Managing the Financial and Grid Impacts of Plug-In Electric Vehicles
PLUG-IN ELECTRIC VEHICLES AND ELECTRIC COOPERATIVES

VOLUME 2

Managing the Financial and Grid Impacts of Plug-In Electric Vehicles

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The National Rural Electric Cooperative Association
NRECA is the national service organization for more than 900 not-for-profit rural electric cooperatives and public power districts providing retail electric service to more than 42 million consumers in 47 states and whose retail sales account for approximately 12 percent of total electricity sales in the United States.

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Volume 2: Managing the Financial and Grid Impacts of Plug-In Electric Vehicles
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The authors thank those who lent their expertise and insights as this report was developed:

- Craig Turner, Engineering Service Manager, Dakota Electric Association
- Ed Kjaer, Transportation Electrification Director, Southern California Edison
- Eddie Webster, Load Management Coordinator, Great River Energy Cooperative
- Eileen Tutt, Executive Director, California Electric Transportation Coalition
- Erik S. Sonju, Vice President, Power Delivery Planning and Design, Power System Engineering
- Mike Hoy, Energy and Member Services Manager, Dakota Electric Association
- Mike Smith, Director of Corporate Strategy and Emerging Technologies, Central Electric Power Cooperative
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William B. Kallock has more than 24 years of experience in the energy efficiency, demand-side management (DSM), and renewable energy industries. As Vice President of Business Development at Integral Analytics, Mr. Kallock is working to develop the next generation of utility load-control programs using Integral Analytics’ patented software. In particular, Integral Analytics’ IDROP load-control product provides the “smarts” for the Smart Grid, automatically balancing loads and resources for utilities and allowing consumers to better manage their homes’ internal energy use. Prior to joining Integral Analytics, Mr. Kallock has held senior positions with Summit Blue Consulting, Enron Energy Services, and Vermont Energy Investment Corporation. Mr. Kallock holds an MBA from the University of Michigan and a Bachelor’s of Science in Mechanical Engineering from Cornell University.
Many electric cooperatives around the country are facing stagnant load growth and decreasing revenues due to changing consumer behavior, energy efficiency, distributed generation, and the downturn in the economy. At the same time, the fixed costs associated with maintaining a functioning grid remain constant and co-ops are obligated to provide electricity at an affordable rate. Plug-in electric vehicles (PEVs) represent a unique opportunity for co-ops to grow load in a way that is socially and environmentally acceptable.

Because of this load growth opportunity, some utilities and co-ops around the country are beginning to promote transportation electrification. However, a common concern among electricity providers is that load growth from PEVs will stress distribution systems or result in new marginal generation costs. Many electricity providers are not actively promoting PEVs because of these uncertainties. But are these concerns well-founded? What financial and grid-related risks and opportunities do PEVs present to electric co-ops?

This paper addresses both the known and anticipated financial and grid impacts of PEVs.

Section 2 of this paper summarizes the current and future electricity requirements of PEVs. Sections 3 and 4 describe the financial and grid impacts of the PEV load, drawing on research from pilot programs and early adopter markets. Section 5 provides hypothetical scenarios that contextualize and quantify the possible financial and grid impacts of PEVs on co-ops. Finally, Section 6 provides an overview of PEV-related technologies and services that are under development—such as smart charging, vehicle-to-home applications, and secondary markets for PEV batteries—that may influence how PEVs interact with the grid in the future.

For more background information about PEV technology and factors influencing the market for PEVs, see Volume 1 of this series, *PEV Mechanics and Market Trends*. As a follow-up to this paper, CRN will release Volume 3, *Keys to Developing a PEV Program for Your Electric Cooperative*, a planning guide for co-ops to promote PEVs and develop PEV programs that maximize financial benefits and minimize grid impacts.
Understanding the electricity requirements of PEVs is essential for understanding subsequent grid and financial impacts. This section describes how much energy PEVs need to draw from the grid on average at the household, community, and regional level.

