their residential distribution systems.” Ryan and McKenzie, 2016.

Figure 23. Utility System Costs and Benefits From Electric Vehicle Charging in California



Source: Ryan, N., and McKenzie, L. (2016). Utilities' Role in Transport Electrification: Capturing Benefits for All Ratepayers. *Fortnightly Magazine*.

In addition to controlling EVs to contribute to load shifting, it is possible to control them in very short increments to help meet different grid management needs. This flexibility enables a utility or aggregator to control load in ways that can provide frequency regulation (a transmission-level service)¹²⁶ or voltage support (a distribution-level service).¹²⁷ In 2014, for example, Potomac Electric Power Co. ran a pilot program in Maryland designed to test demand response and variable pricing programs for EV owners in its territory.¹²⁸ Southern

California Edison has applied demand response to workplace charging and provided customers favorable rates if they allow their charging to be slowed or stopped when background power grid demand increases.¹²⁹ In another example, PG&E and BMW used EV batteries and software to determine how demand on the grid could affect when plugged-in EVs would be charged.¹³⁰

Another version of smart charging, referred to as one-way controlled charging, adds scheduling and modulating charging to the traditional demand response approach.¹³¹ This allows utilities greater flexibility to move charging to times when the grid is most capable of providing the service, saving the EV owner and power company expense by avoiding the need for additional investment in infrastructure or generation capacity. In a 2018 paper, Jonathan Coignard and co-authors conclude that “with its EV deployment target and with only one-way charging control of EVs, California can achieve much of the same benefit of its Storage Mandate for mitigating renewable intermittency, but at a small fraction of the cost.”¹³²

Vehicle-to-Grid Services

In addition to being storage devices that can respond to price signals and other controls, EVs are capable of discharging power back onto the grid when called upon, a practice known as vehicle to grid (V2G). V2G brings an entirely new dimension

¹²⁶ Frequency regulation can involve various end uses such as an EV or water heater responding to a signal and quickly increasing or decreasing their load. See the discussion of various frequency regulation pilots in Hledik, R., Chang, J., and Leuken, R. (2016). *The hidden battery: Opportunities in electric water heating*, p. 6. Cambridge, MA: The Brattle Group. Retrieved from <http://www.electric.coop/wp-content/uploads/2016/07/The-Hidden-Battery-01-25-2016.pdf>. See also Upadhye, H., Domitrovic, R., and Amarnath, A. (2012). *Evaluating peak load shifting abilities and regulation service potential of a grid connected residential water heater*. Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from <https://aceee.org/files/proceedings/2012/data/papers/0193-000008.pdf>

¹²⁷ Voltage support, historically provided by generation resources, is used to ensure that grid system voltage is maintained or, when necessary, restored. “New technologies (e.g., modular energy storage, modular generation, power electronics, and communications and control systems) make new alternatives for voltage support increasingly viable.” Eyer, J., and Corey, G. (2010, February). *Energy storage for the electricity grid: Benefits and market potential assessment guide* (SAND2010-0815), p. 33. Albuquerque, NM, and Livermore, CA: Sandia National Laboratories. Retrieved from <https://www.sandia.gov/ess-ssl/publications/SAND2010-0815.pdf>

¹²⁸ St. John, J. (2014, November 10). *Itron and ClipperCreek launch the EV charger as virtual smart meter*. Greentech Media. Retrieved from <https://www.greentechmedia.com/articles/read/itron-and-clippercreek-launch-the-ev-charger-as-virtual-smart-meter#gs.OxwcEjGK>

¹²⁹ Griffo, P. (2018, July 13). *Charge ready pilot helps LA county public works electrify its service fleet*. Edison International. Retrieved from <https://energized.edison.com/stories/charge-ready-pilot-helps-la-county-public-works-electrify-its-service-fleet>

¹³⁰ Kaluza, S., Almeida, D., and Mullen, P. *BMW i ChargeForward: PG&E's electric vehicle smart charging pilot*. Pacific Gas & Electric Co. Retrieved from <http://www.pgecurrents.com/wp-content/uploads/2017/06/PGE-BMW-iChargeForward-Final-Report.pdf>

¹³¹ Hall and Lutsey, 2017, citing Berkheimer, J., Tang, J., Boyce, B., and Aswani, D. (2014). Electric grid integration costs for plug-in electric vehicles. *SAE International Journal of Alternative Powertrains*, 3(1). Retrieved from <http://papers.sae.org/2014-01-0344/>

¹³² Coignard, J., Saxena, S., Greenblatt, J., and Wang, D. (2018, May 16). Clean vehicles as an enabler for a clean electricity grid. *Environmental Research Letters*, 13(5). Retrieved from <http://iopscience.iop.org/article/10.1088/1748-9326/aabe97/meta>

to EVs as a grid management tool. As described by Hall and Lutsey:

With full V2G capabilities, electric vehicles could be charged when power is cheapest and most abundant and fed back to the grid when the power is most valuable, providing financial benefits to consumers.¹³³

Over the last few years, several pilot V2G programs have been put into place.¹³⁴ Most recently, in 2018, utilities filed several V2G proposals. In June, Consolidated Edison submitted a proposal in New York's Reforming the Energy Vision program to partner with a school bus operator in the White Plains School District.¹³⁵ The companies propose to use five e-buses for student transportation during the school year and for energy storage to meet system needs during the summer.¹³⁶ In November, San Diego Gas & Electric submitted a proposal to the CPUC for a school bus V2G pilot project focused on charging e-bus batteries with renewable energy.¹³⁷

V2G programs have not been deployed broadly yet. There is evidence that, under certain discharge scenarios, bidirectional charging of lithium batteries could hurt their performance and shorten their lifetime.¹³⁸ Other analyses have reached the opposite conclusion, even representing that V2G can extend the life of lithium-ion batteries in EVs.¹³⁹

In a 2018 paper, the authors who had published these papers with opposing viewpoints reconciled their conclusions:

Looking at both studies together, and the rest of the literature on the topic, it appears that strategies to purely maximize return on investment for the EV owner, like that proposed by Dubarry et al., are not viable because of the resulting battery degradation. The compromise is to set limits on the amount of energy traded, based on prognostics. Indeed, by intelligently setting these limits, Uddin et al. show that V2G can both be viable and profitable.¹⁴⁰

Because EV battery warranties assume that batteries are used to fuel a car and not for V2G purposes, participating in V2G activities could put owners at risk of violating the warranty. This will continue until industry establishes a better sense of the acceptable levels of battery discharge in a V2G context. Industry will need to find a balance between providing a return on investment to the battery owner and the use of “a smart control algorithm with an objective of maximizing battery longevity.”¹⁴¹

Although the potential for V2G will be affected by changes in battery design and charging practice, V2G could also be affected by fundamentally restructuring the way automakers use batteries in their products. For example, manufacturers could treat EV batteries not only as a component of the vehicle,

¹³³ Hall and Lutsey, 2017, p. 20.

¹³⁴ The Department of Defense has engaged in some V2G pilots. The University of Delaware in partnership with BMW and NRG Energy conducted a well-known pilot. It involved 15 vehicles that were aggregated and paid \$5 per day (more than \$1,800 annually) to provide energy into the PJM Interconnection grid for frequency regulation during peak periods. Other examples include a V2G demonstration project at Fort Carson, Colorado, and a pilot program at Los Angeles Air Force Base. See Markel, T., Meintz, A., Hardy, K., Chen, B., Bohn, T., Smart, J., et al. (2015, May). *Multi-lab EV smart grid integration requirements study: Providing guidance on technology development and demonstration* (NREL/TP-5400-63963), pp. 27-32. Golden, CO: National Renewable Energy Laboratory. Retrieved from <http://www.nrel.gov/docs/fy15osti/63963.pdf>

¹³⁵ Consolidated Edison Co. of New York. (2018, June 8). *REV demonstration project outline: Electric school bus V2G*. Retrieved from <http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7b94DA14CE-371B-415B-BFBB-D54B2EFD74A1%7d>

¹³⁶ New York Department of Public Service. *REV—demonstration projects* [Webpage]. Retrieved from <http://www3.dps.ny.gov/W/PSCWeb.nsf/All/B2D9D834B0D307C685257F3F06FF1D9?OpenDocument>

¹³⁷ Baumhefner, M., and Muller, M. (2018, November 5). Agreement proposed to electrify San Diego's buses and trucks [Blog post]. Natural Resources Defense Council. Retrieved from <https://www.nrdc.org/experts/max-baumhefner/agreement-proposed-electrify-san-diegos-buses-and-trucks>

¹³⁸ Dubarry, M., Devie, A., and McKenzie, K. (2017, May 12). Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis. *Journal of Power Sources*, 358, 39-49. Retrieved from <https://www.sciencedirect.com/science/article/abs/pii/S0378775317306365?via%3Dihub>. The authors of that paper note that battery degradation related to vehicle-to-grid and grid-to-vehicle strategies has been modeled by others, but that few have actually tested batteries themselves. With respect to one study that has tested lithium-ion batteries and concluded that V2G had little effect on the cells, the batteries tested were lithium iron phosphate cells which are not generally used in EVs. See Peterson, S.B., Apt, J., and Whitacre, J.F. (2010, April 15). Lithium-ion battery cell degradation resulting from realistic vehicle and vehicle-to-grid utilization. *Journal of Power Sources*, 195, 2385-2392. Retrieved from <https://www.sciencedirect.com/science/article/abs/pii/S0378775309017443>

¹³⁹ Uddin, K., Jackson, T., Widanage, W.D., Chouchelamane, G., Jennings, P.A., and Marco, J. (2017, August 15). On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system. *Energy*, 133, 710-722. Retrieved from <https://www.sciencedirect.com/science/article/pii/S0360544217306825>

¹⁴⁰ Uddin, K., Dubarry, M., and Glick, M.B. (2018, February). The viability of vehicle-to-grid operations from a battery technology and policy perspective. *Energy Policy*, 113, 342-347. Retrieved from <https://www.sciencedirect.com/science/article/pii/S0301421517307619#bib22>

¹⁴¹ Uddin et al., 2018.

V2G: Stumbling Block or Steppingstone?

RAP's David Moskowitz proposes that manufacturers consider offering EVs for sale under an arrangement where the automaker retains ownership rights to the battery and lowers the sticker price of the vehicle in exchange.^A

Under this approach, the manufacturer takes on the role of aggregator, works with the utility that is aware of conditions on the grid, and benefits from lower-cost smart charging of the vehicles it sells. The consumer benefits from a lower sticker price or a lower upfront charge for a lease. The state would benefit by reducing the barrier to EV adoption facing middle- and lower-income consumers, who are most challenged by the upfront cost of an EV.

Having an auto manufacturer use EV batteries this way could dramatically accelerate the penetration of EVs and ensure that

charging would be smart. With their participation, automakers would become powerful allies to get the market reforms needed to reveal the full range of services that distributed resources like EVs can provide.

This approach would also simplify things for customers who may just want a break on the sticker price of an EV and may not be interested in the details related to smart charging and grid services. Finally, auto manufacturer participation could promote standards beyond individual states' borders, which could be adopted nationally.

A Moskowitz, D. (2014, June 3). An electrifying new business model [Blog post]. Regulatory Assistance Project. Retrieved from <https://www.raonline.org/blog/an-electrifying-new-business-model/>

but also as an additional source of revenue for themselves through managed charging (see the text box on this page). This could take a form similar to the way Green Mountain Power in Vermont manages home-installed batteries in its Tesla Powerwall program.¹⁴²

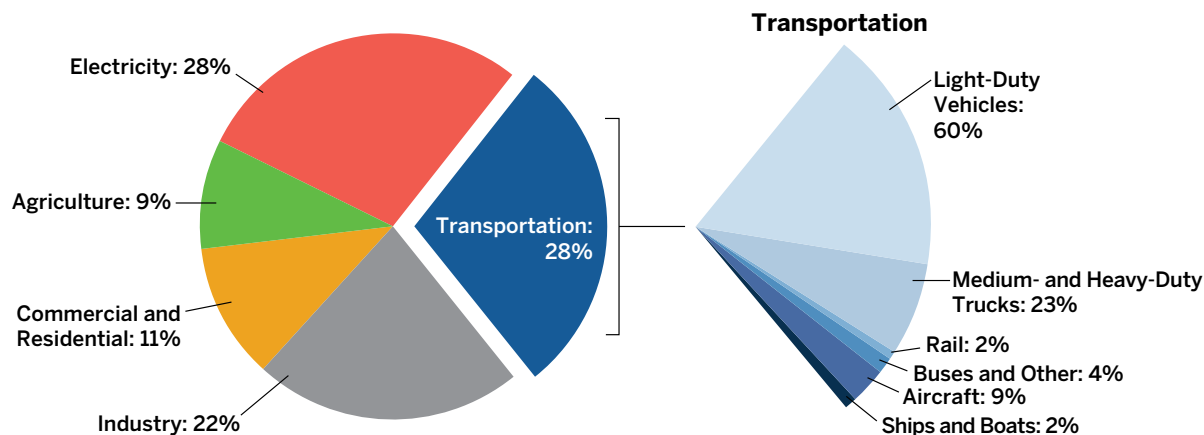
Grid managers utilize various flexibility tools to ensure the power system can respond to variations in supply and load. Today, through smart charging programs and the use of TOU rates, EVs large and small can help through load shedding and demand shifting. EVs also have the potential to provide even greater flexibility as grid resources in the context of V2G applications, although this opportunity is not available today on a broad scale. To ensure that electrification proceeds in a manner that supports the public good, regulators should expect companies to explore the many grid management opportunities available to them through the use of innovations in e-transportation.

Energy and Emissions Efficiency

The third condition for determining whether electrifying transportation is beneficial is that it reduces environmental impacts. Here we are looking at greenhouse gas emissions, but we recognize that electrified transportation also has the potential to reduce other air pollutants.¹⁴³ Electrified transportation can reduce emissions when it produces less pollution than the gasoline or diesel combustion required to provide the same functionality. That is, electrified transportation will be more emissions-efficient than fossil-fueled options if it reduces the amount of emissions per mile traveled in a car or bus. This section first describes analytical frameworks for assessing the emissions effects of electrified transportation, then provides a simple analysis for determining the emissions efficiency of electric vehicles and transit buses.

142 Green Mountain Power. *How does the GMP and Tesla Powerwall program work?* [Webpage]. Retrieved from <https://greenmountainpower.com/help/products-services/gmp-tesla-powerwall-offer/>. See also Farnsworth, D. (2018, December 11). EVs' rise doesn't need to be auto dealers' demise [Blog post]. Regulatory Assistance Project. Retrieved from <https://www.raonline.org/blog/evs-rise-doesnt-need-to-be-auto-dealers-demise/>. This blog post argues that auto dealerships are natural smart charging aggregators for the EVs they sell.

143 For example, EVs can reduce criteria pollutants that affect air quality and public health, including nitrogen oxides and volatile organic compounds, the two major precursors to ground level ozone formation. See the text box on Page 49.

Figure 24. US Greenhouse Gas Emissions in 2016 by Economic Sector and Source

Source: US Environmental Protection Agency, Office of Transportation & Air Quality. (2018, July). *Fast Facts: US Transportation Sector Greenhouse Gas Emissions, 1990-2016*.

As illustrated in Figure 24, the transportation sector accounts for a significant portion of US greenhouse gas emissions, roughly 28 percent in 2016.¹⁴⁴ Further, emissions from transportation grew 21 percent between 1990 and 2016,¹⁴⁵ whereas emissions from the electric sector declined 1 percent over the same period.¹⁴⁶ In fact, today's power sector emits the same amount of carbon dioxide (CO₂) as it did a generation ago, in 1993, although it produces nearly 30 percent more electricity annually.¹⁴⁷ These trends indicate the value of electricity as a fuel source within an overall decarbonization policy.

Decarbonization of transportation will require a shift from the use of petroleum-derived fuels to lower-carbon options such as clean electricity and renewable liquid fuels like biodiesel.

Cars and light-duty trucks account for roughly 60 percent of transportation emissions. Medium- and heavy-duty trucks are the second largest contributor at 23 percent.¹⁴⁸ Passenger travel via light-duty vehicles and public transit buses is the focus of this discussion of emissions reduction opportunities, but opportunities also exist in medium- and heavy-duty

vehicles used for freight and commercial transport and, to a lesser extent, in aviation.

To determine the emissions effects of different technology choices, such as EVs, analysts must first define the parameters of the vehicle life cycle that are included. Emissions from vehicle production; fuel production, transportation, and distribution; vehicle operation; and vehicle maintenance and disposal can all be considered when comparing the merits of a gasoline-powered vehicle and any alternatives. Figure 25 depicts these various stages.¹⁴⁹

One type of comparative analysis of vehicle emissions is "well to wheels," which includes activities from resource extraction through processing and delivery of fuel to the vehicle and use of the fuel in the vehicle. For a petroleum-powered vehicle, the "well-to-tank" stage would include emissions from petroleum extraction, refining, and transportation to the end users (that is, to a gas station). The "tank-to-wheels" emissions for petroleum vehicles include those associated with burning fuel during operation, the

144 US Environmental Protection Agency, Office of Transportation & Air Quality. (2018, July). *Fast facts: US transportation sector greenhouse gas emissions, 1990-2016*. Retrieved from <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100USI5.pdf>

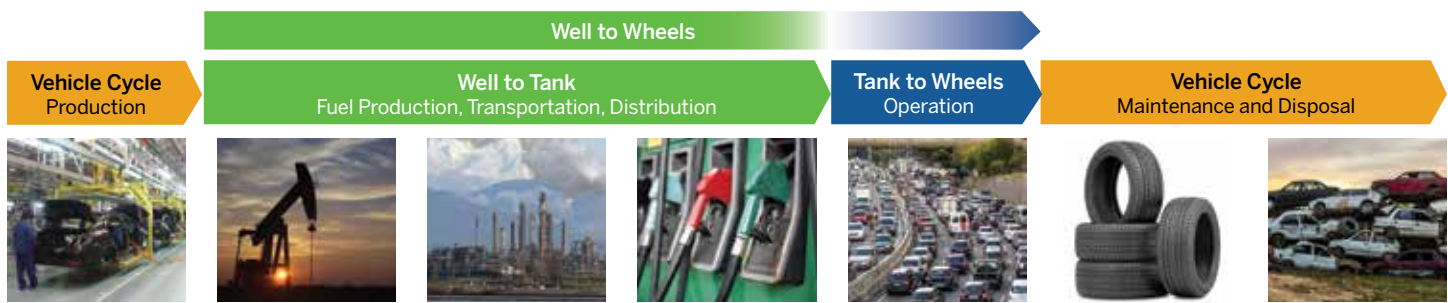
145 US Environmental Protection Agency, Office of Transportation & Air Quality. 2018.

