

Metrics to Measure the Effectiveness of Electric Vehicle Grid Integration

David Littell, Jessica Shipley and Megan O'Reilly

Introduction: Electric Vehicle Opportunities and Challenges

The transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs) presents a unique opportunity for the utility sector. EVs offer a new flexible load that can be integrated into the electric system in a way that maximizes benefits for both EV users and grid operators. And the flexible nature of EV load allows for a decrease in carbon in both the transportation sector as well as the electric sector if EV charging is coordinated with carbon-free generation. But the other side of this opportunity is a caution that if the integration of EVs is not well managed, it could add to load at inopportune times, increasing costs and carbon emissions.

This paper presents a road map for regulators as they integrate EVs. We first outline critical questions that regulators should ask when determining how best to integrate electric vehicles. We then discuss how performance-based regulation (PBR) — the development of high-level goals, performance criteria and clear and measurable metrics to assess whether goals and criteria are met — can be used to facilitate EV integration.

The transportation sector accounts for a significant portion of U.S. greenhouse gas (GHG) emissions, roughly 29% in 2017.¹ The majority of those emissions, 59%, come from light-duty vehicles, primarily passenger cars and light-duty trucks. Between 1990 and 2017, the transportation sector's emissions increased more than any other sector's in absolute terms, while the electric sector's GHG emissions declined.² This contrast demonstrates the opportunity for transportation

¹ U.S. Environmental Protection Agency. *Fast facts on transportation greenhouse gas emissions* [Webpage]. Green Vehicle Guide. Retrieved from <https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions>

² U.S. Environmental Protection Agency. *Sources of greenhouse gas emissions* [Webpage]. Retrieved from <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions>

electrification to lead to beneficial outcomes by shifting transportation energy demand from dirty, high-carbon fuels to increasingly lower-carbon and less polluting electricity.

These benefits multiply because EVs are more efficient at converting energy from electricity into miles driven than ICE vehicles are at converting gasoline to miles driven. In other words, if we have an ICE vehicle and an EV, and we want to drive 100 miles, we have to buy more energy in the form of gasoline to run the ICE than we will need to purchase in the form of electricity to drive that same number of miles in the EV.³ Transitioning to EVs thus allows us to use less energy overall for transportation needs.

This underlying efficiency of EVs in converting energy to miles driven (thus producing less pollution) will continue to drive EV uptake and pollutant reductions. Expressing efficiency as emissions, a full-sized EV has 53% lower emissions than a comparable gasoline car over the life of the vehicle. This efficiency offsets the higher emissions to manufacture EVs after 4,900 miles driven, on average.⁴ Even if an EV is charged entirely on coal-fired generation, the EV will produce lower emissions per mile than a comparable gasoline-powered car. Reductions are much greater when charging with a cleaner generation mix.⁵ Transitioning buses and other fleet vehicles from diesel to electric vehicles similarly reduces GHG emissions.⁶

Fuel switching from gasoline to electricity can reduce energy costs of both the electricity system and the transportation sector. Further, the flexible nature of the transportation electrification load presents an opportunity to integrate EVs into the system in a way that is least cost for customers, ratepayers, utilities and the public. To capture these efficiencies, RAP has identified a three-part strategy, laid out in detail elsewhere:⁷ (1) smart pricing to encourage and properly reward smart charging; (2) smart technology to allow for data sharing and automated responses to allow for

³ A gallon of gasoline contains 120 megajoules (MJ) of energy. That gallon can fuel an average car for 25 miles. In the form of electricity, 120 MJ would produce 33.3 kilowatt-hours, which can run an EV for 114 miles or more. The gas car energy usage is 4.8 MJ per mile, whereas the electrical car energy usage is 1.1 MJ per mile — a 78% reduction in energy consumption per mile. See Regulatory Assistance Project. (2017, May). *Getting from here to there: Regulatory considerations for transportation electrification* (pp. 11-12). Montpelier, VT: Author. Retrieved from <https://www.raonline.org/knowledge-center/getting-from-here-to-there-regulatory-considerations-for-transportation-electrification/>