**Electricity Consumption at the Household Level**

A recent survey of more than 1,000 American PEV drivers found that 81 percent of charging takes place at home. The charging pyramid in Figure 2.1 is a graphic that PEV manufacturers and other PEV stakeholders often use to contrast the relative use of PEV charging at residences (most use), at workplaces (some use), and in publicly accessible locations (least use).

The reason at-home charging is prevalent is because vehicles are typically parked for more than 12 hours per day at a residence, and most PEVs require only three to seven hours to reach a full charge, depending on the electric vehicle supply equipment (EVSE) level and how low the battery was prior to charging. Another

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3. Ibid.
reason residential charging is more widely used is because few workplaces are equipped for PEV charging; only about 300 workplaces nationwide offered PEV charging as of 2014.\(^4\)

Figure 2.2 shows the distribution of vehicle locations throughout the week based on data from the 2001 National Household Travel Survey. This infographic further enforces the preference for residential charging and the likelihood that distribution grid impacts will be seen in residential areas due to increased electricity needs at the household level.

This graphic also helps explain why PEV load is often referred to as “malleable” or “moveable.” Unlike air conditioners or lights, consumers typically don’t care when energy is flowing into their PEV battery, as long as the battery is full when they next want to drive. If a PEV driver returns home at 6:00 p.m. and leaves the next day for work at 7:00 a.m., that provides a 13-hour window for charging a battery that will likely only take three to seven hours to charge.

A number of PEVs are equipped with on-board charge management systems that wirelessly transmit data to optimize and automate charging. Drivers can use these systems to program their cars to charge during specific time periods, such as when electric rates are lower. These charge management systems create the opportunity to manage the PEV load—both for demand response and load shaping. Charge management strategies and technologies will be discussed at more length in Volume 3 of this series.

How much more electricity will households with PEVs consume than typical households? Although the electricity needs of different PEV models vary—and can be influenced by vehicle weight, vehicle speed, road conditions, and use of accessories like heat and air conditioning—an annual average of one kilowatt-hour (kWh) per 3.5 miles of PEV driving is common.\(^6\)

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According to the Energy Information Administration (EIA), the average American household consumes 10,837 kWh of electricity annually.\(^7\)

As shown in Figure 2.3, co-ops can expect a 13 to 40 percent increase in electricity consumption among households that own a PEV, with annual mileage being the key variable influencing overall energy consumption. A survey of 2,039 PEV drivers found that, on average, survey participants drove 28.9 miles per day or 10,548 miles annually; the average annual vehicle miles travelled for all light-duty vehicles is 11,318.\(^8\)

This increase in household electricity consumption is consistent with what utilities are seeing in early adopter markets. For example, Seattle City Light in Washington State, which serves the third-largest PEV market in the nation, advises customers that their electric consumption will increase by about 30 percent when making the switch to fueling with electricity.

“Driving a Nissan LEAF for 10,000 miles is expected to use 2,500 kilowatt-hours of electricity,” states the Seattle City Light website. “That adds up to about $175 for about a year’s worth of driving at City Light’s low rates. The average Seattle resident uses about 9,000 kilowatt-hours of electricity each year at home, so adding a car increases consumption by nearly 30 percent.”\(^9, 10\)

While a 30 percent increase in electricity usage sounds extreme, switching to a PEV nearly always reduces fuel costs per mile for end users once avoided gasoline costs are taken into account.

Consider this example. If, prior to buying a PEV, a co-op member drove a 30-mpg conventional, internal combustion engine (ICE) vehicle 10,000 miles annually, that would require approximately 333 gallons of gasoline per year. A $2–$4/gallon price range for gasoline translates to annual fuel costs of between $666 and $1,332. Now assume the member switches to a PEV and again drives 10,000 miles annually—using 2,500 kWh total—at the average co-op rate of 11.8 cents per kWh. This translates to a fuel cost of $295 annually to drive the PEV. The resulting annual fuel cost savings of switching from an ICE to a PEV is between $371 and $1,037. PEVs will increase electricity bills, but fueling with electricity will reduce overall fueling costs for most end-users, even when gas prices are low.