146 US Environmental Protection Agency. *Sources of greenhouse gas emissions* [Webpage]. Retrieved from <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#electricity>

147 US Energy Information Administration. (2016, March 1). Solar, natural gas, wind make up most 2016 generation additions. *Today in Energy*. Retrieved from <https://www.eia.gov/todayinenergy/detail.php?id=25172>

148 US Environmental Protection Agency, Office of Transportation & Air Quality. 2018.

149 Vimmerstedt, L., Brown, A., Neues, E., Markel, T., Schroeder, A., Zhang, Y., et al. (2015, April). *Transformative reduction of transportation greenhouse gas emissions: Opportunities for change in technologies and systems* (NREL/TP-5400-62943). Golden, CO: National Renewable Energy Laboratory. Retrieved from <https://www.nrel.gov/docs/fy15osti/62943.pdf>

Figure 25. Life Cycle Stages of Vehicles and Transportation Fuels

Source: Vimmerstedt, L., Brown, A., Newes, E., Markel, T., Schroeder, A., Zhang, Y., et al. (2015, April). *Transformative Reduction of Transportation Greenhouse Gas Emissions: Opportunities for Change in Technologies and Systems*.

analysis of which requires knowing the carbon intensity of the fuel and the efficiency of the vehicle. For electric vehicles, well-to-tank emissions would come from extracting raw materials for power plant fuel and transporting it to the power plant. The tank-to-wheels emissions would reflect the carbon output from burning fuel in power plants and losses that occur between generation and the point where the vehicle is plugged in, as well as the efficiency with which the vehicle uses electricity.¹⁵⁰ In our analysis below of the emissions benefits of electric vehicles and buses, we use a version of the well-to-wheels framework.

The well-to-wheels framework excludes emissions associated with the manufacturing and disposal of the vehicle. These “vehicle cycle” emissions are not insignificant, particularly for battery electric vehicles.¹⁵¹ UCS analyzed the life cycle global warming emissions of two types of electric vehicles and found that the biggest difference in vehicle cycle emissions between electric and gasoline cars is the production

of the lithium-ion battery.¹⁵² For both EVs that UCS modeled, the emissions associated with manufacturing represent about one-third of the vehicle’s lifetime emissions.¹⁵³ A midsize EV, roughly equivalent to a Nissan Leaf, was found to have 15 percent—or 1 ton—higher manufacturing emissions than a comparable gasoline vehicle. However, over the life of the vehicle, a midsize EV has 51 percent lower emissions than a comparable gasoline car, meaning the higher manufacturing emissions are offset within 4,900 miles of driving (or about six months).¹⁵⁴ A full-size EV, roughly equivalent to a Tesla Model S, had 68 percent—or 6 tons—higher manufacturing emissions than a comparable gasoline vehicle. Over the life of the vehicle, however, a full-size EV has 53 percent lower emissions than a comparable gasoline car, offsetting the higher manufacturing emissions in 19,000 miles (or roughly 16 months of driving). Despite the emissions implications of battery manufacturing, EVs are unambiguously a cleaner option over their life cycle.

150 Other analyses of the well-to-wheels emissions from electric vehicles assign emissions to these stages slightly differently. Some analyses assign zero emissions to the tank-to-wheels stage of vehicle usage, because technically the vehicle itself does not emit while in operation. We choose to represent the emissions of various stages in the way we describe here because we think it allows for a more useful comparison between EVs and gasoline vehicles.

151 Nealer, R., Reichmuth, D., and Anair, D. (2015, November). *Cleaner cars from cradle to grave: How electric cars beat gasoline cars on lifetime global warming emissions*. Cambridge, MA: Union of Concerned Scientists. Retrieved from <https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf>

152 UCS also analyzed the implications of options for vehicle recycling and disposal. The analysis found that emissions from disposing of either gasoline or electric vehicles are small (less than 5 percent of emissions attributable to production of the vehicles) and similar for both vehicle types, with the exception of the EV battery. UCS’ analysis included recycling of vehicle components at levels that are common today but did not include any

recycling or reuse of the battery—meaning that all emissions are attributed to the first use of the battery in the vehicle. UCS made this conservative assumption because, at the time of the analysis, limited data were available for EV end-of-life emissions or recycling options. Thus, the emissions associated with EV manufacturing discussed here are conservatively high and could be reduced if second life operations for EV batteries become real opportunities. For more on this analysis see Nealer et al., 2015.

153 UCS also notes that greenhouse gas emissions of manufacturing EVs are falling as automakers improve production efficiency. Several strategies could be employed to further reduce manufacturing-related emissions, including advances in manufacturing efficiency and recycling or reuse of lithium-ion batteries, use of alternative battery chemistries that require less energy-intensive materials, and the use of renewable energy to power production facilities.

154 In these calculations, the power sector is assumed to be a mix of sources representative of where EVs are being sold in the US today.

Emissions Effects of Electric Passenger Vehicles

To determine whether and by how much electrification of passenger vehicles is beneficial, we analyze the emissions efficiency of different technologies—that is, the emissions per unit of useful energy output, in this case miles driven. Through beneficial electrification of vehicles, consumers can produce less pollution per mile traveled.

The gasoline-powered vehicle we use for comparison is the 2018 Volkswagen Golf, which is reported to have an average fuel economy of 28 miles per gallon.¹⁵⁵ By dividing the carbon intensity of the fuel—19.6 pounds of CO₂ per gallon of gasoline¹⁵⁶—by the fuel economy of the vehicle, we can estimate the tank-to-wheels emissions intensity of the Golf at 0.7 pounds per mile. To get the full well-to-wheels emissions intensity, we add an upstream (well-to-tank) emissions estimate of 0.21 pounds of CO₂ per mile, relying on an NREL

study of transportation emissions reduction opportunities.¹⁵⁷ Combining these two estimates results in the emissions intensity of 0.91 pounds per mile, as shown in Table 3.

Our illustrative electric vehicle is the 2018 Chevrolet Bolt, which has a fuel economy of 3.57 miles per kWh of charge.¹⁵⁸ The emissions efficiency of EVs will vary with the characteristics of the utility grid that charges them. Because we are adopting a well-to-wheels analysis, the emissions efficiency of EVs will also depend on the upstream fuel cycle emissions for generating electricity—that is, the emissions from extracting fuel and transporting it to a power plant, as well as any line losses that occur between generation and the end user (for example, the charging station).

Using a publicly available life cycle emissions model called GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation), we calculated upstream emissions rates for the mining and transport of power plant feedstock for five representative power system mixes (see Table 4). The mixes we use are 100 percent coal;¹⁵⁹ 50 percent coal and 50 percent natural gas; 100 percent natural gas; 50 percent natural gas with 50 percent renewable energy; and 100 percent renewable energy.¹⁶⁰

To calculate the emissions from electricity use in the vehicle, we use the same five representative power system

Table 3. Volkswagen Golf Emissions

	CO ₂ (pounds/mile)	
Well to tank	0.21	
Tank to wheels	0.70	
Well to wheels	0.91	

Table 4. Well-to-Tank Emissions in Various Power System Mixes

	CO ₂ (pounds/million Btu)				
	100% coal	50% coal/ 50% gas	100% gas combined cycle	50% gas/ 50% non-carbon	100% non-carbon
Well to tank	39	46	52	26	0

155

The US Department of Energy, Office of Energy Efficiency & Renewable Energy, enables a side-by-side comparison of the Volkswagen Golf and Chevrolet Bolt at [fueleconomy.gov](https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=40520&id=39832). Retrieved from <https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=40520&id=39832>

156

US Energy Information Administration. (2016, February 2). *Carbon dioxide emissions coefficients* [Webpage]. Retrieved from https://www.eia.gov/environment/emissions/co2_vol_mass.php

157

NREL cited 100 grams of CO₂ per mile for a car that gets 26.3 miles per gallon. We converted this to 94 grams per mile for our representative vehicle, getting 28 miles per gallon, then converted to pounds per mile using the conversion factor of 454 grams per pound. See Vimmerstedt, et al., 2015, citing Joseck, F., and Ward, J. (2014, March 14). *Cradle to grave lifecycle analysis of vehicle and fuel pathways*. Washington, DC: US Department of Energy. Retrieved from http://www.hydrogen.energy.gov/pdfs/14006_cradle_to_grave_analysis.pdf

158

US Department of Energy, Office of Energy Efficiency & Renewable Energy, side-by-side comparison.

159

No power grid in the US today is, on average, operating with 100 percent coal, so this is shown as a worst-case scenario for comparison.

160

Argonne National Laboratory's 2018 GREET fuel cycle model reports upstream emissions for power plant feedstocks in grams per million Btu. See Table 9 ("Fuel-Cycle Energy Use, Water Consumption, and Emissions of Electric Generation: Btu or Gallons or Grams per mmBtu of Electricity Available at User Sites") in the "Electric" tab of the GREET fuel cycle model. We have used the values for natural gas and coal and converted them to pounds per million Btu using the conversion factor of 454 grams per pound. More information about GREET and access to download the fuel cycle model spreadsheet can be found at <https://greet.es.anl.gov/>.

mixes and include an assumption about line losses. Table 5 shows the emissions rate per million British thermal units (Btu) of delivered electricity for each representative power system.¹⁶¹

Combining the emissions calculated in Tables 4 and 5 with the fuel efficiency of our illustrative electric vehicle will result in the emissions efficiency of that particular vehicle charged on a particular power system mix. Table 6 combines these variables.

A Chevrolet Bolt charged with any of our representative power system mixes—even a 100 percent coal-fired system—will produce lower emissions per mile than a gasoline-powered Volkswagen Golf, shown in Table 3. Charging a vehicle on any power system that is cleaner than 100 percent coal would avoid

A Chevrolet Bolt charged with even a 100 percent coal-fired system will produce lower emissions per mile than a gas-powered Volkswagen Golf.

substantial greenhouse gas emissions.

UCS conducted a similar analysis in 2015 and found that driving an EV in any region of the country produces lower carbon emissions than the average new gasoline-powered car.¹⁶² This analysis translates EV fuel economy into MPGe and estimates the fuel efficiency a gasoline-powered vehicle would need to achieve in order to have greenhouse gas emissions as

low as an EV's.¹⁶³ Figure 26 on the next page shows the results—updated in early 2018 to include more recent data—for each region of the country based on emissions of the average EV operated in that region.¹⁶⁴

The UCS results are based on the average mix of electricity sources in a given region.¹⁶⁵ Individual EV owners may be able to achieve even greater emissions savings by participating in a utility's renewable energy tariff program,

Table 5. Illustrative Electric Sector Carbon Emissions

	100% coal	50% coal/ 50% gas	100% gas combined cycle	50% gas/ 50% non-carbon	100% non-carbon
Fuel source CO₂ (pounds/million Btu)	214		117		
Conversion efficiency	0.35		0.5		
Generated electricity CO₂ (pounds/million Btu)	611		234		
Line losses	10%		10%		
Delivered electricity CO₂ (pounds/million Btu)	679	470	260	130	0

Table 6. Chevrolet Bolt Emissions in Various Power System Mixes

	100% coal	50% coal/ 50% gas	CO ₂ (pounds/mile)		
			100% gas combined cycle	50% gas/ 50% non-carbon	100% non-carbon
Well to tank	0.04	0.04	0.05	0.03	0
Tank to wheels	0.65	0.45	0.25	0.12	0
Well to wheels	0.69	0.49	0.30	0.15	0



Photo credit: General Motors. Licensed under <https://creativecommons.org/licenses/by-nc/3.0/>

¹⁶¹ Typical utilitywide average annual losses from generating plants to meters range from 6 percent to 11 percent, depending on the transmission distances, system density, distribution voltages, and the characteristics of transmission and distribution system components. Lazar, J., and Baldwin, X. (2011, August). *Valuing the contribution of energy efficiency to avoided marginal line losses and reserve requirements*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-eeandlinelosses-2011-08-17.pdf>

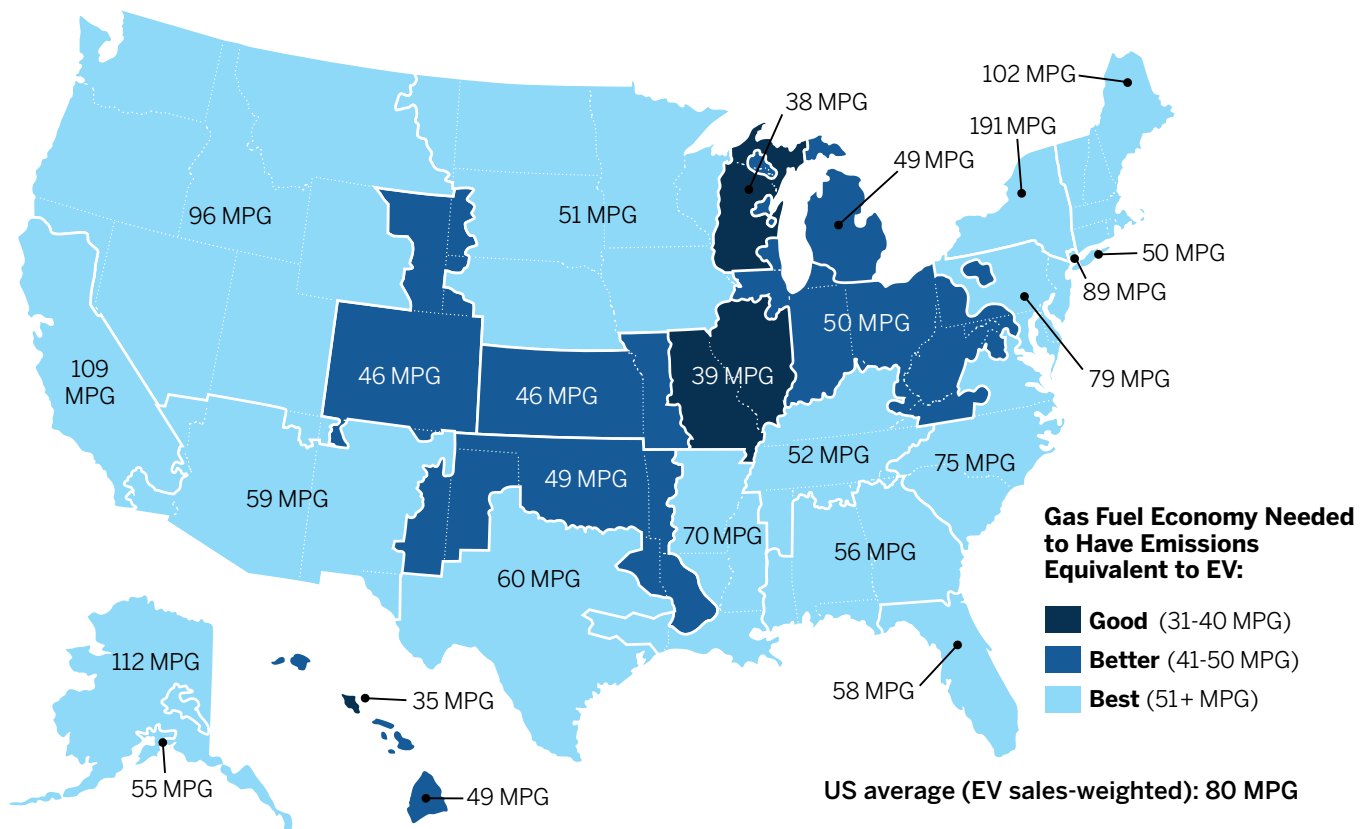
¹⁶² Nealer et al., 2015.

¹⁶³ In other words, if an electric vehicle and one powered by gasoline have the same MPGe, both will produce the same amount of greenhouse gas

emissions for each mile traveled.

¹⁶⁴ Reichmuth, D. (2018, March 8). New data show electric vehicles continue to get cleaner [Blog post]. Union of Concerned Scientists. Retrieved from <https://blog.ucsusa.org/dave-reichmuth/new-data-show-electric-vehicles-continue-to-get-cleaner>. Regional global warming emissions ratings are based on 2016 power plant data in the US Environmental Protection Agency's eGRID 2016 database. Comparisons include gasoline and electricity fuel production emissions estimates using Argonne National Laboratory's GREET 2017 model.

¹⁶⁵ Similarly, our illustrative examples are representations of average emissions for each power system mix.

Figure 26. EVs Produce Lower Greenhouse Gas Emissions Than an Average Gas-Powered Car in Every Grid Region

Source: Reichmuth, D. (2018, March 8). *New Data Show Electric Vehicles Continue to Get Cleaner.*

by installing solar photovoltaic equipment at home and using it to charge their vehicles, or by purchasing power from a community solar installation. And as the nationwide power system continues to decarbonize, the emissions efficiency advantage of EVs over gasoline-powered cars will grow.

Emissions Effects of Electric Transit Buses

Though emissions from bus travel represent only a small portion of overall emissions from transportation, they are important because they are growing more quickly than emissions from any other source in the sector.¹⁶⁶ In addition to reducing

greenhouse gases, electrification of bus travel can provide significant benefits to public health by reducing emissions of other pollutants.¹⁶⁷ The text box on the next page summarizes these benefits.

There are significant opportunities to reduce emissions per mile traveled by electrifying public transit buses. According to the American Public Transit Association, roughly 50 percent of transit buses ran on diesel in 2016, while 23 percent were fueled by CNG or liquefied natural gas.¹⁶⁸ On the following pages, we estimate the emissions savings possible by replacing diesel and CNG buses with electric buses.

M.J. Bradley & Associates compiled tailpipe emissions

¹⁶⁶ US Environmental Protection Agency, Office of Transportation & Air Quality. 2018. Emissions from bus travel may include emissions from non-transit buses, such as those owned by private companies doing multi-city long-haul trips.

¹⁶⁷ Another compelling reason to focus on the electrification of buses is that commercialization of the electric power parts and components for buses can

help advance the technology for electrifying other medium- and heavy-duty vehicles like trucks, which could lead to more substantial emissions benefits.