⁴ Farnsworth, D., Shipley, J., Slinger, J., and Lazar, J. (2019, January). *Beneficial electrification of transportation* (pp. 45-51). Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/beneficial-electrification-of-transportation/>. With their higher motor efficiency, EVs typically produce lower emissions than ICEs on a well-to-wheels basis (i.e., taking into account the carbon intensity of the fuel used), but the size of the advantage depends on the country's fuel mix. 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, and its 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% coal system. In other words, a Bolt charged in any U.S. power system will result in lower emissions per mile than a gasoline-powered Golf. From an overall energy efficiency point of view, life-cycle emissions need to be compared. Recent discussions have focused on EVs' life-cycle emissions, raising concerns about energy-intensive lithium-ion battery production processes. However, these upstream emissions are offset by less emissions-intensive fuel production and use. This results in EVs that produce about half of the emissions of ICE vehicles over their lifetime. Hale, D., and Lutsey, N. (2018, February). *Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions* [Briefing]. International Council on Clean Transportation. Retrieved from https://theicct.org/sites/default/files/publications/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf; and 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 <https://www.nrel.gov/docs/fy18osti/70485.pdf>

⁵ Farnsworth et al., 2019.

⁶ Farnsworth et al., 2019.

⁷ Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., and Jahn, A. (2019). *Start with smart: Promising practices for integrating electric vehicles into the grid*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/start-with-smart-promising-practices-integrating-electric-vehicles-grid/>

smart charging; and (3) smart infrastructure, the strategic deployment of charging and grid infrastructure.

Regulators can put this strategy of managing and facilitating the integration of EVs into the electric system in place by using performance-based regulation. PBR allows for the development of goals, performance criteria and metrics, which regulators can use to ensure EV integration is well managed.

The Power of Performance-Based Regulation

PBR is a mechanism that regulators can use to align utility incentives with policy-mandated goals, including improved reliability, deployment of distributed energy resources, increased energy efficiency, environmental protection, customer satisfaction and protection of vulnerable consumers.⁸ Traditional cost-of-service regulation — which considers performance in terms of sales, revenue and rates and often service reliability, safety and quality — does not always align broader goals with utilities' incentive to act to achieve those goals. In short, utilities operating under a traditional cost-of-service model will respond to the incentives inherent in that model — to increase their rate of return by increasing sales and investments — rather than designing programs to meet societal or legislative goals.⁹ Recognizing that all regulation is incentive regulation, PBR shifts utility incentives so that utilities are operating in concert with goals, such as effective integration of EVs.¹⁰

Generally speaking, PBR mechanisms include several elements that are used to align goals with utility incentives to meet those goals:

- **Guiding goals** (or **guiding incentives**), high-level PBR goals informed by public policy priorities of the jurisdiction.
- **Directional incentives**, which specify measurable performance criteria using goals and measurable metrics.
- **Operational incentives**, which relate to the guiding goals and often the directional goals and provide metrics to measure operational considerations when implementing guiding or directional goals.
- **Measurable performance criteria**, which allow for straightforward assessment of whether guiding, directional or operational incentives are achieved.
- **Metrics**, which are quantifiable measures of any incentive, such as standard power system measures or consumer impact measures.

⁸ Littell, D., Kadoch, C., Baker, P., Bharvirkar, R., Dupuy, M., Hausauer, B. ... Logan, J. (2018a). *Next generation performance-based regulation: Volume 1 (Introduction—Global lessons for success)*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/next-generation-performance-based-regulation-volume-1-introduction-global-lessons-for-success/>; and Pató, Z., Baker, P., and Rosenow, J. (2019). *Performance-based regulation: Aligning incentives with clean energy outcomes*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/performance-based-regulation-aligning-incentives-clean-energy-outcomes/>

⁹ Littell et al., 2018a, and Pató et al., 2019.

¹⁰ Bradford, P. (1989). *Incentive regulation from a state commission perspective*. Remarks to the Chief Executive's Forum.

- **Outputs**, specific results of utility actions, often tracked as a measurable performance criterion or metric, and **outcomes**, how utility services affect ratepayers and society, generally the desired results from a specific guiding goal, directional incentive and/or operational incentive.¹¹

This structure of PBR elements is sometimes condensed into goals, performance criteria and metrics, as we will do here for simplicity of reference.

Through the use of a PBR process, regulators can take goals set by legislative action or less formal policy development and determine how best to incentivize action toward that end point. This type of regulation is especially useful for goals, such as efficient EV integration, where regulatory direction can provide a path for success that would otherwise be absent.