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\(^10\) The example from Seattle City Light assumes an annual efficiency of 4 miles/kWh at $0.07/kWh for 10,000 miles per year.
Early data shows that PEV adoption is often geographically localized and can create pockets of higher electricity consumption among households that are connected to the same transformer. This phenomenon is often referred to as the “clustering effect.” Driving patterns, demographics, and other factors interrelate to create clusters.

Even if adoption is low at the regional level, it is likely that PEV ownership in your co-op service area will be concentrated in particular areas or clusters. Dakota Electric in Minnesota, for example, has just 43 members enrolled in a PEV charging rate program (out of 102,000 total members) and two of those PEV owners are connected to the same transformer on the same block. This phenomenon—when one transformer is serving two to three homes with EVSE—is referred to as a “PEV cluster.”

An analysis of several PEV clusters in the San Francisco, Calif., Bay Area found that, while PEV charging is taking place, neighborhood transformers must deliver approximately four times the amount of electricity than during times when PEV charging is not taking place. The hourly load profile for one of the Bay Area clusters analyzed is shown in Figure 2.4. This cluster consists of two neighbors, each with a PEV that accepts up to 3.6 kW, who scheduled their vehicles to charge after midnight.

Please note that every PEV clustering situation results in different load impacts. The example in Figure 2.4 is from a mild climate during a shoulder season where there is no significant heating or cooling needs. Because the combined load of the two homes without charging (the green line) is low, PEV energy consumption appears to be very significant compared to the normal household load. This is one isolated example to show how PEV clusters can impact the load profile.

The potential grid impacts of the clustering effect will be discussed in more detail in Section 4. Electricity providers are learning more and more about how to predict where these clusters will appear and how clusters will impact the distribution system. Methods for forecasting where PEV clusters may appear in your co-op service territory will also be discussed in Volume 3.

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11 Personal communication with Michael Hoy, Energy and Member Services Manager, and Joe Miller, Public Relations Director, at Dakota Electric on September 8, 2014.
Just as certain areas of a service territory will have higher rates of PEV adoption than others, different regions of the country are seeing higher electricity consumption due to PEVs. To date, PEV adoption—and, hence, electricity consumption—is highly concentrated in “early adopter” markets. For example, Californians just passed the 100,000 PEV sales mark, representing 40 percent of all the PEVs sold in the U.S.13 Twelve percent of national PEV sales are in the Southern California Edison service territory alone.14

Future PEV adoption rates are currently the subject of several research efforts that attempt to capture the many variables influencing consumer choices about PEVs. In Volume 1 of this report, several forecasts from reputable research organizations were cited, offering a wide range of very different projections. While the International Energy Agency (IEA) predicts that approximately eight million PEVs will be on American roadways by 2030, the Department of Energy’s Pacific Northwest National Laboratory (PNNL) predicts that roughly 37 million PEVs will be on the roads by 2030.15, 16 To put these figures into context, as of 2012, there were 253 million registered vehicles in the U.S.17

Part of the reason it is difficult to accurately forecast PEV adoption is because PEV technology is changing rapidly. Most importantly, advancements in battery technology that provide longer life, longer range, and lower cost options will have a significant impact on regional adoption rates. For example, at this time most PEV purchases are in urban areas; however, the penetration of PEVs in suburban and exurban areas is growing because the range of PEVs is increasing. Nissan is reported to be developing a low-cost battery with a 250-mile range which would be suitable for most rural driving needs.18

Regional adoption rates will also depend on state and federal tax credits and other incentives for PEVs. For example, by the end of 2014, Atlanta is expected to have 18,000 to 20,000 PEVs and currently is the second largest U.S. metropolitan market for electric-vehicle registrations.19 This growth is being spurred by generous state tax credits; if other states offer similar incentives, they may experience similar levels of PEV growth.

Additionally, as of 2013, eight states—California, Connecticut, Maryland, Massachusetts, New York, Rhode Island, Oregon, and Vermont—have mandates in place requiring that a certain percentage of new vehicle sales be zero-emission vehicles (ZEVs). ZEVs are defined as vehicles with no tailpipe emissions and include all-electric vehicles and plug-in hybrids. Successful implementation of ZEV mandates across these eight states would result in 3.3 million PEVs by 2025, more than 10 times the current number of PEVs on American roads.20

A number of utilities are also ramping up their efforts to promote PEVs to their end-users and influence public policies that would speed the adoption of PEVs. Volume 3 provides more details about incentives and PEV-related legislation and policies.