¹⁶⁸ American Public Transportation Association. (2018, March). *2017 Public transportation fact book*, p.15. Washington, DC: Author. Retrieved from <https://www.apta.com/resources/statistics/Documents/FactBook/2017-APTA-Fact-Book.pdf>

Electrification's Impact on Other Pollutants

This paper and other similar analyses demonstrate that considerable greenhouse gas reduction benefits can arise from transportation electrification. The impacts of electrification on other air pollutant emissions, however, are not as well-studied and are difficult to generalize due to a number of factors. These include differences in the generation fuel mix, vehicle fleet age distribution, and projections for improvements in both.

Criteria pollutants such as particulate matter and nitrogen oxides contribute to a variety of environmental and health impacts, including ozone (smog), water body eutrophication, decreased lung function, aggravated asthma and other respiratory symptoms, and even premature death in people with heart or lung disease. Fossil-fueled power plants, such as those using coal and gas, and petroleum-fueled vehicles emit varying levels of these pollutants depending on the type of technology, its age, and other variables. Thus, determining whether transportation electrification reduces these pollutants involves knowing the marginal power plants that will ramp up to meet newly electrified load, and comparing those emissions impacts to the emissions from petroleum-fueled vehicles that will be displaced.

Gasoline-powered vehicles are generally already low emitters of nitrogen oxides and particulate matter. Replacing these vehicles with EVs that cause increases in coal- or oil-fired electricity could actually increase emissions. On the other hand, older diesel vehicles are high emitters of these pollutants. As a result, replacing those vehicles with electric ones can yield significant

public health benefits, especially in urban areas where those vehicles are used for public transit and school busing and in other commercial and municipal fleets.

M.J. Bradley & Associates analyzed the criteria pollutant emissions associated with transportation electrification for the Northeast and mid-Atlantic states.^B The analysis found that reductions in nitrogen oxides would be small before 2030, in part because coal-fired power plants are assumed to still be operating. The analysis also found that electrifying medium- and heavy-duty (i.e., diesel) vehicles resulted in greater air quality benefits than electrifying light-duty (gasoline-powered) vehicles: a 33 times greater reduction in nitrogen oxides and a 7.5 times greater reduction in particulate matter per mile.

This points to the need to focus near-term transportation electrification efforts on diesel vehicles to achieve criteria pollutant emissions reduction benefits, particularly if coal-fired power plants are still operating in a given area. In areas that are promoting electrification of gasoline-powered vehicles, knowing what power plants will need to ramp up or avoid being curtailed to serve that demand will be important to understanding whether criteria pollutants will be reduced.

B Lowell, D., Saha, A., and Van Atten, C. (2018, October). *Decarbonizing transportation: The benefits and costs of a clean transportation system in the Northeast and mid-Atlantic region*. Concord, MA: M.J. Bradley & Associates. Retrieved from https://www.ucsusa.org/sites/default/files/attach/2018/10/UCS_Final_Report_FINAL_11Oct18.pdf

comparisons for several types of diesel and CNG buses across different types of operation cycles,¹⁶⁹ using testing data from the Altoona Bus Research and Testing Center under the Federal Transit Administration's model bus testing program. The analysis combined tailpipe emissions data with upstream emissions estimates for extraction, production, and transport

of fuel to compile a well-to-wheels estimate of the emissions impacts of both kinds of buses.¹⁷⁰ We use the results from this analysis as the baseline from which to estimate the potential emissions savings from electric buses. Table 7 on the next page shows the emissions intensity for CNG and diesel buses operated on two types of bus routes.¹⁷¹

169 The operation cycle types analyzed included very low-speed urban operation with many stops per mile, medium-speed urban/suburban operation, and very high-speed commuter-type service with few stops per mile. M.J. Bradley & Associates. (2013). *Comparison of modern CNG, diesel, and diesel hybrid-electric transit buses: Efficiency and environmental performance*. Concord, MA: Author. Retrieved from <https://mjbradley.com/sites/default/files/CNG%20Diesel%20Hybrid%20Comparison%20FINAL%2005nov13.pdf>

170 Data on upstream (well-to-tank) emissions were taken from the GREET model.

171 Based on M.J. Bradley & Associates, 2013. The illustrative CNG and diesel buses represented in this table are both 40-foot models manufactured by New Flyer.

Table 7. Emissions Intensity for Compressed Natural Gas and Diesel Buses

	CO ₂ (pounds/mile)			
	Urban route with many stops		Urban/suburban route with medium number of stops	
	CNG	Diesel	CNG	Diesel
Well to tank	4.0	2.3	2.7	1.6
Tank to wheels	6.4	6.3	4.3	4.4
Well to wheels	10.4	8.6	7.0	6.0

Source: Based on M.J. Bradley & Associates. (2013). *Comparison of Modern CNG, Diesel, and Diesel Hybrid-Electric Transit Buses: Efficiency and Environmental Performance*.

Diesel and CNG buses emit similar levels of greenhouse gases from their tailpipes owing to the lower carbon content of natural gas but higher fuel economy for diesel buses. Upstream impacts of methane emissions from natural gas production and processing cause total well-to-wheels emissions from CNG buses to be generally higher than from diesel buses.¹⁷²

As with electric cars, the emissions efficiency of electric buses will vary with the characteristics of the utility grid that charges them. We adopt the same well-to-wheels analysis here as we did above for passenger vehicles.

Our illustrative electric bus is a Proterra Catalyst 40-foot model with a reported fuel economy of 1.38 to 2.42 kWh per

mile, depending on the series.¹⁷³ For the purposes of this comparison, we assume the bus uses 2.15 kWh per mile.¹⁷⁴

Using the same assumptions about upstream emissions and the same illustrative power system mixes as our passenger EV analysis above, Table 8 shows the emissions intensity for the electric bus.

The results, similar to those for electric cars, show that electric buses can save greenhouse gas emissions on a per-mile basis when charged on even the dirtiest power system mix. A UCS analysis from 2018 confirms this finding. Using a similar approach to its life cycle assessment of EVs, UCS concludes that battery electric buses have lower greenhouse gas emissions than diesel and natural gas buses in every region of the country (see Figure 27).¹⁷⁵

Our comparisons for EVs and e-buses both use a representation of average electric sector emissions to characterize the emissions reduction opportunities. This approach estimates the average emissions from plugging a vehicle into the grid for each kWh of electricity delivered to the vehicle, and it treats all the electricity consumed for the operation of that vehicle equally. Using this approach allows us to show in an illustrative way how changes in the generation mix will affect emissions in future years.

An alternative approach would be to estimate the marginal emissions intensity of the electricity used to power

Table 8. Proterra Electric Bus Emissions in Various Power System Mixes

	CO ₂ (pounds/mile)				
	100% coal	50% coal/ 50% gas	100% gas combined cycle	50% gas/ 50% non-carbon	100% non-carbon
Well to tank	0.3	0.4	0.4	0.2	0
Tank to wheels	5.0	3.4	1.9	1.0	0
Well to wheels	5.3	3.8	2.3	1.2	0

172 For the purposes of this table, we are showing the 20-year global warming potential values for greenhouse gases because methane is a short-lived climate forcer, having 86 times the warming potential of carbon dioxide over a 20-year time horizon.

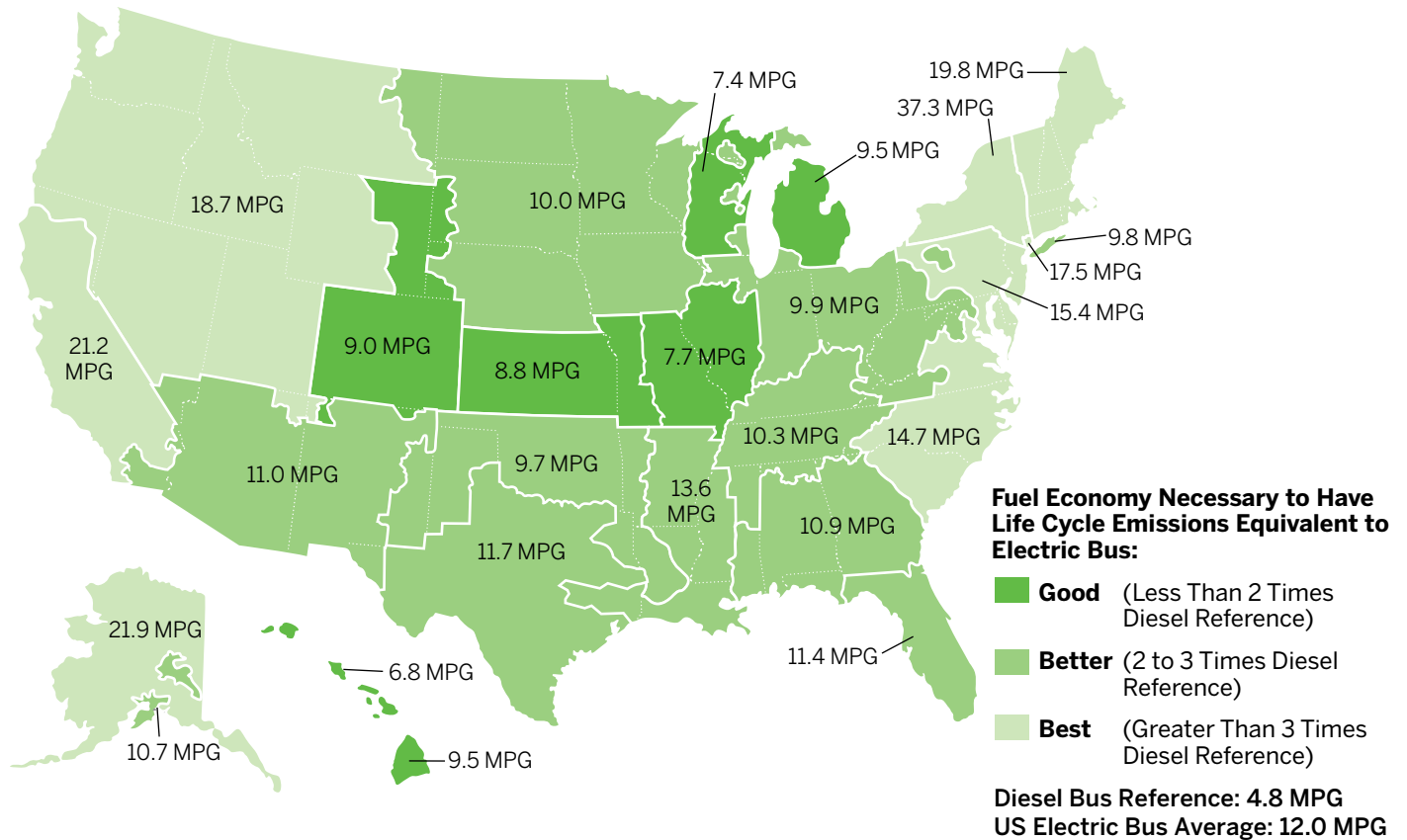
173 Proterra, 2018.

174 This is the average fuel economy that Proterra buses achieved in an analysis of actual performance NREL conducted in California. See Eudy et al., 2016.

175 O'Dea, J. (2018, July 19). Electric vs. diesel vs. natural gas: Which bus is best for the climate? [Blog post]. Union of Concerned Scientists. Retrieved from <https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate>. Regional global warming emissions ratings are based on 2016 power plant data in the US Environmental Protection Agency's eGRID database. Argonne National Laboratory's GREET 2017 model was used to estimate emissions from diesel and electricity fuel production.

176 In our first paper in this series, we discuss the possible methods for analyzing marginal emissions. See Farnsworth et al., 2018.

the vehicles. This is estimated by identifying one or more power plants (or a type of power plant such as additional natural gas generation) likely to be deployed or to increase output when demand spikes due to plugging in cars and buses. A marginal emissions approach may be important for analyzing the short- and medium-term effects of particular vehicle deployment programs in a given utility service territory.¹⁷⁶

Figure 27. Battery Electric Buses Produce Lower Greenhouse Gas Emissions Than Diesel Buses in Every Grid Region

Source: O'Dea, J. (2018, July 19). *Electric vs. Diesel vs. Natural Gas: Which Bus Is Best for the Climate?*

As we stated at the outset, for electrification to be considered beneficial, it must meet at least one of these conditions without adversely affecting the other two:

1. Saves consumers money over the long run;
2. Enables better grid management; and
3. Reduces negative environmental impacts.

As our discussion illustrates, there are good reasons to conclude that electric transportation meets all three of our

BE conditions now or will within several years. Due to their efficiency, EVs are less costly and less polluting to operate. Because they are flexible, EVs can be controlled and serve as useful resources for grid managers. As decision-makers consider these opportunities, we encourage them to apply these three BE conditions to ensure that electrification proceeds in a manner promoting the public interest.

Putting Beneficial Electrification Into Action for Transportation

Policymakers, regulators, and utilities should consider complementary approaches that address the barriers to investment in new technology.

Thus far, this paper has sought to analyze and enumerate the circumstances in which transportation electrification can be beneficial. We have shown that consumers can save money, the power grid can be managed to reduce costs and integrate more renewable energy, and policy goals like emissions reductions can be achieved.

We now turn to a discussion of some of the opportunities for and barriers to beneficial electrification of transportation within policies, programs, and regulations. We identify how policymakers might go about putting BE into action for transportation.

This section provides a set of observations about ensuring that electrification in the transportation sector is beneficial. We refer to these initial observations as considerations. After outlining them, we lay out a set of BE-related strategies for states to consider.

It is worth reiterating a few of the foundational policy ideas from our companion paper on BE principles.¹⁷⁷ In particular, it is useful to develop and prioritize state policy goals (for example, encouraging innovation and job creation and saving consumers money) before making decisions about specific BE implementation efforts.

In addition, as we will discuss in several parts of this section, it is important for policymakers, regulators, and utilities to address how new policy initiatives and legacy frameworks may or may not complement one another, and to identify barriers to economically efficient utility and private investment.

Considerations for Safeguarding the Public Interest

Equity and Environmental Justice

Ensuring equity in e-transportation means that states will need to consider the degree to which all consumers have equal

Ensuring equity means that states will need to consider the degree to which all consumers have equal access to electricity as a transportation fuel.

access to electricity as a transportation fuel and the ability to share in the benefits of this new mode of transportation—regardless of consumers' specific economic and geographic circumstances.¹⁷⁸

The development of the US Interstate Highway System, for example, meets this standard. During the Eisenhower administration, the federal government determined the need and decided to publicly fund what would become a national highway system. Because it's a public resource, everyone who can afford a vehicle has access, and everyone can benefit from the economic activity that an interstate transportation system supports.¹⁷⁹

Tesla's vision of making charging available only to its customers is a model of infrastructure development distinct from the spirit that brought forth our interstate highway system. Tesla's development of charging stations that are inoperable with non-Tesla products is narrowly designed to serve Tesla, rather than the larger public.

Although Tesla's development of charging infrastructure is a private endeavor, one has to ask—in light of this kind of market-driven exclusivity—whether e-transportation and all its benefits can be shared by everyone in the absence of conscious policy interventions on behalf of the public. The answer remains to be determined.

To the extent that state public policy—and the related stakeholder processes—recognizes equity as part of the broader public interest, then one can expect the benefits of e-transportation to be more equally shared.¹⁸⁰

177 See Farnsworth et al., 2018.

178 Numerous topics related to low income arise in the context of e-transportation that are beyond the scope of this paper. For an insightful discussion of many of these, see Bosco, J., Howat, J., and Van Alst, J.W. (2018, August). A consumer advocate's perspective on the future of transportation electrification. In Schwartz, L. (Ed.), *The future of transportation electrification: Utility, industry and consumer perspectives*. Berkeley, CA: Lawrence Berkeley National Laboratory. Retrieved from

http://eta-publications.lbl.gov/sites/default/files/feur_10_transportation_electrification_final_20180813.pdf

179 Tolls, however, can be grossly inequitable—for example, by charging a Prius the same toll as a Chevrolet Suburban, despite the latter being heavier, wider, and longer. For further discussion of reasonable transportation cost allocation, see the Appendix.

180 Hall and Lutsey, 2017.

As Hall and Lutsey note:

Utilities have the ability to influence the developing market in a positive way through the implementation of rate policies that benefit consumers, outreach and education programs, investment in charging infrastructure, and utility lead-by-example programs. Utility policy can help to accelerate electric vehicle adoption in ways that ultimately benefit the grid and all ratepayers.¹⁸¹

Articulating utility policy rests clearly on the shoulders of state lawmakers and regulators.

It is also important for states to recognize, even where they intend to be inclusive, that they may not have all the information they need to actually deliver on those good intentions. California provides a compelling example of a jurisdiction that is willing to try to understand the limitations that need to be addressed to ensure equitable access to e-transportation's benefits. For example, through the passage of Senate Bill 350 in 2015, California determined that it lacked sufficient information to fully realize the potential of cleaner energy resources—including energy efficiency, solar photovoltaics, and other renewable generation—to serve low-income customers and disadvantaged communities in the state.¹⁸²

Consequently, the California Energy Commission published the first of two papers in 2017 setting out a framework and indicators to measure low-income customers' access to those resources.¹⁸³ As a follow-up, CARB will

produce the second study, focusing on barriers for low-income customers and disadvantaged communities to zero-emissions and near-zero-emissions transportation options. The study will include recommendations on how to increase access to these new transportation resources.¹⁸⁴

The SB 350 example illustrates that, even where a state supports the policy goal of sharing e-transportation benefits broadly, solutions are not always readily apparent and need to be explored with as many of the types of potential beneficiaries as possible.¹⁸⁵

An important facet of equity for policymakers to consider is environmental justice. Ensuring environmental justice means ensuring that “no population bears a disproportionate share of negative environmental consequences resulting from industrial, municipal, and commercial operations” or the effects of policies, laws, and rules.¹⁸⁶ As articulated by the Natural Resources Defense Council's Anjali Waikar, “Environmental justice really reflects the fundamental reality that vulnerable communities are all too often subject to the disproportionate burden of pollution and contamination.”¹⁸⁷

Although the growth in EV adoption should be seen as beneficial across the economy,¹⁸⁸ taking environmental justice into consideration means that policymakers need to understand the effects on at-risk communities before formulating and adopting policy. For example, lower-income communities are often near industrial sites where there is disproportionately greater exposure to air pollution from highway traffic, idling

181 Hall and Lutsey, 2017, p. 1.

182 California Assembly Bill 523 is another example. It requires 25 percent of Energy Commission Electric Program Investment Charge technology demonstration and deployment money to fund projects with sites located in, and benefiting, disadvantaged communities. In addition, 10 percent of these funds must be spent at sites located in, and benefiting, low-income communities, defined as census tracts with median household incomes at or below 80 percent of the statewide median income or the applicable low-income threshold identified by the Department of Housing and Community Development. See Stano, M. (2018, January 18). California Public Utilities Commission approves over \$60 million for clean energy research projects benefiting low-income and disadvantaged communities [Blog post]. The Greenlining Institute. Retrieved from <http://greenlining.org/blog/2018/cpuc-funds-clean-energy-research-disadvantaged-communities/>

183 Scavo, J., Korosec, S., Guerrero, E., Pennington, B., and Doughman, P. (2016, December). *Low-income barriers study, Part A: Overcoming barriers to energy efficiency and renewables for low-income customers and small business contracting opportunities in disadvantaged communities*. Sacramento, CA: California Energy Commission. Retrieved from https://www.energy.ca.gov/sb350/barriers_report/

184 See California Energy Commission. (2018, June 25). *Energy equity indicators tracking progress*. Sacramento, CA: Author. Retrieved from https://www.energy.ca.gov/renewables/tracking_progress/index.html#eei. This report establishes a framework and indicators to measure low-income customers' access to energy efficiency, weatherization, and renewable energy investments in California.