Basic Questions Regulators Should Ask

There are some foundational questions for energy, transportation and environmental regulators to consider when determining how to successfully integrate EVs into the electric system and when evaluating specific utility proposals for investments in EV charging infrastructure, new rate designs or new EV-related programs. These questions will help regulators decide whether and how to use performance-based regulatory tools, including metrics or performance incentive mechanisms, to increase the likelihood that utility EV efforts result in positive outcomes. The questions include:

- What are the carbon and pollution reduction goals of the jurisdiction? Are they expressed as reductions in total energy demand, pollution reductions or number of EVs adopted? Do goals vary for passenger vehicles used privately or in commercial fleets such as taxis, car- and ride-sharing schemes, medium-duty vehicles such as for urban logistics and heavy-duty trucks, electric buses and even electric marine vessels or aircraft?¹² Are those goals clear?
- Is the goal of supporting an EV build-out to build utility sales, to serve customers, to provide access to third-party EV companies, to provide EV opportunities to underserved communities, to clean up emissions, to support grid stability by taking excess renewable generation or even to provide power during times of grid need? Is the goal consistent with other state goals? Whatever the goal, how can it be served most cost-effectively? What are the range of successful and low-cost deployment strategies?
- If the trajectory of EV adoption is not clear, can regulators work with stakeholders and the public to establish an ultimate target, time frame and milestones for achievement?
- Are goals for charging infrastructure clear for the various contexts in which that infrastructure

¹¹ Littell, D., Kadoch, C., Baker, P., Bharvirkar, R., Dupuy, M., Hausauer, B. ... Logan, J. (2018b). *Next generation performance-based regulation: Volume 2 (Primer—Essential elements of design and implementation)*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/next-generation-performance-based-regulation-volume-2-primer-essential-elements-of-design-and-implementation/>

¹² The first passenger EV airline is planning service in Boston, for example. See Reid, D. (2019, June 18). All-electric jet firm Eviation announces US airline as first customer. *CNBC*. Retrieved from <https://www.cnbc.com/2019/06/18/all-electric-jet-firm-eviation-announces-us-airline-as-first-customer.html>

is needed — for example, at single-family homes, shared multiunit buildings, commercial structures (e.g., supermarkets, retail stores) and parking lots, on freeways or highways and for fleet charging? Is there already programmatic support for home, commercial and other public and institutional infrastructure? Are these programs authorized generally, and which agency is responsible for rebates or support? How do those programs relate to utility programs to support charging and EV rate designs?¹³

- In order to promote the understanding of new rate designs, support mechanisms and options available for EVs, what education and outreach activities are most helpful for agencies, utilities, car dealerships, car manufacturers and other entities?
- What program designs for charging infrastructure support the highest level of private contributions? What models exist for incentivizing EV purchases and charging infrastructure that explicitly address issues faced by low- and moderate-income customers and communities?
- What rate designs (encouraging charging via off-peak pricing or when supply is abundant and low cost) and charger controls (such as using chargers to absorb high off-peak, solar, wind and hydro load) encourage EV charging practices that are consistent with efficient and reliable use of the grid?
- How long will it take to pay back ratepayer investments? Can EV load grow sufficiently to pay back the costs of the charging infrastructure over a reasonable period of time?
- What utility investments should regulators authorize utilities to add to the rate base for public charging infrastructure? Which public charging infrastructure should be allowable utility investments in whole or in part? The options for consideration include on-street chargers; public or private parking garage chargers; chargers at municipal, school and government buildings; fleet chargers; or advanced metering infrastructure in low- and moderate-income neighborhoods.
- What investments in information systems and technology or other grid needs are necessary, if any, to support EV charging infrastructure? Will the utility pay for the “make-ready” needs of this infrastructure, up to and including the utility meter or the full cost of chargers?
- What performance criteria and metrics would regulators specify to provide answers to these questions for customers and the public? What performance criteria and metrics would regulators specify to provide information to design effective and cost-effective regulatory mechanisms in the future?
- What approaches have met with success in other jurisdictions on each of these issues?