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14 Personal communication with Edward Kjaer, Director of Plug-In Electric Vehicle Readiness at Southern California Edison (SCE), on September 12, 2014.
The Potential Financial Impacts of PEVs

In This Section:

- Increased Revenue and a New Line of Business
- PEV Load and Wholesale/Retail Energy Markets
- How Demand Impacts Wholesale Electricity Prices
- The Connection Between Wholesale Power Costs and PEVs

This section discusses how PEV load may impact cooperatives and other energy providers financially. While co-ops and other electricity providers are in the business of selling electricity—and PEVs represent an opportunity to increase electricity sales—the financial impact of PEV load is complex. The dynamics of regional wholesale and retail energy markets and the timing of PEV charging must be considered to accurately understand the financial benefits and drawbacks of PEVs.

This section introduces the different financial variables that co-ops should consider as PEV adoption increases. Because energy markets vary regionally, the exact financial impacts of the new load from PEVs will vary from co-op to co-op. Section 5 presents different scenarios exemplifying possible financial impacts co-ops may face.

Increased Revenue and a New Line of Business

The co-op business model requires maintaining current levels of electricity sales. However, the increased use of distributed generation, new regulations on coal and nuclear plants, changing consumer behavior, and energy efficiency improvements pose challenges to this model. As declining utilization of the power system puts pressure on the cost of service, energy providers must find new sources of revenue to cover their fixed costs. However, increasing sales of a mature product is no easy task; power is a commodity and there is limited room for innovation.21

Electrification of the transportation industry is one of the greatest growth opportunities the electric industry has seen to date. The financial benefits of replacing petroleum—which currently fuels 93 percent of the transportation industry—with electricity are significant. According to one estimate, if 100 percent of vehicles in the United States were fueled by electricity, this transition in consumer energy spending would shift half a billion dollars daily from the petroleum industry to the electricity industry.22

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Financial benefits to co-ops from an increase in the PEV load may include the following.

- **Increased Revenue.** If charging is managed carefully, PEV load can serve as a source of incremental revenue. At the median residential rate of 12 cents per kilowatt-hour, co-ops could expect to collect between $340 and $515 a year from all-electric PEV owners. Revenue increases vary depending on electricity prices, the model of PEV end-users purchase, and the annual mileage of the PEV.

- **A Highly Malleable Load.** Compared with other electric loads, PEV load is advantageous in that it is highly malleable. Co-ops with PEV charge management programs can influence when PEV load comes on and off their systems, reaping the benefits of additional revenue while minimizing or avoiding the need to pay for additional generation capacity or infrastructure upgrades.

- **PEV Load Can Offset Financial Losses from Solar.** Customers who own both a PEV and a solar electric system use the same amount of electricity as the average customer. In other words, PEV load can offset some of the excess solar customers are selling back to utilities.²³

- **A Politically and Environmentally Accepted Form of New Load.** In a political environment increasingly concerned with the challenge of reducing greenhouse gas (GHG) emissions, PEVs offer an accepted—even celebrated—form of new load. Co-ops and utilities are often under political and regulatory pressure to decrease energy consumption and frequently are mandated to pursue energy-efficiency measures. But PEVs are a rare exception, even in states like California that have some of the strictest energy-efficiency mandates for utilities. “This load [from PEVs] is the only new load that policymakers in California are promoting,” explains Eileen Tutt, Executive Director of the California Electric Transportation Coalition.²⁴

- **Opportunity for Member Engagement.** Utilities are an important stakeholder in PEV adoption. The customer of the PEV manufacturer is also the customer of the electric provider. As customer expectations for service and engagement change, utility PEV programs will become increasingly important for ensuring customer satisfaction. A 2010 survey conducted by the Edison Electric Institute found that almost two-thirds of residential customers wanted their “utility [to] take a leadership role in encouraging a shift toward electric transportation.”²⁵ PEVs also present an opportunity to engage with important employer members to facilitate workplace charging.