185 Several tools exist to facilitate an equity-conscious approach to electrification. For example, see The Greenlining Institute's *Electric vehicles for all: An equity toolkit*. Retrieved from <http://greenlining.org/publications-resources/electric-vehicles-for-all/>

186 Waikar, A. (2017, December 13). *What is environmental justice? Vulnerable communities across America pay the highest price for environmental justice issues brought upon by polluters* [Video]. Natural Resources Defense Council. Retrieved from <https://www.nrdc.org/stories/what-is-environmental-justice>

187 Waikar, 2017.

188 It should be remembered that EVs bring with them many societal benefits that offset some equity concerns, including lower total environmental impacts and the potential for downward pressure on electricity rates.

trucks, or industrial plants. Consequently, mitigation solutions for these local pollution issues will need to be part of a larger portfolio of e-transportation solutions that a jurisdiction might consider. It also means that one should not expect one-size-fits-all solutions but instead solutions tailored to the specific needs of communities.

These might include more stringent controls or an accelerated schedule for retirement of stationary emissions sources; public transportation; and the electrification of freight yard vehicles like forklifts, tractors, and machinery used to move shipping containers.

Land Use Management

It is an understatement to say that planning for the development of e-transportation in a state will be an extensive undertaking. It will require analysis of the development, operation, and management of facilities and related services for the various types of transportation that are adopted.¹⁸⁹ It will call for estimates of future demand for, investment in, and use of infrastructure. It will involve new stakeholders and new relationships.

All these changes will, in turn, help shape what cities and towns look like and how state economies will respond. Transportation planning in this broad sense is far beyond the scope of this paper. Several observations can be made, however, about potential pitfalls and basic needs to consider as states



If e-transport simply produces “e-congestion,” we haven’t thought this through very well.

proceed down this road.

First, planning for the development of e-transportation is an opportunity for states to have a larger conversation and revisit their assumptions and practices in order to improve the ways that people and goods move around the landscape.¹⁹⁰ Likely all of us have, at some point, tried to secure some sort of public transit option

that turned out not to be available. We may have seen bridges and streets in need of repair or simply been unable to find a sidewalk and had to drive a short distance instead.¹⁹¹ We have all experienced traffic congestion, whether on seasonal trips or during our daily commutes. And we would probably agree: If e-transport simply produces “e-congestion,” we haven’t thought this through very well.¹⁹²

This raises the simple question: Are we going to continue doing with EVs all the same things we have been doing with ICE vehicles? Add to that question the potential effects of trends discussed in the first section of this paper, including lower battery costs, autonomous driving, and shared transportation. Is it unrealistic to expect a further decline in battery prices? What if battery prices drop to \$50 per kWh by 2025? What if the EV growth rate doubles—perhaps due to battery prices—and EVs continue to be adopted without rate designs to manage their charging? Letting an e-transportation market develop in a policy vacuum can be expected to compound the problems we experience today and create new ones.

189 Numerous topics related to land use arise in the context of e-transportation that are beyond the scope of this paper. For a thoughtful discussion of many of these, see Ho, B., and Bright, U. (2018, July 19). *Transportation reimagined: A roadmap for clean and modern transportation in the Northeast and mid-Atlantic region*. Natural Resources Defense Council. Retrieved from <https://www.nrdc.org/resources/transportation-reimagined-roadmap-clean-and-modern-transportation-northeast-and-mid>

190 For a discussion of public process and stakeholder engagement, see Farnsworth et al., 2018, pp. 45-51.

191 For a discussion of allocating costs for road and bridge maintenance, see the Appendix.

192 See, for example, the recent decision by Los Angeles County transportation officials to end favorable status to zero-emissions vehicles carrying only the driver. Nelson, L.J. (2018, April 26). Commuters who drive alone in zero-emission cars will no longer get free trips in L.A.’s toll lanes. *Los Angeles Times*. Retrieved from <http://www.latimes.com/local/lanow/la-me-ln-toll-lane-zero-emission-20180426-story.html>

Urban planner Robert Calthorpe argues, for example, that the widespread adoption of EVs, self-driving or otherwise, will not solve our transportation problems.¹⁹³ EVs, he and others argue, will instead cause more congestion and exacerbate sprawl.¹⁹⁴ A Calthorpe associate, transportation consultant Jerry Walters, points out that a key distinction in this context is the number of people per vehicle. Without increasing that number, we can only expect to increase the total vehicle miles traveled. And this, of course, would increase congestion.¹⁹⁵

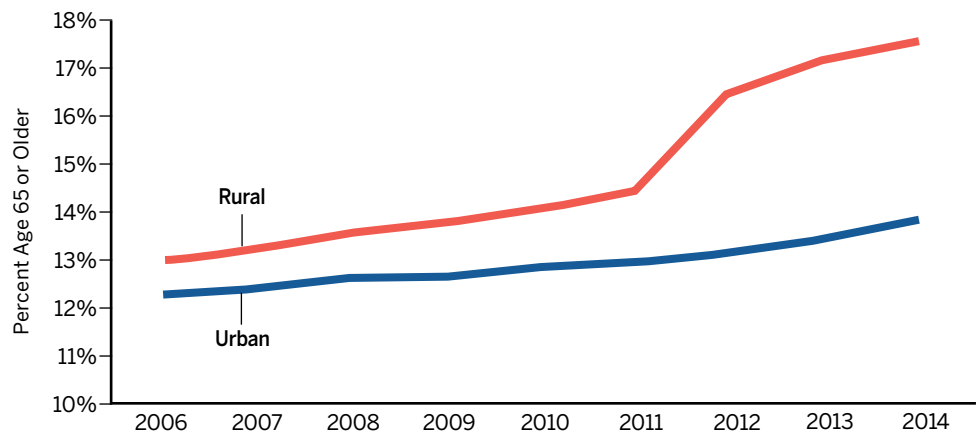
This land use planning-related discussion is only one example of the many debates that states probably will encounter as they discuss how to accommodate the development of e-transportation proposals and related activity. We encourage state agencies and stakeholders to publicly engage on these and other e-transportation topics to ensure that electrified transportation develops beneficially and in a manner that is consistent with the public good.

Rural Transportation Needs

The transportation needs of rural America exemplify the importance of states' considering geographic factors while developing electrification policies. Rural communities differ in significant ways from urban ones, and their transportation needs differ as well. Considering that 1 in 5 Americans—about 60 million people—live in rural America,¹⁹⁶ meeting rural transportation needs will be a crucial aspect of successfully electrifying the transportation sector.

Demographic data illustrate some of the likely transportation needs of rural communities. For example, the percentage

Figure 28. Rural and Urban Age Trends



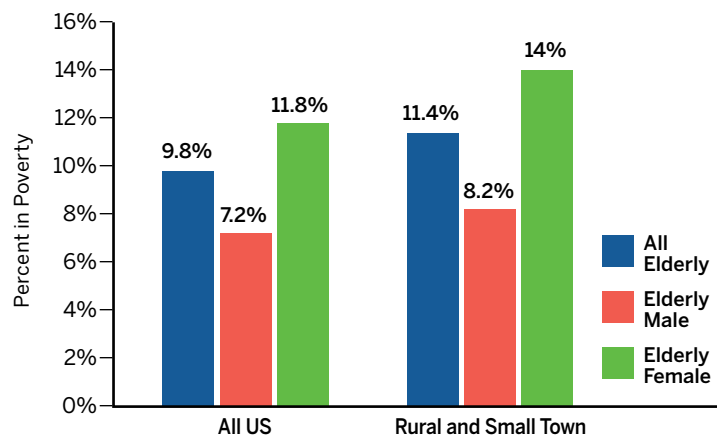
Source: Mattson, J. (2016, November). *Rural Transit Fact Book 2016*.

of the population age 65 or older is both higher and increasing more rapidly in rural areas than in urban ones (see Figure 28).¹⁹⁷

Similarly, the poverty rate among the elderly—especially women—in rural and small-town populations is higher than the national average, as illustrated in Figure 29.¹⁹⁸

These numbers suggest that rural residents may be more likely to be physically or financially dependent on shared

Figure 29. Poverty Rate Among Elderly by Location and Gender, 2010



Source: Housing Assistance Council. (2013, May 2). *Aging in Rural America: A Demographic Snapshot of Rural Seniors and Their Homes*.

193 Markoff, J. (2018, October 27). Urban planning guru says driverless cars won't fix congestion. *The New York Times*. Retrieved from <https://www.nytimes.com/2018/10/27/technology/driverless-cars-congestion.html>

194 Calthorpe, P., and Walters, J. (2017, March 1). Autonomous vehicles: Hype and potential. *Urban Land Magazine*. Retrieved from <https://urbanland.uli.org/industry-sectors/infrastructure-transit/autonomous-vehicles-hype-potential/>

195 Calthorpe and Walters, 2017.

196 US Census Bureau. (2017, August 9). *One in five Americans live in rural areas*.

Retrieved from <https://www.census.gov/library/stories/2017/08/rural-america.html>

197 Mattson, J. (2016, November). *Rural transit fact book 2016*. Fargo, ND: Upper Great Plains Transportation Institute, Small Urban and Rural Transit Center. Retrieved from <https://www.surtrc.org/transitfactbook/downloads/2016-rural-transit-fact-book.pdf>

198 Housing Assistance Council. (2013, May 2). *Aging in rural America: A demographic snapshot of rural seniors and their homes* [Webinar]. Retrieved from <https://www.slideshare.net/ruralhome/hac-seniors-may2013webinarpresentationweb>

transit rather than private car ownership.

In fact, unlike urban and suburban Americans, rural populations increasingly rely upon public transit.¹⁹⁹ Between 2007 and 2015, rural public transit ridership increased nearly 8 percent, while urban transit ridership increased just over 2 percent.²⁰⁰ During roughly the last two decades, the number of rural and small-town public transit agencies has increased to about 1,400.²⁰¹ Rural electrification policies centered on private EVs alone are, therefore, unlikely to meet all rural transportation needs.

However, the need for rural transit does not eliminate the role of private EVs in meeting the transportation needs of some rural residents. In a recent publication, UCS compared the potential benefits of EVs for rural populations with those for urban consumers. UCS concluded that residents of small towns and rural counties have more to gain because they drive farther to work, shop, and see a doctor. Because of these added miles, they have to repair their vehicles more frequently and spend more on gasoline. According to UCS, rural drivers have the greatest potential for economic gain by switching from a conventional sedan to an EV—as much as twice the savings as urban residents.²⁰² In most of the rural counties UCS considered, a driver could save on average \$870 a year.²⁰³

Geographic differences between urban and rural transportation will also affect the relative need for EVSE. Rural residents travel longer distances, on average, than urban

Rural drivers have the greatest potential for economic gain by switching to an EV—as much as twice the savings as urban residents.

residents: more than 30 percent more miles. Low-income rural workers travel nearly 60 percent more.²⁰⁴ These numbers suggest that plans for EVSE development will need to take these fundamental differences into consideration.

As noted above, engaging with rural communities is the best way for states to determine their actual transportation needs. Rural residents may be best served by substantial investments in e-buses and EVSE; however, engaging with communities may enable more innovative solutions.

For years, many people unable to access public transit have relied on neighbors or someone else in the community to help them get to medical appointments or the grocery store. In Hispanic communities, this driver is called a *raitero*. This approach continues today in many communities and involves individual drivers who, for a fee, are willing to transport people who cannot typically afford a vehicle.²⁰⁵

As a model for rural transportation, this approach is part ride-hailing and typically involves a car or van used like a taxi or transit bus.²⁰⁶ Recently, the California town of Huron launched the Green Raiteros program, using settlement funds made available by the CPUC,²⁰⁷ to acquire EVs and help coordinate EV

199 Litman, T. (2017). *Public transportation's impact on rural and small towns: A vital mobility link*. Washington, DC: American Public Transportation Association. Retrieved from www.apta.com/resources/reportsandpublications/Documents/APTA-Rural-Transit-2017.pdf

200 Litman, 2017. More recent numbers for use of rural transit are difficult to locate, but one study reports that urban public transit ridership has decreased except in Boston and New York. American Public Transportation Association. (2017, March 3). *Public transportation ridership report: Fourth quarter 2016*. Washington, DC: Author. Retrieved from <http://www.apta.com/resources/statistics/Documents/Ridership/2016-q4-ridership-APTA.pdf>

201 Litman, 2017.

202 Gatti, D., and Pinto de Moura, M.C. (2018, December 13). Rural drivers can save the most from clean vehicles [Blog post]. Union of Concerned Scientists. Retrieved from <https://blog.ucsusa.org/daniel-gatti/clean-vehicles-save-rural-drivers-money>

203 Relying on data from the 2017 National Highway Traffic Survey, UCS developed a model to approximate types of vehicles and distances driven for counties in the Northeast and mid-Atlantic region. Gatti and Pinto de Moura, 2018.

204 Litman, 2017.

205 Kinser, S. (2018, October 19). Green Raiteros: Greening transportation for communities that need it most [Blog post]. Heising-Simons Foundation. Retrieved from <https://www.hsfoundation.org/green-raiteros-greening-transportation-for-communities-that-need-it-most/>

206 Brown, P.L. (2017, June 17). The anti-Uber. *The New York Times*. Retrieved from <https://www.nytimes.com/2017/06/17/opinion/sunday/the-anti-uber.html>

207 As part of a 2012 Federal Energy Regulatory Commission-approved settlement between NRG Energy and the CPUC, NRG is spending \$519,400 on an 18-month partnership with San Joaquin Valley Latino Environmental Advancement Project, the Fresno County Rural Transit Authority, the Shared Use Mobility Center, and West Hills Community College to build upon an existing grass-roots ride-hailing program in the San Joaquin Valley. Espino, J. (2018, January 19). EV update: PG&E to deploy EV charging stations in low-income communities [Blog post]. The Greenlining Institute. Retrieved from <http://greenlining.org/blog/2018/pge-to-deploy-ev-charging-stations-in-low-income-communities/>



Photo credit: Tim Daw <https://timdawphotography.pixieset.com/g/green-raiteros/>

ride-hailing for community members (pictured above). This is precisely the kind of tailor-made solution that can be developed when communities are consulted and engaged to develop transportation solutions that work best for them.

Strategies to Support Beneficial Electrification

As noted above, it is important for policymakers to consider ways in which policy initiatives and legacy frameworks may or may not complement one another. In developing e-transportation policies, it will be valuable not only to identify strategies for achieving goals, but also to identify any barriers to their achievement. The following strategies are concrete actions states can undertake to implement e-transportation policies that will promote the public good.

Building-Related Standards

Given the different types of housing across the country, ensuring access to EVSE will require a thoughtful and long-term effort, especially for existing housing. According to a 2015

study on electric vehicle charging in apartment-based housing:

The high percentage of charging that is occurring in detached housing (about 95 percent) is reflective of who is buying or leasing [plug-in electric vehicles], as well as the ease of plugging into existing outlets or upgrading to higher amperage circuits in a homeowner's garage.²⁰⁸

According to the study, this imbalance isn't likely to change soon without policy intervention:

Project research indicates that many apartment residents have not yet requested charging stations and those "future residents" looking for apartments have not yet requested EV charging as an amenity that would sway their decision about where to rent their next apartment.²⁰⁹

States recognize this challenge and have made efforts to address it. For example, homeowners associations in Oregon are required to approve an application by a homeowner to install EVSE, subject to conditions, and homeowners are liable for all costs, including those related to any damage of common property.²¹⁰ California has similar rules that would affect property transfers in common interest communities.²¹¹ California has also passed several laws that would limit the ability of homeowners associations to prevent homeowners from installing EVSE for their own use on their property and parking spaces but also allow some restrictions on EVSE installation and use.²¹² Florida has also recently passed a "right to charge" law. In Colorado, landlords cannot prohibit tenants from installing EVSE at their own expense on leased premises, and common interest communities cannot prohibit residents from charging EVs.²¹³

Where states have not passed legislation addressing these barriers to EV ownership, individuals will continue to have to negotiate these issues with homeowners associations.²¹⁴

208 NOVA. (2015, April). *Electric vehicle charging in apartment-based housing: Obstacles and opportunities*. Retrieved from <http://files.novaworks.org/Reports/EV-MUD.pdf>

209 NOVA, 2015.

210 OR Revised Statutes, § 94.550.

211 In California, for example, unreasonable restrictions on the installation or use of EV charging infrastructure cannot be included in any instruments that would affect the sale or transfer of property in a common interest development. CA Civil Code, § 1353.9.

212 CA Civil Code, § 4745. Retrieved from https://leginfo.ca.gov/faces/codes_displaySection.xhtml?sectionNum=4745.&lawCode=CIV

213 CO Revised Statutes, §§ 38-12-601; 38-33.3-106.8.

214 ChargePoint has developed a handbook for EV owners on how to engage with homeowners associations. Wolf, L. (2017, November 2). EV charging for condos: Get your HOA to say "yes" [Blog post]. ChargePoint. Retrieved from <https://www.chargepoint.com/blog/ev-charging-condos-get-your-hoa-say-yes/>

Furthermore, there are likely to be building and safety provisions and permit requirements that homeowners will need to consider.