¹³ See the discussion of designing rates to encourage beneficial electrification in Farnsworth, D., Shipley, J., Lazar, J., and Seidman, N. (2018, June). *Beneficial electrification: Ensuring electrification in the public interest* (pp. 41-45). Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/beneficial-electrification-ensuring-electrification-public-interest/>

PBR for Electric Vehicles: Goals and Examples

As a starting point for developing performance-based regulation for EVs, policymakers need to set high-level goals to guide priorities for EV integration. Regulators can then set performance criteria to focus on how those goals can and should be met. To determine whether those goals have been achieved, regulators must have good data. PBR can help: First, it can provide a means by which regulators can require the tracking of data on progress toward critical goals in successful EV integration, and second, it can require utilities to develop data on the effectiveness of steps to meet those goals, including the cost-effectiveness of investments and tariffs. The sidebar below outlines data that is useful to regulators to determine whether these goals are being met. As regulators develop a larger baseline set of data, they will increasingly be able to focus on the best ways to measure success toward metrics, performance criteria, targets and high-level goals. Indeed, metrics will determine what is measured and how regulators regulate.

The tables that follow offer illustrative sets of EV guiding goals, measurable performance criteria and metrics. The tables are organized by possible guiding goals:

- First, consumer education and outreach, leading to EV uptake and increased data acquisition.
- Second, supporting charging infrastructure deployment to allow for increased EV uptake and efficient utilization.
- Third, ensuring that regulators can manage the integration of EVs to benefit the grid and public as a whole — for example, through appropriate rate design and efficient charger deployment.

The examples provided here are not exhaustive and are intended to provide suggestions for areas where a PBR metric and perhaps a financial performance incentive (not addressed in this paper) can support the collection of data, the development of baselines and utility and regulator understanding of what education and outreach is needed and how charging infrastructure, rate design and other approaches work for smart EV integration goals appropriate for that jurisdiction.

Four examples of useful data for regulators

1. Circuits and feeders with excess seasonal or year-round daytime capacity to accommodate charging load at peak.
2. The elasticity of demand for on-peak charging versus off-peak charging by charger installation use (residential, commercial/retail, commercial/fleet, municipal/fleet).
3. Average and median utility/ratepayer cost for installation of charging infrastructure by charger installation use as well as by charger and charging station.
4. Utilization of chargers by charger, charging station and charger installation use. Regulators will want to test and determine what practices and technologies will maximize the net benefits to ratepayers and avoid unnecessary costs.

Goal 1: Build understanding of EV charging costs, benefits and consumer savings

There is a demonstrated trend toward increased transportation electrification,¹⁴ but EV adoption is still in its early stages. Education and awareness about EVs themselves — the charging infrastructure and how to use it, the economics of EVs (including incentives and beneficial rate structures) and the environmental benefits — will assist customers in deciding if an EV is a wise choice and will support regulators in developing this market. Because there is little baseline information, regulators may want to focus on ways to acquire more data and ensure that necessary data is collected and transparently reported.¹⁵ Regulators may require this data so they can determine what outreach, incentives and rate designs are most effective at reducing grid and/or customer costs and are most helpful to customers.

Regulators may also want to consider requiring regulated entities to report required data on a regular basis to allow for midcourse corrections — changes that may be needed to ensure that the program is designed to meet the predetermined goals. By requiring frequent and regular reporting (quarterly or year-to-date), regulators can assess whether a program or pilot is providing information effectively and whether anything is drifting seriously off course.

Policymakers may want to direct the utility to provide outreach and information to consumers on EV-specific incentives — such as special EV charging rates, the economic and environmental benefits of EVs or specific discounts for off-peak charging — through utility mailings or social media. Policymakers might not explicitly task the utility with these roles but instead issue a general set of policy mandates for implementation by an energy office and public utility commission or other energy, utility or environmental regulator. If so, the regulators may need to refine general policy mandates down to specific goals, performance criteria and metrics. See Table 1 for a set of goals, performance criteria and metrics for general EV outreach on consumer benefits and charging information.

Refining goals, performance criteria and metrics can be accomplished in a number of ways. The important point is that this process needs to be done carefully. Regulators and the utility first need to agree on the end goal to be achieved and then select the best metric to measure a representative and meaningful set of data. The best metric is one that is useful to the utility for operational management, to the regulator for oversight and to consumers for understanding the value they get from the grid and their own consumption decisions.

¹⁴ See, for example, Myers, A. (2019, January). 4 U.S. electric vehicle trends to watch in 2019. *Forbes*. Retrieved from <https://www.forbes.com/sites/energyinnovation/2019/01/02/4-u-s-electric-vehicle-trends-to-watch-in-2019/#40e97fb85a3c>; and Hertzke, P., Müller, N., Schenk, S., and Wu, T. (2018, May). *The global electric vehicle market is amped up and on the rise*. New York: McKinsey & Co. Retrieved from <https://www.mckinsey.com/industries/automotive-and-assembly/ourinsights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise>

¹⁵ Farnsworth et al., 2019 (pp. 60-61).