- **Long-Term Load Growth Opportunity.** Although PEVs do not present a quick fix to the financial challenges many electricity providers face today, a growing number of utilities are putting time and resources into accelerating PEV adoption now in the hopes that PEVs will provide a boost to finances down the line. PEV charging could provide co-ops with a new, consistent source of off-peak electric sales revenue that could be used for capital expenditures, assuring the future value of existing assets.

If 100 percent of vehicles in the U.S. were fueled by electricity, consumer energy spending would shift half a billion dollars daily from the petroleum to the electricity industry.

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²⁴ Personal communication with Eileen Tutt, Executive Director of the California Electric Transportation Coalition, on October 16, 2014.

Three major California utilities—San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and Pacific Gas and Electric (PG&E)—are preparing to request approval from the state to invest significantly in the electrification of transportation: a total of around $1 billion over the next five years. These funds would be rate-based and directed toward PEV marketing efforts and the deployment of public and workplace charging infrastructure.26

A number of other utilities are working to accelerate the PEV market by investing in charging infrastructure. Duke Energy (N.C.) is developing and testing a wireless charging technology.27 Austin Energy operates 200 public charging stations in central Texas and offers a 50 percent rebate to customers who install a residential charger; rebate recipients must agree to share information with Austin Energy about their charging habits and participate in a charge management pilot program.28 New Jersey utility Public Service Enterprise Group is offering free smart-charging equipment to any employer in the state with at least five employees and a need for the equipment.29

Ed Kjaer, Director of Transportation Electrification at Southern California Edison (SCE), describes why SCE sees PEVs as an important long-term business opportunity.

“We’re a mature industry with a mature product offering,” says Kjaer. “We’re spending billions of dollars in grid modernization. Meanwhile, we have declining utilization of the system. The rise of energy efficiency and subsidized solar are causing customers to avoid using the system. At the end of the day, it’s putting pressure on cost of service. In an ideal world, we would grow load, growing load to provide more throughput to be able to spread our fixed costs. But increasing energy sales is a challenge in our industry because we’re selling a mature product. We think that connecting transportation to the ‘grid of the future’ is a win-win for all stakeholders. Ratepayers benefit because it provides downward pressure on cost of service and helps enable integration of future renewables.”30

Although SCE is located in a highly urban market where PEVs are heavily promoted by the state government, ratepayers in nearly all markets stand to benefit financially from PEVs. Depending on local electricity and gasoline costs, an electric gallon—or “e-gallon”—is between 70 and 85 percent cheaper than a gallon of gasoline and less prone to fluctuations.31

Like the utilities described above, co-ops may also have the opportunity to request that their governing bodies approve financial investments in strategically shaping the adoption of PEVs. Bruce Giffen, the General Manager of Illinois Rural Electric Cooperative, recently received board approval for a marketing campaign promoting the co-op’s on-bill financing program for PEVs. Giffen reports that there was no pushback from his board related to funding the campaign because growing off-peak load by promoting PEVs benefits the entire membership.32

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32 Personal communication with Bruce Giffen, General Manager at Illinois Rural Electric Cooperative, on December 3, 2014.
PEVs offer an opportunity for load growth, but co-ops must be able to serve that load cost-effectively in order to benefit financially. A basic understanding of wholesale and retail markets is necessary in order to appreciate the range of financial impacts PEVs may present. Before delving into the specific financial impacts of the PEV load, this subsection provides a refresher course on energy markets and how new loads, in general, may financially impact co-ops.

RETAIL AND WHOLESALE ENERGY MARKETS
Markets for electricity have both retail and wholesale components. Retail markets involve the sale of electricity between a co-op and its consumer members. Retail transactions, especially at the residential level, are very straightforward. Typically, residential rate models involve selling each kilowatt-hour of electricity at a predetermined rate in addition to a monthly service charge. Sometimes rates vary depending on the time of day.