The 2015 study on EV charging at apartments provides three recommendations to encourage greater access for residents of multi-unit dwellings:

1. Education for site managers;
2. A tiered state funding program to ensure a workforce trained in EV charging assessment and planning; and
3. A state capital improvements (cost-sharing) grant program to assist property owners by providing certified assessors to help plan and design EV charging projects.²¹⁵

Although existing construction comes with special challenges to the spread of EV adoption, the transition for new construction could occur much more rapidly in many parts of the country.²¹⁶ New construction is an ideal opportunity to deploy new technology and ensure that unnecessary barriers to deployment are removed. EV readiness in local policies and regulations will be determined in part by “the role of building and electrical codes in encouraging or inhibiting the implementation of EVSE.”²¹⁷

The Southwest Energy Efficiency Project contends that adopting codes requiring buildings to be EV-ready is one of the most effective and lowest-cost strategies for state and local

governments to encourage more EV purchases.²¹⁸ Building codes set out requirements for new construction and in this case could include standards for electrical capacity and wiring to more readily facilitate the future installation of charging equipment.²¹⁹ As one might expect, incorporating this capacity during construction is far less expensive and disruptive than retrofitting parking lots or garages.²²⁰ The Southwest Energy Efficiency Project maintains that the cost of putting in two charging stations in a ten-space parking lot would “amount to \$920 per charger during new construction, versus \$3,710 per charger for a retrofit, largely because of trenching, demolition, and additional permitting costs.”²²¹

Standards for Charging Equipment

For EVSE to be capable of being integrated into the power system by grid managers, it would be useful for standard equipment to allow the end user or grid operator, an aggregator, or another party to monitor the state of charge and control charging. Appliance standards could call for EV chargers to have Wi-Fi or another utility interface (for example, an open standard for connecting to the internet), enabling them to receive a grid signal.²²²

It is not clear whether the US Department of Energy will recommend standards for EV chargers, or how the

215 NOVA, 2015.

216 US Department of Energy, Office of Energy Efficiency & Renewable Energy. (2015, August). *Plug-in electric vehicle deployment policy tools: Zoning, codes, and parking ordinances* [Webpage]. Retrieved from <https://afdc.energy.gov/bulletins/technology-bulletin-2015-08.html>

217 New York State Energy Research and Development Authority. (2012, November). *EV-ready codes for the built environment: Electric vehicle supply equipment support study*. Retrieved from <https://www.nyserda.ny.gov/-/media/Files/Programs/ChargeNY/EV-Ready-Codes-for-the-Built-Environment.pdf>

218 Frommer, M. (2018, October 23). Cracking the code on EV-ready building codes: Among best ways for cities, states to encourage consumers to switch to electric cars [Blog post]. Southwest Energy Efficiency Project. Retrieved from <http://www.swenergy.org/cracking-the-code-on-ev-ready-building-codes>

219 See Frommer, 2018. The discussion focuses on two codes. One is the International Residential Code applying to new one- and two-family residential projects with access to an off-street parking space in a garage or driveway; it can be found at http://www.swenergy.org/data/sites/1/media/documents/publications/documents/Sample%20IRC_EV%20Building%20

[Code%20Proposal.pdf](http://www.swenergy.org/data/sites/1/media/documents/publications/documents/Sample%20IBC_EV%20Building%20Code%20Proposal.pdf). The other is the International Building Code applying to multi-family residential and commercial construction projects; it can be found at http://www.swenergy.org/data/sites/1/media/documents/publications/documents/Sample%20IBC_EV%20Building%20Code%20Proposal.pdf.

220 The Southwest Energy Efficiency Project provides a list of nearly two dozen examples of cases where municipalities have adopted code changes or ordinances designed to prepare new housing and commercial and public buildings for these expected changes in transportation trends. It is available at https://docs.google.com/spreadsheets/d/17MXkN7IUKYkBPbNgXPirUzZ_C7bh7w5pZlvs-LoBOY/edit?usp=sharing.

221 Frommer, 2018, citing Pike, E., Steuben, J., and Kamei, E. (2016, November). *Plug-in electric vehicle infrastructure cost-effectiveness report for San Francisco*. Pacific Gas & Electric Co. Retrieved from <http://evchargingpros.com/wp-content/uploads/2017/04/City-of-SF-PEV-Infrastructure-Cost-Effectiveness-Report-2016.pdf>

222 If we are capable of supporting pay-per-view and two-way instant polling, this is achievable.

Environmental Protection Agency might further articulate voluntary Energy Star standards.²²³ What is clear, however, is that EVs and EVSE with built-in control systems offer substantial benefits. Including Wi-Fi or another utility interface to ensure that EVs receive a grid signal will help support load shifting and demand response—practices that can improve grid flexibility and reliability and the economics of e-transportation.

Pilot Programs: First Steps

A pilot program is a transitional arrangement between regulators and a utility that allows experimentation under time limits and other constraints in order to understand how a similar but larger-scale ongoing program might work. A pilot program can serve as an opportunity to test ideas, develop capabilities, learn, and gain experience before committing to, for example, a full-scale EVSE buildout or rate design changes.²²⁴ A good pilot can be designed to scale smoothly to a full program with minimum hurdles and lag time.

We identify several topics for regulators to consider as they review and authorize EV pilots.

Goals and Priorities

The first step in reviewing a pilot proposal is to determine whether it clearly articulates goals and policies. This will ensure that affected stakeholders and investors have a good sense of what the state supports and what the regulator expects. For example, will pilot programs promote BE?

When incremental EV charging loads are moved to less expensive, off-peak times of the day, the resulting utility savings can be shared with consumers. Lower-priced charging will be a key way to attract greater investment in EVs and help states meet other goals, such as for clean energy. Will the pilot promote grid management?

Will the pilot promote economic benefits for consumers? To ensure that incremental load does not exacerbate system peaks (unnecessarily increasing costs for everyone on the

grid), smart charging mechanisms and rate designs need to be adopted to guide the utility as it serves this incremental load.

Will the pilot be responsive to the wishes of many consumers who want to reduce transportation-related air pollution? Accounting for emissions reductions associated with EV adoption will help in conveying the benefits of an EV policy to the public and will help states meet environmental and equity goals.

Data Gathering: Scope and Timeliness

Because EV adoption is relatively new in many states, there are circumstances where all concerned may have to learn as they go. This includes consumers, utilities, and regulators. Consequently, regulators may need to get comfortable with requiring more extensive reporting than they might normally consider for typical utility programs, particularly with respect to ensuring transparency and access to data. Although utility pilots may be limited in size, budget, and term, they needn't be cloaked from general view.

Regulators will need to decide what information will be useful in evaluating the success of utility EV charging proposals. They will need to establish key metrics or performance indicators that will help demonstrate whether the program is proceeding successfully. Examples may include:

- Program expenses;
- Charge station deployment (planned and installed);
- Load profiles, showing when drivers are plugging in;
- EV charging electricity rates; and
- Estimates of avoided CO₂ emissions.

Metrics could be reported in a quarterly or year-to-date format. They could also identify market segment, such as residential, workplace, fleets, multi-unit dwellings, low-income, and disadvantaged communities.

In 2017, for example, the Washington Utilities and Transportation Commission approved a pilot for Avista that allows the company to own and operate, as part of its

223 US Department of Energy and US Environmental Protection Agency. *Electric vehicle supply equipment* [Webpage]. Retrieved from <https://www.energystar.gov/products/other/evse>

224 Often following upon legislative or regulatory authorization or investigations, many states have authorized utilities to submit plans for pilot programs. They include Washington (Puget Sound Energy and Avista), New York (Consolidated Edison, National Grid, New York State Electric and Gas, and

Rochester Gas and Electric), California (PG&E, Southern California Edison, San Diego Gas & Electric), Michigan (DTE Electric), Minnesota (Xcel), and Virginia (Dominion Energy). See, for example, Merchant, E.F. (2018, January 17). *PG&E launches country's largest utility-sponsored EV charging program*. Greentech Media. Retrieved from <https://www.greentechmedia.com/articles/read/pge-launches-countrys-largest-utility-sponsored-ev-charging-program#gs.Ur4bY>

regulated services, up to 265 Level 2 chargers and seven DCFCs throughout its territory.²²⁵ Avista is required to submit quarterly reports on program participation levels, expenditures, and revenues for each service offered. Additionally, it is required to report the DCFC station locations, levels of utilization, and amount of overall fixed and variable costs recovered through user payments. All these data will help in determining the success of the program.

Not only is it important to get performance information as pilots proceed, but if that information is not available in time for the regulator to take meaningful corrective action if necessary, then it won't be as useful as it could be. Getting timely information is an important point and can be illustrated as follows.

Consider a situation in which the regulator determines the need to take corrective action with regard to, for example, a two-year pilot program, but the pilot requires only annual reporting. An annual report likely would come to the regulator in the first or second month of the second year. The earliest that staff might have a recommendation regarding any program adjustments would be March. Scheduling a hearing probably could take at least another month, putting it into April. For the regulator to reach any conclusions and direct any corrective actions could take another month or two—sending the timeline into May or June. And establishing a filing, review, and approval process for compliance with such an order could take an undetermined amount of time.

The point is that—in the context of a time-limited pilot—it makes little sense to rely on an annual report as a source for relevant and actionable information. It would be far more useful to have key metrics reported more regularly, and in a simple format.²²⁶

Ongoing Convenings

The data that EV pilots produce help the utility and regulators to determine how effectively programs are working

and whether improvements are needed. Conducting regular meetings among stakeholders, utilities, and regulators is another way to ensure the effectiveness of pilot programs. In a San Diego Gas & Electric EV pilot, for example, the CPUC's reporting, monitoring, and data collection requirements and rationale illustrate and provide insight into the topics regulators should consider.²²⁷ The CPUC order requires the utility to meet with commission staff every three months to provide updates on topics related to EV charging infrastructure installations, including:

- The amount of interest in locating EV sites at multi-unit dwellings and workplaces;
- The number of EV site installations that were approved, or that are in the pipeline, for deployment;
- The criteria used in selecting the installation sites;
- The number of EV site installations and EV charging stations the utility has deployed under its vehicle-grid integration program;
- The rate option the site hosts have chosen;
- The usage rates at these EV site installations and charging stations;
- The timing patterns of EV charging;
- The amount of program funds spent during the quarter and the cumulative amount spent; and
- Observable trends or correlations between the number of EV site installations deployed compared with EV charging use and growth in the number of EVs.

The CPUC order also requires semi-annual reports containing the information reported in the quarterly check-in meetings and a description of any program changes that San Diego Gas & Electric implemented prior to the date of the report.

Allowing Sufficient Flexibility

Policymakers may want to consider how much flexibility to provide entities charged with implementing EV pilots. As long as these entities are delivering measurable results that

225 Washington Utilities and Transportation Commission, 2017, paragraph 6, citing Docket UE-160082, Order 1.

226 The CPUC reporting requirements for a 2014 PG&E pilot program provide an excellent example. See Pacific Gas & Electric Co. (2017), *Electric vehicle charge network quarterly report*. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M196/K991/196991538.PDF>

227 California Public Utilities Commission, Application 14-04-014, Decision 16-01-045 on January 28, 2016, pp. 140-141. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M158/K241/158241020.PDF>

meet policy goals and objectives, it could be useful to grant them the leeway to propose the specifics of program design, implementation, and delivery and then to adjust and innovate in response to lessons being learned and changing market conditions.

Integrated Planning

Because existing policies can help or hinder beneficial electrification, it will be useful for states to consider how their policies affect opportunities associated with current innovations in the transportation sector.²²⁸ For example, states could use utility integrated resource planning (IRP) or a policy like it (known as integrated planning)²²⁹ to envision the potential for transportation electrification and its effects on the state's and region's power system.²³⁰

An integrated planning process provides utilities, regulators, and public participants the opportunity to take an in-depth look at the energy demands over an agreed-upon planning horizon, such as ten to 20 years. Fundamental to the success of IRP is credible modeling of projected demand trajectories. As states consider their ability to accommodate different types of EV charging needs, projecting various EV deployment scenarios to gain a better sense of that demand will be important.

IRP also provides the ability to look at available resources

and those that need to be acquired to meet projected demand reliably and at least cost. The analysis compares multiple alternatives and examines the costs, reliability, public policy compliance, and environmental impacts of each. The alternatives examined typically differ in cost and in environmental and reliability performance (beyond mandated requirements), so trade-offs among these performance outcomes can be evaluated by the utility, stakeholders, and the regulator.²³¹

As states consider their ability to accommodate different types of EV charging needs—especially charging that requires high capacity—they might find it useful to first inventory their subtransmission resources, and especially those that are underused or may have been abandoned.²³² Subtransmission lines are power lines that typically operate at a voltage below 100 kilovolts (kV), as illustrated by Figure 30.²³³ They are served by transmission lines whose typical voltages are above 100 kV.²³⁴ For example, in Vermont, Green Mountain Power's subtransmission system is served by Vermont Electric Power Co.'s 115-kV transmission system.²³⁵ Green Mountain Power is also interconnected to National Grid, a neighboring electric distribution company operating in New York and Massachusetts, in several locations at subtransmission voltages.

The value in looking at the existing subtransmission system in this context is that it may serve as EVSE.²³⁶ Vehicle charging could be an added use and produce an even greater

228 Utility commission or siting board processes granting a "certificate of public convenience and necessity" involve similar, though narrower, analyses to that conducted in the context of IRP. This would be another venue in which a state could engage in the analysis of reasonable alternatives to a proposed electrification or gas infrastructure project. Dworkin, M., Farnsworth, D., and Rich, J. (2001, June). The environmental duties of public utility commissions. *Pace Environmental Law Review*, 18(2), 335-382. Retrieved from <https://digitalcommons.pace.edu/pehr/vol18/iss2/7/>

229 EV adoption scenarios, and assessments of the grid and resource needs to reliably serve EVs, should be considered not just in an IRP context but also in the context of distribution system planning and transmission planning. This discussion focuses only on IRP.

230 In most states, the plan itself and particular investment decisions are not "approved" per se, but are found to be a reasonable guide to future actions. Actions recommended in the plan are also generally not preapproved by regulators, and, as conditions shift, the utility is expected to adapt its plans and decision-making. Lazar, J. (2016, July). *Electricity regulation in the US: A guide* (2nd edition), p. 92. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/electricity-regulation-in-the-us-a-guide-2/>

231 Lazar, 2016, p. 108.

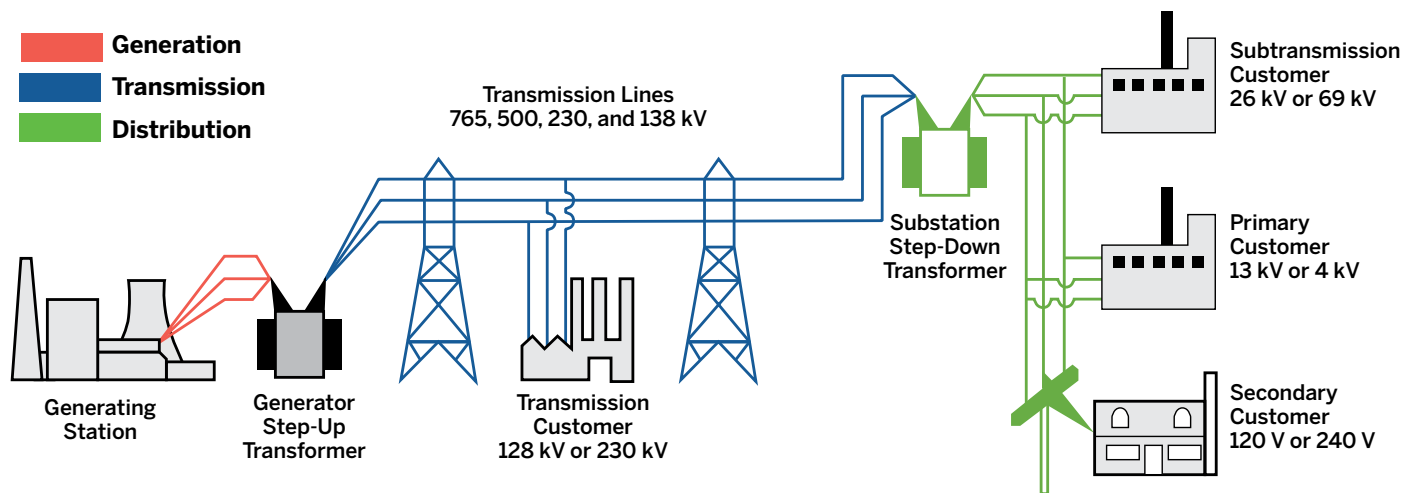
232 This idea was suggested by our colleague David Littell. Also, PG&E developed a guide and proprietary map tool enabling charging providers to identify sites with sufficient grid capacity and driver demand. See Pacific Gas & Electric Co. *Site information for electric vehicle direct current fast chargers* [Webpage]. Retrieved from https://www.pge.com/en_US/about-pge/environment/what-we-are-doing/electric-program-investment-charge/direct-current-electric-vehicle-fast-chargers.page

233 US-Canada Power System Outage Task Force. (2004, April). *Final report on the August 14, 2003 blackout in the United States and Canada: Causes and recommendations*. Retrieved from <https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf>

234 Vermont Electric Power Co. *Glossary of electric system terms*. Retrieved from <https://www.velco.com/about/learning-center/glossary>

235 The Vermont Electric Power Co. system is connected to bulk transmission systems administered by ISO New England, New York ISO, and Hydro-Québec at voltages of 115, 230, and 345 kV.

236 DCFCs require 150-kW service or higher.

Figure 30. The Subtransmission System

Source: US-Canada Power System Outage Task Force. (2004, April). *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations*.

return on these investments than was initially expected.²³⁷

This possible use of the subtransmission system can be expected to raise numerous questions:

- Are there available former power generation sites or switching stations, for example, containing functional transformers and related equipment?
- Are these sites capable of switching the direction of power—that is, no longer being used as a way of getting generation out to the rest of the system, but instead being used as a high-capacity means of getting energy delivered on site to charge vehicles?
- Are these sites capable of supporting the type of charging required by the types and number of vehicles that one might expect to come into a busy charging station over the course of a day?
- Are there sites near major highways where they would be especially suitable to support e-transportation, such as underutilized manufacturing facilities with high electric supply availability?