Table 1. Goals, performance criteria and metrics for building understanding of EV costs and benefits

Goal	Performance criteria	Metric
Increase EV sales with utility/state incentives ¹⁶	Measure EV sales to determine sales increase due to available incentives (likely requiring a baseline or data on incentives and nonincentive sales or customer survey)	EV sale increases over baseline; EV sales with incentives versus nonincentive sales; or customer surveys on whether incentives made a difference in purchase decision
Increase customer awareness of special EV charging rates	Utilities will provide customer information on available EV rates through multiple channels of communications	Percent of customers aware of special EV rates through survey
Increase customer awareness of lifetime economic and environmental benefits of EVs compared with ICEs	The utility will provide customer information on lifetime economic and environmental benefits of EVs compared with ICEs	Percent of customers aware of cost savings from EVs; percent of customers aware of environmental benefits of EVs ¹⁷
Increase customer awareness of time-varying component of rates to save them money and reduce environmental impacts	The utility will provide customers with information on time-varying rates and how these can help customers save money and reduce environmental impacts	Percent of customers aware of time-varying rate discount; percent of customers aware that charging off-peak reduces environmental impacts
Increase digital (social media and website) outreach to customers on EV charging, rates and savings for customers	The utility will set up a dedicated portal, accessible from any web browser and smartphone, with information on EV rates, potential savings and environmental impacts	Number of hits on website: Track time spent on EV website, click-through rates and repeat visits and one-time visits; include feedback button on website to allow immediate customer feedback

¹⁶ Because other variables besides utility action affect the increased sale of EVs, it is critical to either set an accurate baseline (such as expected EV sales in the absence of these utility programs) or have a well-designed customer survey on whether utility programs made a difference in a purchase. Collection of data on metrics can itself assist utilities and regulators in setting accurate baselines.

¹⁷ Note that some of these metrics would require the utility or regulator to undertake a customer survey. To make a customer survey effective, careful design and consultation with a group of stakeholders is likely to enhance effectiveness of the survey in providing useful data for the utility, regulator and public in evaluating utility programs.

A number of these metrics will require a well-designed customer survey. Although that survey can be designed and undertaken by a commission, agency or nonprofit, it is not unusual for a commission to assign the survey job to the utility even if the survey instrument is developed through a public process. A focus on the customer makes a transparent survey mechanism important for gauging achievement of customer awareness and outreach goals. A public process to design the survey will result in a more robust survey.

It may be the role of nonprofits, vehicles dealers or state agencies to promote an understanding of options for vehicles and their performance with the electricity grid. Regulators might assign that role to the utility in some jurisdictions, which could be accompanied by specific metrics to track number of events, effectiveness of outreach and increased customer awareness.

The following goals, criteria and metrics in Table 2 are examples of those that could be used to consider the success of EV adoption.

Table 2. Goals, performance criteria and metrics for EV adoption

Goal	Performance criteria	Metric
Encourage EV adoption	Track the increased registrations of EVs	Track EV registrations to addresses the utility serves
Track or calculate EV charging patterns to assess off-peak versus on-peak charging to move to more off-peak charging in the future	The utility will track or calculate EV charging load, including the portion of load during coincident peak hours or peak periods ¹⁸	Percent of charging off-peak and on-peak
Track and communicate money and fuel savings of customers who drive EVs	The utility will calculate avoided fuel savings ¹⁹ according to a regulator-approved methodology	Track or calculate estimated fuel savings in gallons, total costs to ratepayers and average savings per customer
Track and communicate how much EV adoption reduces GHG and air pollutant emissions	The utility will calculate avoided GHG and air pollutants in tons and other criteria useful to air regulators	Track or calculate annual GHG, nitrogen oxides, sulfur oxides and particulate reductions in tons and pounds per all customers and per EV driver ²⁰

¹⁸ Farnsworth et al., 2019 (pp. 67-69). A common concern with new load, and here daytime or evening charging, is that it might drive up system or local circuit peaks. Measuring that impact and the impact of charging pricing or control programs on system or circuit coincident peaks or peak periods is therefore important.