It should be emphasized that states and companies need not conduct formal IRP to prepare themselves to respond effectively to the challenges of developing e-transportation. Whether regulators rely upon formal IRP or another approach, the key will be to review plans for investments ahead of time in an integrated manner that lays out reasonable demand scenarios and explores all reasonable supply options.²³⁸

The value in having this structured look ahead, regardless of how formal the administrative process, lies in being able to identify a plan for growth and investment for the state before capital is committed to expenditures. The key question to answer: Will the approach adopted “remain cost-effective across a wide range of futures and sensitivity cases and also minimize adverse environmental consequences associated with its execution?”²³⁹

Here we have discussed integrated planning, largely within the framework of IRP. States can also use distribution system planning and transmission planning as analytical tools to help inform policy and investment choices. States can expect to

²³⁷ Although this discussion primarily considers repurposing old assets, a similar analysis could apply to establishing favorable locations for new charging sites.

²³⁸ This is the case in a traditionally regulated environment in which a utility will seek approval of expenditures. It is also the case with restructured states, where decisions about default service or transmission expansions, for example, can be shaped to reflect least-cost and least-risk opportunities. In both cases, the “least-cost” criterion implies “the lowest total cost over

the planning horizon, given the risks faced.” Lazar, J., and Farnsworth, D. (2011, October 28). *Incorporating environmental costs in electric rates: Working to ensure affordable compliance with public health and environmental regulations*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/incorporating-environmental-costs-in-electric-rates-working-to-ensure-affordable-compliance-with-public-health-and-environmental-regulations/>

²³⁹ Lazar, 2016.

have to develop new charging infrastructure as their transportation markets grow. However, as part of their planning for infrastructure that might need to be built to accommodate high-capacity charging, regulators will find it useful to know that utilities have first identified any existing infrastructure suitable for the purpose.

Energy Efficiency Standards and Programs

Beneficial electrification opportunities demonstrate that it is time to rethink traditional energy efficiency programs, measures, and metrics. For example, the metrics used in state energy efficiency resource standards offer another example of a state policy that may warrant revision in light of electrification.²⁴⁰ The most typical formulation for such a standard requires a regulated electric utility to annually obtain (by offering rebates and incentives) and document energy savings in kWhs that equal or exceed a specified percentage of the utility's retail sales of electricity in some prior year or years. Natural gas utilities may have similar obligations for obtaining energy savings in therms. These kinds of requirements can discourage BE and energy efficiency itself in at least two ways.

First, the standards and related performance incentives almost always set targets and measure energy savings in the sales units that apply to the regulated utility (that is, in kWhs for electric utilities or therms for natural gas utilities) rather than in terms of primary energy such as Btu or joules. But when an electric utility encourages beneficial electrification of an end use that had been powered by a fossil fuel, it isn't kWhs that are saved. It's therms, or gallons of gasoline or diesel. Consequently, even if electrification is efficient—meaning the electric option uses fewer Btu than the fossil-fueled alternative—the energy savings can't be applied

Metrics used in state energy efficiency resource standards may warrant revision in light of electrification.

toward the utility's obligation under the standard.

The second way in which a typically formulated energy efficiency resource standard discourages BE is that the electric utility's savings obligation increases when its kWh sales increase. So, the more the utility encourages electrification, the more energy savings it must obtain.

States could address these related barriers readily—for example, by including an electrification component, or carve-out, in their standards or reformulating their metrics for measuring reductions to reflect primary energy use or greenhouse gas emissions. They could also prevent increased kWh sales attributable to BE from adding to the energy savings requirement. New York state recently adopted a statewide cumulative annual site energy savings target that is delineated in Btu and will incentivize the most cost-effective efficiency measures across all fuels.²⁴¹ In the Wisconsin Quadrennial Review process, the Public Service Commission set energy savings goals for 2019-2022 in terms of kW, kWhs, therms, and million Btu.²⁴² Additionally, commissioners set fuel-specific minimum performance standards.

Some states also have prohibitions against utility programs to increase load, which can be expected to occur as electrification increases. Such provisions are unnecessary if electrification is beneficial, as it reduces or prevents increases in costs and environmental impacts for all ratepayers. This is why we encourage states to apply the three BE conditions to determine whether electrification programs and associated load growth are indeed in the public interest.²⁴³

240 Levin, E. (2018, August). *Getting from here to there: How efficiency programs can go beyond MWh savings to next-generation goals*. Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from https://aceee.org/files/proceedings/2018/node_modules/pdfjs-dist-viewer-min/build/minified/web/viewer.html?file=../assets/attachments/0194_0286_000100.pdf

from <https://www.nyserda.ny.gov/-/media/Files/Publications/New-Efficiency-New-York.pdf>

242 Public Service Commission of Wisconsin, Quadrennial Planning Process III, Docket 5-FE-101, Final Decision of June 6, 2018, pp. 12-13. Retrieved from http://apps.psc.wi.gov/vs2015/ERF_view/viewdoc.aspx?docid=343909

241 New York State Energy Research and Development Authority and Department of Public Service. (2018). *New efficiency*. New York. Retrieved

243 Farnsworth et al., 2018, p. 9.

Decoupling Mechanisms

More than half of states have decoupling mechanisms used to break the link between sales volumes and earnings. These have been important in promoting energy efficiency without hurting utility shareholder returns but may pose a challenge to electrification. If decoupling mechanisms allow a fixed amount of revenue per customer, but electrification requires modest increases in utility investment in supply and distribution plant, there may be no means to recover the increased costs. For example, a family with two EVs may require installation of a larger distribution transformer to enable both vehicles to be charged at the same time during low-cost and low-emissions hours. This is a simple matter to ameliorate for a narrowly defined set of investments, but it cannot be ignored.

Rate Design

The engineering and economic truth about load associated with transportation electrification is that it is flexible and controllable. Unlike during the past century when electricity generated needed to be consumed at virtually the same time, vehicle charging occurs at times other than when the vehicle is being used. And because of this, charging can be managed over the course of the day in response to conditions on the grid. We have moved from a power system once focused on providing adequate supply for anticipated demand, to a system where active supply and active demand can be optimized continuously to ensure balance.

Today, the challenge is increasingly to ensure that the power system is able to use demand and supply resources together to ensure reliability at least cost. Innovative technology (such as smart thermostats, controlled water heating, and smart EV charging) allows utilities and customers to make more granular decisions about their energy use. Storage capacity in EVs, for example, offers unprecedented opportunities to schedule charging and absorb greater variable energy resource production.

This is the point of RAP's second BE condition: enables better grid management. EV charging flexibility creates value for:

- Utilities, through load shifting (including reduced variable energy resources curtailment) and the provision of ancillary services; and
- Consumers, who, through time-sensitive rate designs, can charge their vehicles in ways that are advantageous to themselves, the utility company, and the environment.²⁴⁴

As EV charging load increases demand on our power grids, it is incumbent on utilities and regulators to ensure that existing resources are managed to optimize this increased demand and that all ratepayers share equitably in the economic benefits of smart grid management. Providing EV customers with clear price signals through rate design is one key to achieving this. Well-designed rate structures will lead to EV charging that is aligned with grid needs, help increase utilization of existing resources, and reduce costs for all ratepayers. In contrast, poorly designed rates may lead to increased system costs, which can result in higher rates. This section discusses how rate design for residential, commercial, and public charging customers can maximize the grid management benefits of EVs and avoid potential pitfalls that could slow the transition to electric transportation.

Using Residential Rates to Send Price Signals

Typical residential rates in the US consist of a fixed monthly charge and an energy charge, which is a price per kWh of consumption. Most residential rates apply a flat energy charge—that is, one that does not vary over the course of the day or year.²⁴⁵ This pricing does not give EV drivers a clear signal to charge in a way that reflects grid conditions. Rather, customers will likely charge whenever it is easiest for them because the cost is the same during all hours. It does not communicate that at some times of the day, power is much

²⁴⁴ "Time-sensitive" rate designs include time-of-use and critical peak pricing designs.

²⁴⁵ The vast majority of residential rate structures do not include a demand charge, a feature of rate design that is discussed in more detail on Page 67.

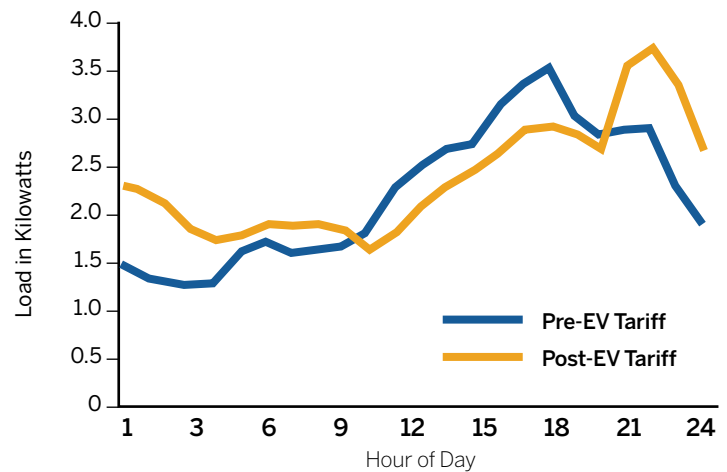
However, some utilities are beginning to propose such charges for residential customers, and the issues we will identify for commercial, industrial, and public charging rate design could become real issues for residential EV rate design as well. In January 2018, Massachusetts became the first state to approve such a rate structure, for customers of the Eversource utility.

cheaper to produce and deliver. Nor does it communicate that at certain times EV charging would be beneficial to grid management because it would increase utilization of existing assets during otherwise low-usage hours. Flat rates also do little to encourage EV adoption, by giving EV drivers no opportunity to obtain very low-cost transportation fuel.

Time-varying energy charges are better able to accomplish these objectives. Standard TOU rates typically consist of two or more pricing levels based on predetermined time periods. EV drivers can, by choosing to charge less during system peak hours and more during off-peak times, benefit the grid and reduce their costs. TOU rates also have the advantage of being relatively simple for customers to respond to because they know the time periods in advance and can use smart chargers and other “set it and forget it” technology to easily respond. Figure 31²⁴⁶ shows how a three-tiered TOU rate might look compared with a flat rate.²⁴⁷

“Whole house” TOU rates apply to all of a customer’s load, and EV-only rates apply just to the EV charging portion of the load. Both are effective at encouraging customers to charge EVs off peak. Baltimore Gas and Electric tested how EV-driving customers would respond to a whole-house TOU

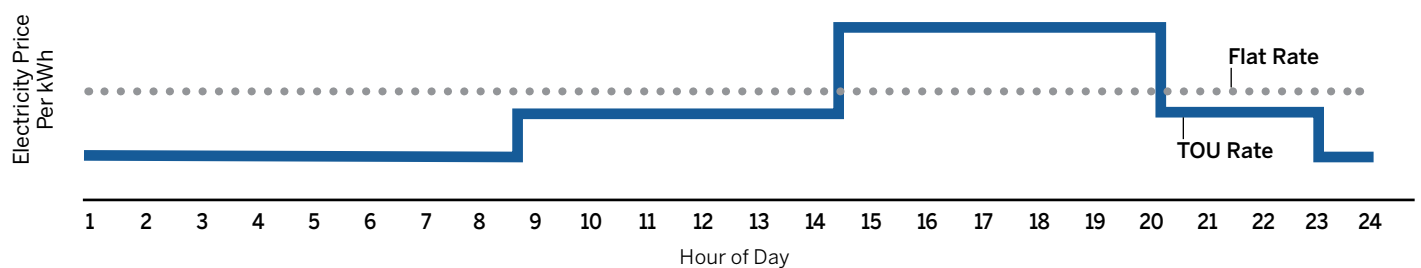
Figure 32. Customers on Time-of-Use Rates Shift Their EV Charging Away From Peak Periods



Source: Murach, J. (2017). *BGE Electric Vehicle Off Peak Charging Pilot*.

rate and found that customer peak load shifted to later evening hours and away from the system peak time of 6 p.m. (see Figure 32).²⁴⁸ PG&E customers who have enrolled in EV-only rates conduct 93 percent of EV charging off peak; on Southern California Edison’s EV-only rate, 88 percent of charging is off-peak.²⁴⁹

Figure 31. Illustrative Time-of-Use Pricing



Source: Whited, M., Allison, A., and Wilson, R. (2018, June 25). *Driving Transportation Electrification Forward in New York: Considerations for Effective Transportation Electrification Rate Design*.

²⁴⁶ Whited, M., Allison, A., and Wilson, R. (2018, June 25). *Driving transportation electrification forward in New York: Considerations for effective transportation electrification rate design*. Cambridge, MA: Synapse Energy Economics. Retrieved from <http://www.synapse-energy.com/sites/default/files/NY-EV-Rate-%20Report-18-021>.

²⁴⁷ Critical peak pricing and peak-time rebates are other forms of time-varying pricing that could be used to communicate cost implications to customers and encourage off-peak charging. For more information on these rate structures, see Lazar, J., and Gonzalez, W. (2015). *Smart rate design for a*

smart future. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/smart-rate-design-for-a-smart-future>

²⁴⁸ Murach, J. (2017). *BGE electric vehicle off peak charging pilot* [Presentation]. Baltimore Gas and Electric Co. Retrieved from <http://www.madrionline.org/wp-content/uploads/2017/06/BGE-EV-rate-design-pilot.pdf>

²⁴⁹ Whited et al., 2018.

EV Barriers in Commercial and Industrial Rate Design

Time-varying rates are more commonly used in standard tariffs for larger commercial and industrial (C&I) customers. For the same reasons as articulated above, time-varying energy charges in C&I rates that reflect shared system costs will be effective at communicating the times at which EV charging will benefit the grid. For example, in places with growing quantities of solar on the grid, workplace charging in the middle of the day can take advantage of cheaper and cleaner power and help smooth out a utility's load curve.

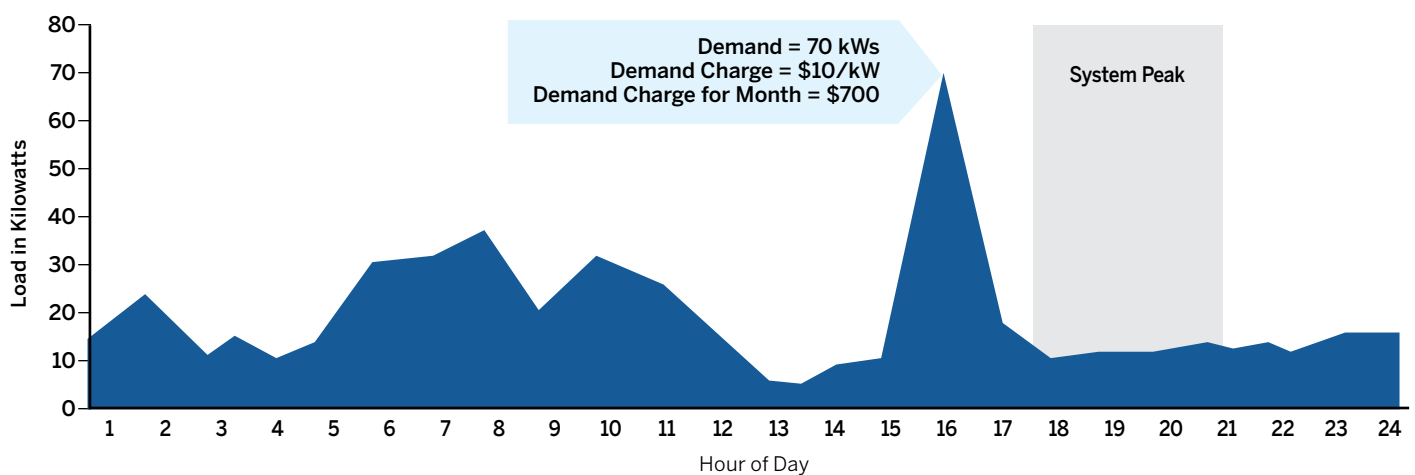
In addition to time-varying rates, large-customer rates historically have included a demand charge. Rather than being based on when and how much energy is consumed, demand charges are assessed on the customer's maximum peak demand (measured in kW) during a month. Customer demand is sometimes measured at the same time as the system's peak period (to calculate what are called coincident peak demand charges), but often is measured whenever the customer's individual peak demand occurs, regardless of time. Charges calculated this

Demand charges should be limited to recovering customer-specific costs. Shared costs should be recovered through systemwide time-varying energy charges.

way are called non-coincident peak demand charges. Figure 33 shows an illustrative example.

Demand charges, especially non-coincident peak demand charges, pose a significant challenge to the economics of EV charging, particularly at commercial and public charging locations.²⁵⁰ Demand charges are meant to reflect the incremental capacity costs the utility must incur to serve an individual customer's peak demand. These charges should be limited to recovering customer-specific costs, such as the proximate transformer and any dedicated facilities installed specifically to meet customer demand, but should not include recovery of costs for shared distribution and transmission infrastructure. Such shared costs should be recovered through systemwide time-varying energy charges.²⁵¹ Doing so will align with fundamental goals of rate design, such as communicating cost

Figure 33. Illustrative Non-Coincident Peak Demand Charge



250 This discussion focuses on non-coincident peak demand charges, but coincident peak demand charges also pose challenges for EV charging. Coincident peak demand charges are often used to recover costs associated with serving system peak demand. For more discussion of the merits of C&I rate design options, see Linvill, C., Lazar, J., Dupuy, M., Shipley, J., and Brutkoski, D. (2017). *Smart non-residential rate design*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <http://www.raponline.org/knowledge-center/smart-nonresidential-rate-design/>. In particular, on

Page 25 the authors discuss the benefits of using critical peak pricing (an energy charge that is significantly higher during a limited number of hours per year) for recovering costs that are specifically associated with meeting peak demand, and the relative merits and drawbacks of using a coincident peak demand charge for accomplishing the same task.

251 For more on RAP rate design principles, see Lazar and Gonzalez, 2015, and Linvill et al., 2017.

information and aligning cost causation with prices, but also will encourage customers to shift load where it is feasible and valuable and to control or reduce load when it is worthwhile to do so.

In addition to the need to design rates that better communicate system cost information, demand charges should be reconsidered in light of their impacts on the economics of EV charging. Demand charges are based on the highest instantaneous usage at a given location. Because vehicle charging can cause spikes in demand, charging can trigger a high demand charge. Demand charges can effectively become a fixed charge that cannot be avoided by better managing EV charging into lower-cost times of day. For businesses subject to a demand charge in their tariff, installing electric vehicle charging can greatly increase their monthly utility bills, creating a major deterrent to providing charging to employees or patrons.

A demand charge that is passed on to drivers for use of the charging station can increase the per-kWh cost to charge, with the demand charge being responsible for a very large portion of the bill. As the per-kWh cost for drivers increases, electric vehicles’ economic advantage over gasoline cars will decrease. In particular, demand charges can lead to expenses for charging that are close to or higher than the equivalent cost of gasoline, which is 38 cents per kWh for our representative vehicles.²⁵² This is perhaps best illustrated with an example. Table 9 shows how a typical rate design for a commercial customer would affect the per-kWh charge for an electric vehicle if charger use were relatively low (250 kWhs per month). The rate design includes a non-coincident peak demand charge of

Table 9. Illustrative Standard Commercial Rate Design and Impact on Economics of EV Charging

	Rate	Usage	Cost
Non-coincident peak demand charge	\$10/kW	6.6 kW	\$66.00
Energy charge (not time-differentiated)	\$0.12/kWh	250 kWhs	\$30.00
Total bill			\$96.00
Average per kWh			\$0.384

252 This assumes vehicle efficiencies the same as the Chevrolet Bolt and Volkswagen Golf discussed earlier (3.57 miles/kWh and 28 miles per gallon, respectively) and gas costing \$3 per gallon.

Table 10. Illustrative Smart Commercial Rate Design and Impact on Economics of EV Charging

	Rate	Usage	Cost
Non-coincident peak demand charge	\$2/kW	6.6 kW	\$13.20
Energy charge	\$0.05 to \$0.75/kWh	250 kWhs	\$12.50 (assumes off-peak charging)
Total bill			\$25.70
Average per kWh			\$0.103

\$10 per kW and a non-time-differentiated energy charge of 12 cents per kWh. The charger itself draws a demand of 6.6 kW.

In contrast, a rate design with a demand charge that recovers just the customer-specific site infrastructure costs and includes a time-differentiated energy charge would have a very different result for the same charger, illustrated in Table 10.

Southern California Edison recently proposed, and had approved by the CPUC, a new tariff design for commercial customers that eliminates demand charges for the first five years of the program. The charge will be phased back in over the following five years, as EV adoption is expected to grow. With higher utilization rates, the per-kWh costs at individual chargers will decline, making the impact of demand charges more manageable from the perspective of an individual driver or commercial business that wishes to offer EV charging.

EV Barriers in Public Charging Rate Design

Public charging via DCFC stations faces similar challenges with respect to rate design as we described for larger customers. In fact, many DCFC stations are billed on a commercial rate, and the difficulties that demand charges pose for charging economics are much more pronounced for these stations. Most DCFC stations have low overall usage (in total kWhs) but have significant spikes in demand due to the high power delivery nature of the chargers. This means demand charges can be significant portions of the overall bill for public chargers—accounting for more than 90 percent of costs at some chargers in California.²⁵³ This can make

253 Fitzgerald, G., and Nelder, C. (2017, March). *EVgo fleet and tariff analysis—Phase 1: California*. Boulder, CO: Rocky Mountain Institute. Retrieved from https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2017/04/eLab_EVgo_Fleet_and_Tariff_Analysis_2017.pdf

Table 11. Illustrative Standard Commercial Rate Design and Impact on Economics of Fast EV Charging

	Rate	Usage	Cost
Non-coincident peak demand charge	\$10/kW	100 kW	\$1,000.00
Energy charge (not time-differentiated)	\$0.12/kWh	1,000 kWh	\$120.00
Total bill			\$1,120.00
Average per kWh			\$1.12

the economics of charging at these stations very difficult, particularly while utilization rates are low.

The tables on this page describe an example. Consider a public charging station with two 50-kW chargers; if two vehicles were to use it at the same time, the total demand would be 100 kW.²⁵⁴ If each charging session lasts one hour and there are ten sessions per month, the monthly energy usage would be 1,000 kWh. On a tariff with a demand charge of \$10 per kW and an energy charge of 12 cents per kWh, the demand charge will represent 90 percent of the total bill and lead to a per-kWh charge nearly three times the equivalent cost of gasoline (see Table 11). Doubling the usage of the charging station to 20 sessions per month would only reduce that per-kWh charge to 62 cents—still too high to make economic sense for drivers.

By just reducing the demand charge to \$2 per kW, the economics for drivers look better,²⁵⁵ putting the per-kWh expense more in line with the equivalent cost of gasoline (see Table 12).

Table 12. Illustrative Smart Commercial Rate Design and Impact on Economics of Fast EV Charging

	Rate	Usage	Cost
Non-coincident peak demand charge	\$2/kW	100 kW	\$200.00
Energy charge	\$0.12/kWh	1,000 kWh	\$120.00
Total bill			\$320.00
Average per kWh			\$0.32

254 The two vehicles would need to be charging at the same time only once during the month in order to hit this demand level.

255 We are leaving the energy charge assumption the same as in Table 11, because we assume drivers who use public chargers will do so when they need a charge and will end up paying whatever the energy charge is at that time. It could be during a peak hour, in which case the rate likely would be higher than our example of 12 cents, or it could be an off-peak time likely

Public Transit Fleets and Demand Charges

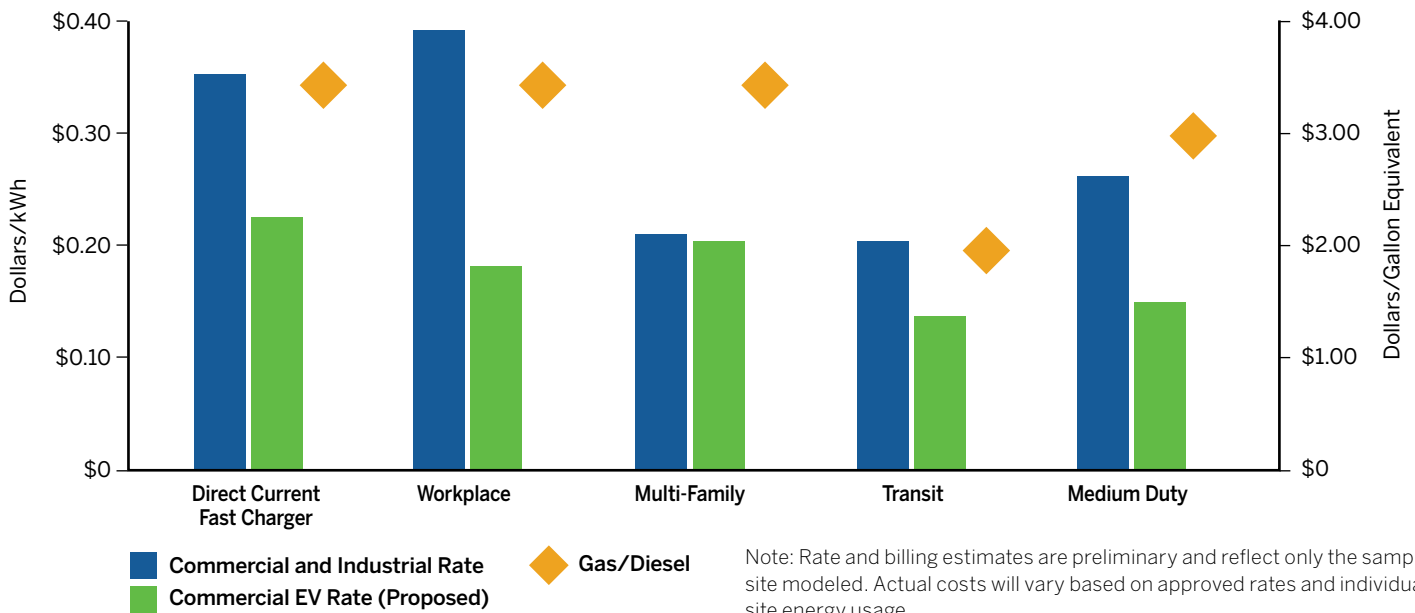
Using demand charges to recover costs other than those directly associated with dedicated facilities installed specifically to meet customer demand poses significant challenges for the economics of electrifying public transit fleets. Public transit fleet chargers face many of the same challenges as public fast chargers: Demand spikes can be significant due to the need to charge a large vehicle quickly, but overall utilization of charging infrastructure may be low (at least in early stages). This can make the cost per mile for going electric prohibitive. Fleet managers will need to charge buses in a manner that meets route scheduling needs and may not be able to schedule charging over longer time periods in order to reduce demand levels. Helping public transit fleets to electrify by designing rate structures with low (or no) demand charges—at least while utilization is expected to be low—is one way for utilities to encourage beneficial electrification and build “good” load at the same time. PG&E’s newly proposed EV commercial tariffs are an example of rate structures that will make a significant difference for transit operators, bringing the expected average fuel cost well below that of diesel. See below for more on the company’s proposal.

This illustrates the essential challenge for public charging infrastructure: While utilization is low, the economics for public charging are more difficult, but too few charging stations and poor rate design can hinder greater EV adoption. In early years, it may make sense to eliminate demand charges for public charging infrastructure to reduce costs for drivers and encourage more widespread adoption.

In November 2018, PG&E proposed a C&I rate design that, if approved, could address some of the challenges with demand charges we describe.²⁵⁶ The proposal would apply to smaller workplaces and multi-family dwellings, as well as larger

to carry a lower rate. The time-varying energy charge levels will be utility-specific.

256 Pacific Gas & Electric Co. (2018, November 5). *PG&E proposes to establish new commercial electric vehicle rate class*. Retrieved from https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20181105_pge_proposes_to_establish_new_commercial_electric_vehicle_rate_class

Figure 34. Estimated Average Charging Costs Under Current and Proposed PG&E Rate

Source: Pacific Gas & Electric Co. (2018, November 20). *PG&E Commercial EV Rate Proposal*.

installations such as those for public fast chargers. With this rate design, the company proposes to replace demand charges with “subscription pricing,” a monthly fee that allows customers to choose the amount of power based on their charging needs. For example, a customer will pay a certain price for a 50-kW connection. If that demand is exceeded during the month, the customer pays an overage, but the subscription price does not change. In other words, the overage does not establish a new demand level (as would be typical of demand charges) that could automatically ratchet up a demand charge. Energy usage under this proposal will be based on TOU pricing with peak, partial-peak, and off-peak rates. PG&E expects this design to result in significant savings over existing C&I rates, particularly for fast charging and workplace charging, as shown in Figure 34.²⁵⁷

In conclusion, rate design can ensure that the price signals sent to customers reflect power system needs. Through lower costs, rate design can encourage customers to help with integrating variable energy resources and contributing to grid

reliability. The lower cost of variable resources and the automation associated with end uses and other parts of the power system are not only making customer contributions to the grid possible, they are making them valuable. Time-varying rates can be designed to help utilities and customers take advantage of these opportunities to shift and control load when it benefits the system. And time-varying rates can refine and direct price signals, helping grid managers while saving consumers money. Unless they adopt these kinds of rates, states are less likely to see investment in EVs and more likely to require distribution system investment to accommodate unnecessary costs associated with increasing system peaks.

Licensing Third-Party Charging Service Providers

In addition to enabling and promoting e-transportation investments by regulated utilities, states may want to allow third-party entities to operate as charging service providers. However, because charging service providers, like regulated

²⁵⁷ Pacific Gas & Electric Co. (2018, November 20). *PG&E commercial EV rate proposal* [Presentation]. Retrieved from <https://caltransit.org/cta/assets/>

File/Webinar%20Elements/WEBINAR-PGE%20Rate%20Design%2011-20-18.pdf. C&I rates depicted are from 2017 General Rate Case Phase 2.

utilities, sell electricity, states will face the question of how to regulate these entities. Should businesses engaged in charging vehicles be licensed and regulated like utilities? Or should they be treated like competitive retail service providers subject

to a certification process that reviews their qualifications and conditions for service? Private investors may look for clarity on these questions as they decide whether and how much to invest in EVSE within a state.

Because utility service requirements are established and enforced under state authority, states have ultimate responsibility for answering these questions. The trend appears to be for state legislatures to exempt third-party charging service providers from typical public utility regulation.²⁵⁸ In the absence of legislative action, some utility commissions have reached similar decisions.²⁵⁹ Not all states or state commissions have explicitly addressed this question.

Although typically a competitive supplier that is certified would not face price regulation, some oversight may be

Should businesses engaged in charging vehicles be licensed and regulated like utilities? Or should they be treated like competitive retail service providers?

appropriate in the nascent stages of this market development. For example, when someone driving on a highway needs to stop and recharge, it may not be like finding a gas station, with multiple options and the ability to drive on another 30 miles if necessary. Instead there may be only one charging station available. Until multiple charging stations are available that can compete with one another, that sole charging station on the highway is operating as a de facto monopoly supplier. However states choose to proceed, it will be important to have adequate consumer protections in place to ensure that providers give good customer service and follow reasonable practices. These could include such things as transparency, price disclosure, and perhaps a price cap based on equivalent cost of gasoline.

258 For example, HI Revised Statutes, § 269-1; MD Code Annotated, § 2-113, § 1-101, (j) 3. iii; and Revised Code of WA, 80.28.320, 2011. Maine's Legislature has declared that third-party charging service providers do not fall within the definition of "public utility." Notably, however, Maine's law restricts such providers that submeter from charging for more than "kilowatt-hours used." See ME Revised Statutes Annotated, Title 35A § 313-A. Retrieved from <http://legislature.maine.gov/legis/statutes/35-A/title35-Asec313-A.html>.

259 For example, Massachusetts Department of Public Utilities, Docket 13-182A, Order on Department Jurisdiction Over Electric Vehicles, the Role of Distribution Companies in Electric Vehicle Charging and Other Matters, August 4, 2014. Retrieved from <https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/9233599>. See also New York Public Service Commission, Case 13_E_0199, Declaratory Ruling on Jurisdiction Over Publicly Available Electric Vehicle Charging Stations, November 22, 2013.

Conclusion

Beneficial electrification provides one of the biggest opportunities in the power sector today to connect consumers with far more affordable and cleaner resources and to help utilities better manage the grid and reduce harm to the environment and public health. It is an economical and practical path forward for saving consumers money, improving flexible management of the power grid, and reducing transportation-related greenhouse gas emissions.

In this paper, we have applied RAP's three beneficial electrification conditions to two specific opportunities—

Beneficial electrification is an economical and practical path forward for saving consumers money, improving grid management, and reducing emissions.

electrifying passenger vehicles and transit buses—to illustrate that electric transportation benefits are achievable today. Decision-makers will play a crucial role in ensuring that transportation electrification proceeds in a beneficial manner and that the opportunities it creates will be available in all states and to all consumers.

Appendix: Revisiting the Gas Tax

As they electrify their transportation sectors, states will need to consider how best to incorporate electric vehicles (EVs), electric buses, and other vehicles using electricity as fuel into the way they fund transportation sector construction and maintenance. In recent years, various taxes and other mechanisms have been unable to keep up with transportation infrastructure costs. These mechanisms are also designed largely without regard for the ways bridge and roadway costs are incurred. Here, we look at how transportation infrastructure has been funded and recommend how states can improve on that track record as they consider how the addition of electrified transport will contribute to maintaining and improving our transportation infrastructure.

Background

The American Society of Civil Engineers periodically characterizes the condition and performance of the nation's infrastructure. In 2017, the society gave an overall score of D-minus, which includes a C-plus for bridges, a D for roads, and a D-minus for public transit.²⁶⁰ The US Chamber of Commerce echoes these conclusions: "America's infrastructure is in terrible condition."²⁶¹

According to the 2017 American Society of Civil Engineers report, "the U.S. has been underfunding its highway system

for years," resulting in a \$543 billion backlog of highway and bridge repairs.²⁶² Federal investment in highways has historically been paid for from the dedicated Highway Trust Fund, supported by user fees.²⁶³ However, the fund has come close to insolvency for many years due to the limitations of its primary funding source, the federal motor fuels tax—a tax per gallon of gasoline and diesel that has not been raised for 25 years.²⁶⁴ (Although it applies to both fuels, we refer to it as a gas tax.)

In discussing the design of the federal gas tax, the Institute on Taxation and Economic Policy in 2014 identified two reasons for the tax's growing ineffectiveness.²⁶⁵ The first is that fuel efficiency of automobiles has improved. The institute estimated that since 1997, fuel efficiency gains reduced federal gas tax purchasing power by 6 percent. The second reason—which has far greater consequence—is the rising cost of construction. The Institute on Taxation and Economic Policy estimated

Roadway Funding Mechanisms

- Gasoline and other fuel taxes per gallon;
- Annual registration fees;
- Annual gross weight fee;
- Sales tax;
- Property taxes;
- Per-mile charge; and
- Developer impact and mitigation fees.

260 American Society of Civil Engineers. *2017 Infrastructure report card*. Retrieved from <https://www.infrastructurereportcard.org/wp-content/uploads/2017/10/Full-2017-Report-Card-FINAL.pdf>. A grade of D indicates that the "infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of serious concern with strong risk of failure."