¹⁹ Farnsworth et al., 2019 (p. 10). As with GHG and air pollutant reductions, tracking fuel savings requires a methodology to estimate average or particular EV displacement or average or particular classes of petroleum-fueled automobiles.

²⁰ Calculating and tracking GHG and air pollutant reductions attributable to the adoption of EVs requires a few steps and assumptions. First, it

Again, there are many ways to formulate effective goals, performance criteria and metrics. These are some examples of what those might look like in some detail.

Goal 2: Encourage the development of EV infrastructure while controlling costs

Beyond basic EV education, EV uptake correlates to the demand for and availability of charging for different use scenarios — for example, private charging, workplace charging and destination charging (hotels, restaurants, parking garages). Again, as the implementation of EV infrastructure is in its early phase, it is imperative to spur EV uptake, depending on the jurisdictional policy. Charger capabilities and driver needs vary significantly, and, as a result, the right number and type of charging stations will vary by region, state, city and neighborhood, depending on trips taken, population density, existing grid and transport infrastructure and user familiarity and comfort with charging infrastructure. In addition, EV infrastructure may be slower to come to low-income and disadvantaged areas or to multifamily dwellings without specific incentives or mandates.

Data collection will therefore be an important part of charging infrastructure development. It will help to clarify needs and see that they are being met, ensure that charging infrastructure is working effectively to serve driver needs and ensure that adequate infrastructure is sufficiently deployed to provide enough comfort for consumers to spur EV uptake. At the same time, it will be important to make sure that a rollout of extensive charging infrastructure is cost-effective²¹ and does not result in unused or ineffective charging stations.

These metrics may need to be modified to track customer charging, in addition to charging points, with mobile charging devices that work at home and at public charging stations. These devices can act like a separate mobile submeter for a specific customer on a specific EV charging plan and are being piloted now in states such as Rhode Island.

requires tracking EV sales or usage to determine how EVs are displacing the use of fossil-fueled vehicles. It will also require simplifying assumptions about the quantity of carbon dioxide and other pollutant emissions attributable to EVs, by using data about the emissions associated with the electricity generation mix serving a particular utility's customers. This can then be compared with the carbon dioxide and other pollutant emissions from internal combustion vehicles to determine by how much the EVs are reducing emissions. Metrics such as this have been proposed to commissions (e.g., Rhode Island), but not adopted to date.

²¹ The cost-effectiveness of EV charging infrastructure can be defined in relationship to each jurisdiction's goals which might be, for example, increased EV deployment, decreased air pollution, decreased customer long-term costs per mile traveled, increased electrification of municipal bus fleets or increased equity in availability of charging infrastructure to low- and moderate-income neighborhoods. Because this issue is beyond the scope of this paper, we do not address here how regulators might set those cost-effectiveness criteria.

Table 3. Goals, performance criteria and metrics for encouraging development of EV infrastructure

Goal	Performance criteria	Metric
Increase efficient EV charger deployment	The utility will track EV charger deployment and usage	Track number of charging station hosts taking advantage of incentives: Require reporting of average number of chargers per site; types of chargers; average cost per site and port; rates offered; rates selected; charging behaviors by rate class; host application processing times; average time spent at charging point, average time parked, average kilowatt charges
Encourage charging deployment that meets customer needs	Measure effectiveness of incentives for hosts of charging stations to track and encourage customer use	Track number of incentives taken; track utility requirements for charging hosts and charger usage (e.g., removal of demand cap for EV fast chargers for an introductory period of time; payment of EV service connection costs)
Ensure forward-looking behavior to accommodate EV charging infrastructure	Measure effectiveness of incentives to support charging infrastructure	Track number of sites where incentives are provided to future-proof residential and other sites; track compared with benchmark where incentives not taken
Encourage efficient buildout of EV charging infrastructure by using existing infrastructure	Measure effectiveness of incentives for use of existing infrastructure where appropriate	Track use of incentives for using existing infrastructure (e.g., light poles, telecommunications distribution poles) and other synergies with existing electrified public transport lines
Encourage charging infrastructure buildout by streamlining utility interconnection process	Measure time from application to approval for service or interconnection; site owner costs to utility, if any, for interconnection	Business days from application for interconnection or service to utility approval; business days from approval to utility service or interconnection completions; site owner expense to utility services in procuring interconnection or service