261 US Chamber of Commerce. (2018). *Roadmap to modernizing America's infrastructure*. Retrieved from <https://www.uschamber.com/lets-rebuild-america>

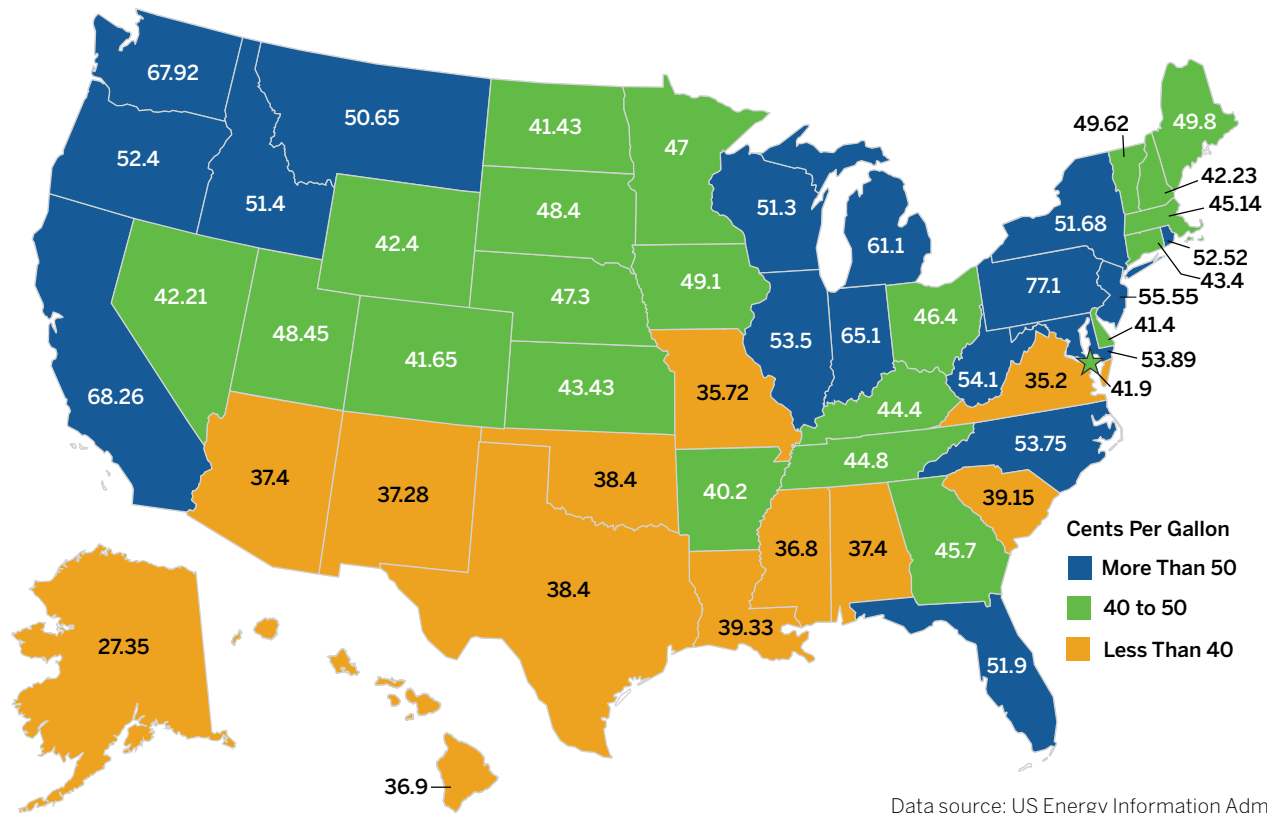
262 American Society of Civil Engineers, 2017.

263 The fund is also supported through congressional authorizations and Treasury general fund revenues. Federal Highway Administration. (2017).

Funding federal-aid highways (Publication No. FHWA-PL-17-011). Washington, DC: Author. Retrieved from https://www.fhwa.dot.gov/policy/olsp/fundingfederalaid/FFAH_2017.pdf

264 The tax of 18.4 cents per gallon for gasoline and 24.4 cents for diesel has remained the same since 1993. Institute on Taxation and Economic Policy. (2014, May). *The federal gas tax: Long overdue for reform*. Washington, DC: Author. Retrieved from <https://itep.org/wp-content/uploads/pb43fedgastax.pdf>

265 The Congressional Budget Office projects that the revenues credited to the highway and transit accounts of the Highway Trust Fund will be insufficient to meet the fund's obligations by 2026. Hall, K. (2016, September 9). [Letter to Sen. Jim Inhofe, chairman of the Committee on Environment and Public Works]. Retrieved from <https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/costestimate/inhofeletteraugust2016htf.pdf>

Figure 35. Gasoline Taxes: Combined State and Federal

Data source: US Energy Information Administration.

that since 1997, the increase in transportation construction costs reduced the purchasing power of the federal gas tax by 22 percent. Together, these factors have caused the gas tax to lose 28 percent of its value since 1997.²⁶⁶ More recently, the US Chamber of Commerce has argued that inflation has eroded nearly 40 percent of the federal gas tax's value.²⁶⁷

States also fund road and bridge construction and maintenance through numerous mechanisms, including a gas tax. States assess these taxes in different ways, including a per-gallon tax collected at the pump and a value-added tax on the wholesale price of a gallon.²⁶⁸

Other measures states use include tolls and licensing fees. The Tax Foundation reports that, as of fiscal year 2013,

the revenue from these different approaches covered just 41.4 percent of state and local road spending and is losing purchasing power to the degree that states don't index taxes to inflation.²⁶⁹ Figure 35 shows the combined state and federal gasoline taxes in each state.²⁷⁰

Perceiving that non-gasoline vehicles don't pay their share, several states are considering mechanisms to ensure that EVs also contribute.²⁷¹ As of the summer of 2017, 17 states had adopted registration fees, and two states were considering fees based on vehicle miles traveled.²⁷² As states go forward with such efforts, we recommend they first reconsider how to allocate roadway costs equitably among users—that is, in light of the construction and maintenance costs they create.

266 Institute on Taxation and Economic Policy, 2014.

267 US Chamber of Commerce, 2018.

268 Drenkard, S. (2017, January 27). State gasoline tax rates in 2017 [Blog post]. Tax Foundation. Retrieved from <https://taxfoundation.org/state-gasoline-tax-rates-2017>

269 Drenkard, 2017.

270 Based on US Energy Information Administration state-by-state fuel tax data. Retrieved from <https://www.eia.gov/tools/faqs/faq.php?id=10&t=10>

271 Spector, J., and Pyper, J. (2017, July 5). *Updated: 17 states now charge fees for electric vehicles*. Greentech Media. Retrieved from <https://www.greentechmedia.com/articles/read/13-states-now-charge-fees-for-electric-vehicles#gs.sxcV5=c>

272 Spector and Pyper, 2017.

Spreading the Costs

Before continuing, we want to recognize that we are asking utility regulators to consider transportation sector funding, a key aspect of transportation policymaking. We do this because electrification is obviously connecting the utility sector with the transportation sector, but also because utility regulators are especially well-suited to this type of discussion. Understanding how EVs should contribute to the development and maintenance of the transportation system is a cost-of-service question, the type regulators face every day. Utility rates, like transportation funding, include distinct elements that together determine the utility’s overall revenue requirements, the portion to be derived from each class of user, and the rates by which these will be recovered from individual consumers.

Many cost-of-service principles are equally applicable to transportation sector issues. Electric utilities and transportation agencies, for example, face:

- A mix of heavy industrial users and small residential users;
- High-use peak periods and costs, as well as low-use and off-peak periods and costs. (Utility cost allocation studies consider both size and character of the usage of each class, and costs.);
- A similar system structure. Roadways (and electric grids) are networks, with arterial roadways (transmission lines carrying heavy loads) tied to residential streets and rural roads (distribution power lines carrying lighter loads); and
- Vastly different costs for construction and maintenance of different types of roads (or power lines).

To use utility regulatory language: Current highway cost allocation and rate design frameworks do not track these cost drivers well.²⁷³ Although electric utility cost allocation studies

Table 13. User Fee Payments Relative to Allocated Costs

Vehicle class	Portion of allocated costs paid in fees (federal and state)
Autos	100%
Single-unit trucks (pounds)	
25,000 or less	190%
25,001 to 50,000	80%
50,001 or more	50%
Combination trucks (pounds)	
50,000 or less	160%
50,001 to 70,000	110%
70,001 to 75,000	100%
75,001 to 80,000	90%
More than 80,000	90%

Source: Based on Federal Highway Administration. (1997). 1997 Cost Allocation Study Final Report.

are performed every few years, there has been a fairly limited amount of work on highway cost allocation. But the principles are well-developed: Traffic volume, vehicle weight, and vehicle length are primary drivers of highway construction and maintenance costs. The Federal Highway Administration’s most recent full study of cost allocation estimated that automobiles pay their appropriate share of allocated federal and state highway costs but most trucks do not.²⁷⁴ Table 13 summarizes these findings.²⁷⁵ The federal government has not updated this study for many years, however.²⁷⁶

A 2017 Oregon highway cost allocation study articulates the central purpose behind identifying cost causation:

Cost responsibility is the principle that those who use the public roads should pay for them and, more specifically, that users should pay in proportion to the road costs for which they are responsible.²⁷⁷

273 We recognize that roadway costs are a small part of the total costs of driving. See Victoria Transport Policy Institute. (2016, October). *Transportation cost and benefit analysis: Techniques, estimates and implications* (2nd edition). Retrieved from <http://www.vtpi.org/tca/>

274 Federal Highway Administration. (1997). *1997 Cost allocation study final report*. Washington, DC: Author. Retrieved from <https://www.fhwa.dot.gov/policy/hcas/final/toc.cfm>

275 Based on Federal Highway Administration, 1997, Table ES-5.

276 An addendum in 2000 reported similar inequities. Federal Highway Administration. (2000). *Addendum to the 1997 cost allocation study final report*. Washington, DC: Author. Retrieved from <https://www.fhwa.dot.gov/policy/hcas/addendum.cfm>

277 ECONorthwest. (2017). *Oregon highway cost allocation study*, p. 3. Oregon Department of Administrative Services. Retrieved from <https://www.oregon.gov/das/OEA/Documents/2017report.pdf>

Roadway costs consist of distinct construction and maintenance expenses. Construction costs include those associated with corridor land acquisition; the initial design and construction of new roads with adequate capacity to carry anticipated types and volumes of traffic; and adjustments to the design and capacity of simple roads to carry heavier and wider vehicles. Heavy vehicles require stronger roads, and wider vehicles require wider roads. Both requirements increase costs.

To build state highways, interstate highways, and some arterial roadways within cities, government makes capital expenditures to acquire land. When roads are widened, additional land often must be acquired. These costs are generally proportional to the width of the corridor.

In the case of new residential developments or subdivisions, the land use approval process normally requires the real estate developer to provide residential streets, so there is no capital cost to the municipality for constructing these roads. There are maintenance costs, however, which we will address.

Cars are 5 to 6 feet wide. Trucks are up to 8.5 feet wide. Roadway lanes must be about 9 feet wide to accommodate car traffic, but up to 12 feet wide to accommodate truck traffic. Thus, about 75 percent of the width-related costs of roadways are attributable to all traffic (cars and trucks), but 25 percent should be assigned exclusively to truck traffic. Neither fuel taxes nor registration fees reflect this.

Construction costs for a road with 9-foot lanes and sufficient strength to carry auto traffic (such as asphalt 2 to 4 inches thick) should be assigned to all traffic, as part of having roadway capacity. Any incremental width and strength demands (for example, lanes 12 feet wide, roadbeds up to 24 inches thick, and concrete or asphalt layers up to 8 inches thick) are truck-related costs and should be assigned exclusively to wider and heavier trucks. Current roadway funding schemes do not do this.

Maintenance costs include expenses related to weather and time that do not vary with usage. They also include usage-related costs associated with wear and tear from vehicles, which increases exponentially with heavier vehicles and varies

with lane width needed for wider vehicles.

Some maintenance costs are a function of weathering. Asphalt absorbs moisture, which freezes, resulting in potholes. Earth movement from earthquakes and land subsidence shifts the soil and damages roads. These costs are largely unrelated to usage. In the absence of a way to equitably allocate such costs, it would be reasonable to assign them to all users.

Most major highway maintenance costs, however, are related to usage. Highways with more and heavier traffic require more maintenance. And that maintenance is much more expensive, as lanes must be closed for hours (often overnight) at considerable expense. Although residential streets may be maintained with a light treatment (for example, every few decades), arterial roads require resurfacing at much shorter intervals and complete “grind and overlay” maintenance closer to every decade. This is usage-related maintenance. It is reasonable to assign these costs on the basis of traffic volume, weight, and width.

Light vehicles seldom exceed the elastic limits of roadways and cause very little wear-related maintenance requirement. Studded tires cause significant damage to roadway surfaces. And heavy vehicles cause the clear majority of roadway structure damage.

Because approximately 25 percent of the roadway width for highways is exclusively needed for large trucks, so should 25 percent of maintenance be assigned exclusively to these vehicles. All traffic should share the balance, but in proportion to the wear caused by different vehicle weights, with the impacts growing exponentially, not linearly, with increased weight.

Table 14 illustrates the roadway impact, per gallon, of typical cars, pickup trucks, and heavy trucks.²⁷⁸ Because of its greater width and weight, a pickup has a roadway impact that is nearly 3 times that of a car. But because a car is 50 percent more fuel-efficient than a pickup, the pickup pays only 1.5 times as much through fuel taxes. Given its width and weight, the heavy truck has 34 times the roadway impact of a car but pays only 6 times as much toward those costs through a fuel tax. An appropriately designed charge would impose costs on different vehicle types consistent with their roadway impact ratio.

²⁷⁸ Table 14 assumes a linear relationship between weight and roadway impact and thus probably understates the heavy vehicle cost responsibility.

Table 14. Illustrative Charges Compared With Roadway Impacts

Vehicle	Width without mirrors (feet)	Weight (pounds)	Roadway impact (width times weight)	Roadway impact relative to car	Typical fuel economy (MPG)	Fuel consumption relative to car	Fuel tax as percentage of roadway impact
Car	5	4,000	20,000	1:1	30	1:1	100%
Hybrid car	5	4,000	20,000	1:1	45	0.67:1	67%
¾ ton pickup	7	8,000	56,000	2.8:1	20	1.5:1	54%
Large truck	8.5	80,000	680,000	34:1	5	6:1	18%

Source: Author analysis

Raising Revenue Equitably

As we have outlined, roadway construction and maintenance costs are driven by four key factors: vehicle width, vehicle weight, peak period traffic volume, and weather. At the center of determining the suitability of various roadway funding mechanisms is the question of how well each addresses the four key factors of cost causation.

Table 14 demonstrates how, as a class, all automobile users subsidize truckers. Even though trucks pay about 5 times more per mile than cars, this is only about 18 percent of their impact, and an inequitable assessment. Even hybrid automobiles, with high fuel efficiency, pay a disproportionate share of roadway costs based on weight, width, and volume.

Table 15 illustrates the relationship of different motor vehicle revenue mechanisms to roadway cost drivers. Neither the gross weight fee, the annual registration fee, nor the sales tax incorporates any characteristics of road usage. Gross weight fees are applied annually. Although they track weight closely, they do not track weight-induced roadway costs

Table 15. Do Different Motor Vehicle Revenue Mechanisms Reflect Roadway Cost Drivers?

	Fuel tax per gallon	Gross weight fee	Annual registration fee	Sales tax
Width	Yes, weakly	Yes, weakly	No	No
Weight	Yes, weakly	Yes, weakly	No	No
Peak usage	Yes, weakly	No	No	No
Weather	No	No	No	No

Source: Author analysis

because the fee is identical whether a truck travels 1,000 or 100,000 miles a year.

The only mechanism in Table 15 that is usage-related is the fuel tax per gallon. But since diesel vehicles are typically wider and get more ton-miles per gallon than gasoline vehicles, this approach undercharges diesel vehicles. To properly recognize the construction and maintenance costs diesel vehicles impose, the diesel tax per gallon would need to be about 2 or 3 times the gasoline tax.

A common criticism of the gasoline tax is that less-efficient vehicles, like pickups and sport-utility vehicles, use more fuel and thus pay more tax than lighter and smaller vehicles. This is true—but the larger vehicles also require wider roads and impose greater wear on roads, thus creating greater need for road maintenance. As illustrated in Table 14, even with inferior fuel economy, these heavier vehicles contribute less than their share toward paying roadway costs.

Equity and Electric Vehicles

EVs do not pay typical fuel taxes, despite using electricity as a fuel. But they do use roads and arguably should share in the cost of roadway construction and maintenance. As noted earlier, 17 states have imposed fixed fees on EVs to offset the fact that, because they do not use gasoline or diesel fuel, these vehicles do not contribute to this pool of roadway construction and maintenance revenues.²⁷⁹

Electricity in many states is subject to a state excise tax that goes to the state general fund and not necessarily to

279 Spector and Pyper, 2017.

transportation-related matters. Electricity may also be subject to municipal taxes. These funds are directed to general government purposes, including maintenance of local streets and roads. Natural gas is subject to similar state and local taxes. Propane is subject to retail sales and use taxes, which are general fund taxes for state and local government. Gasoline and diesel fuel typically are not subject to these general government taxes.

So, EVs do not pay “road tax,” but they do pay general government tax as a levy on fuel consumption. Vehicles powered by gasoline and diesel fuel do pay road tax but do not contribute to general government tax receipts on their fuel consumption. It would be equitable to recognize and redirect the general government taxes paid on electricity as a vehicle fuel from general government purposes to roadway purposes.

To improve the equity of taxation, where EVs pay a fee for roadway use, it would be equitable to extend the sales and use taxes and gross revenue taxes paid by electricity consumers to gasoline and diesel fuel.²⁸⁰ If this were done, then all roadway usage (by any type of vehicle) would contribute equitably to roadway costs, and all categories of vehicular fuel consumption (electricity, gasoline, diesel fuel) would contribute equitably to general government costs.

Conclusion

Transportation system funding is a larger problem than determining the appropriate contribution that should be collected from vehicles that use electricity for fuel. Current gasoline and diesel taxes are inequitable and do not provide sufficient support, simply because larger vehicles impose more ton-miles of use on roadways per gallon. Vehicle weight has an exponential, not linear, impact on roadway construction costs and on wear and maintenance requirements. To be equitable, the taxes for larger vehicles need to be 2 or 3 times the amount per gallon of the gasoline tax imposed on passenger vehicles.

The annual registration fee is the most inequitable of all roadway charges today. The mere existence of a vehicle (unless parked on a public street) creates no annual costs for roadways. Only the use of the vehicle creates such costs. Building these costs into usage-related charges, such as the fuel tax, will be more equitable than annual fees. Much of the current inequity can be addressed by reducing annual vehicle registration fees, raising the gasoline tax, and setting the diesel fuel tax at a more rational multiple of the gasoline fuel tax.

Decision-makers can address the issue of EVs by recognizing and appropriating into the motor vehicle fund, where applicable, any general government taxes that EV drivers currently pay on electricity.

280 See the proposal by Acadia Center for an energy equivalent surcharge, “which would apply across all transportation fuels not currently taxed ... on a per-energy-unit basis [per Btu]. An energy-equivalent surcharge could operate like the gas tax, with the surcharge assessed when the vehicle refuels. For an EV, the energy-equivalent surcharge could be assessed per

kilowatt hour of electricity.” Acadia Center. (2018, March). *Electric vehicles and state funds: Current contributions in Massachusetts and long-term solutions to transportation funding*. Retrieved from <https://acadiacenter.org/document/electric-vehicles-and-state-funds/>



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