Goal 3: Use existing grid resources to integrate EV load to maximize net benefits to all ratepayers

Benefits to ratepayers can be maximized where EVs are integrated in a manner that takes advantage of the flexibility they can add to the grid. EVs can be used to decrease investment in generation, minimize distribution system upgrades and maximize the use of existing infrastructure, all of which can reduce costs to ratepayers. In short, EVs can be a significant source of flexibility to the grid. The California Public Utilities Commission noted three characteristics of EVs that make them potential grid resources: (1) EVs provide operational flexibility as a result of their dual functionality of load (charging and potential ability to discharge stored energy back to the grid); (2) they have embedded communications and actuation technology; and (3) they have low rates of capacity utilization, being idle more than 95% of the time and needing to charge only about 10% of the time to maintain enough charge for driving purposes.²² Consequently, with appropriate incentive structures, EVs can be used as a flexible resource to shape, shift and shed²³ load to meet grid conditions. Analysis of those grid conditions, in turn, can ensure that EV charging is built out in ways that take advantage of existing grid infrastructure, again maximizing net benefits to all ratepayers.

²² Farnsworth et al., 2019 (pp. 45-51).

²³ Farnsworth et al., 2019 (p. 10).

Table 4. Goals, performance criteria and metrics for integrating EV load into the grid

Goal	Performance criteria	Metric
Use batteries to minimize impacts/need to upgrade distribution system	Measure installation of batteries at a certain number of fast charging stations at locations (strategic selection to avoid distribution system upgrades)	Track charging stations that install batteries in tandem with charging station: location, number of batteries, capacity of batteries in total and by circuits where needed
	Require data from charging hosts on battery condition	Track data on fast charging discharge and low power recharge; track battery energy discharge during peak and critical peaks, both energy and maximum peak reduction during period; track battery charging during off-peak and super off-peak, both energy during entire period and maximum charge during period
Decrease investment in generation; minimize distribution system upgrades	Survey to evaluate utility hosting capacity map or heat mapping for use in determining optimal charger locations	Track distribution system upgrades to accommodate EV charging infrastructure, systemwide and by circuits
Maximize existing distribution system	Develop mapping tool to determine grid locations with capacity for charging stations and how much during specific charging use cases (day for retail, nighttime for municipal fleets, etc.)	Track use of mapping tool as a reference when permitting charging stations; survey users about mapping tool usage and usefulness
Integrate new EV load to avoid exacerbating any existing load issues	Measure enrollment in time-of-use rates or specific EV rates; calculate EV charging savings when enrolled in time-of-use rates compared with what that same amount of charging would have cost on standard utility rates	Track use of incentives/enrollment in time-of-use rates; track impact on charging behavior when on a time-of-use rate compared with peak; track hours of energy used off-peak and the associated reduction in evening peak due to charging occurring off-peak; calculate new load integrated into the grid in terms of both energy and peak charging demand
Improve efficiency of EV infrastructure usage	Measure EV charging behavior, load shapes of various types of users of EV installations by type and locations: evening chargers, daytime chargers, plug-in hybrids versus all-electric, and heavier-duty demand charging such as fleets	Load shapes for retail charging locations, fleet charging for municipal and commercial fleets, home chargers and whether it varies by type of rate offering or service type

Conclusion

The advent of EVs is transforming two major sectors of the U.S. economy — transportation and electricity — in significant ways. Vehicles will increasingly charge rather than gas up. Electricity load growth will displace the use of liquid transportation fuels. Transportation will become more efficient and cleaner as this transition continues and as increased renewables contribute to even cleaner electricity to fuel EVs. And a very flexible demand-side electricity resource will open up avenues of grid flexibility.

In the midst of this transition, utilities and regulators are endeavoring to modify existing regulatory mechanisms and create new ones — such as models to allow utilities to capitalize some of the costs of EV charging stations. In this context, it is critical that regulators collect and analyze data to enable an understanding of cost-effective utility investments and how best to leverage private market investments.

If regulators do a thorough and expert job analyzing these questions and setting forth goals that align with state priorities, performance criteria and tracking metrics, they will be able to better avoid the risk of stranded investments in unnecessary infrastructure, ensure equitable EV opportunities and reasonably evaluate least-cost solutions in this new regulatory frontier.



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50 State Street, Suite 3
Montpelier, Vermont 05602
USA

1 802-223-8199
info@raponline.org
raponline.org