Wholesale energy market dynamics are more complicated. Wholesale markets involve the sale of electricity between the generator of the electricity and the distributor of the energy (e.g., distribution co-ops). Electricity generators may include generation and transmission (G&T) co-ops, investor-owned utilities, public power systems, and federal power marketing agencies. Wholesale energy markets vary regionally and can generally be broken into two broad categories: centralized markets (run by regional transmission organizations) and noncentralized markets.

- Centralized Markets. About 60 percent of the electric users in the country are served by co-ops or utilities that participate in centralized wholesale markets, sometimes called regional transmission organizations (RTOs), which were created in the 1990s during electricity restructuring. There are seven RTOs in the U.S. that manage the transmission grid and support a fair and competitive market for wholesale electricity. These centralized markets have a formalized, transparent system for buying and selling electricity, usually through an auction. The prices established during these auctions are often used as an index for prices in bilateral power purchase agreements used in traditional power markets.

- Noncentralized Markets. Noncentralized wholesale markets exist primarily in the Southeast, Southwest, and Northwest. About 40 percent of all retail customers are in noncentralized wholesale markets. Many utilities in these markets are vertically integrated: they own the generation, transmission, and distribution systems used to serve their electric consumers. Noncentralized wholesale markets also include federal agencies—such as the Bonneville Power Administration and Tennessee Valley Authority—which market the output from federally owned power generation facilities. These agencies give preference to municipal and other publicly owned electric systems in allocating their output. In regions of the country with noncentralized power markets, electricity is usually procured either through self-supply or through bilateral power purchase agreements. A bilateral power purchase agreement is a contract between a buyer and seller of electricity that defines mutually agreeable terms over a specified period of time.

Much of the wholesale market—both centralized and noncentralized—is competitive. This means that prices reflect supply and demand, which are, in turn, determined by many factors, including fuel prices, capital costs, transmission capacity, weather, economic activity, and demographics. Sharp changes in demand, as well as extremely high levels of demand, affect prices as well (see the following section for more details), especially if less-efficient, more-expensive power plants must be turned on to serve load.

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33 RTOs are sometimes referred to as Independent System Operators (ISOs).
Because of these wholesale market dynamics, while most residential customers pay a uniform retail rate for each kilowatt-hour of electricity, co-ops can face fluctuating wholesale costs due to market forces. While power purchase agreements can protect co-ops from some of these price fluctuations, co-ops may still need to buy additional wholesale power outside of a power purchase agreement on “spot markets” facilitated by RTOs. Buying power on spot markets exposes co-ops to potentially high energy prices that would result in a loss for the co-op.

Generation and transmission (G&T) co-ops face a slightly different set of circumstances. Some G&Ts do not generate but, instead, sign power purchase agreements that define wholesale power prices. G&Ts may choose to buy some of their peak power on the spot market. G&Ts that generate electricity face the risk that the raw fuel—coal, natural gas, or plutonium—will increase in price.

How Demand Impacts Wholesale Electricity Prices

Demand for electricity follows cycles throughout both day and year. Regionally, electric demand may peak in either the summer or the winter. Spring and fall are typically “shoulder” months, with lower peak demand. Seasonal peaks vary regionally, although the highest levels of power load in most regions of the United States occur during heat waves and are most acute during the daily peak load hours reached in the late afternoon.37 Because electricity storage options are limited, generation must rise and fall to provide exactly the amount of electricity end-users need. Wholesale power prices are typically highest during peaks.

The fluctuations in wholesale power costs reflect the differences in how base and peak electricity are generated. Base load power is anecdotally referred to as the amount of electricity the grid uses during the middle of the night; this is the power used to meet our most fundamental electricity needs, such as keeping refrigerators and clocks running.

A power plant supplying base load power needs to be able to run for months on end without needing to be taken offline for maintenance. Base load power plants tend to be coal-fired, nuclear, or hydroelectric. These types of power plants are expensive to build, but fuel costs per kilowatt generated tend to be low.

Peaking power is the energy used to meet extra high electricity needs, such as electricity demand due to a very hot day when many people are using more air conditioning than usual. Typically, peak is defined as a 15-minute period when the largest load of electricity is used each month.

The peak period can be set in the power purchase agreement as specific days and hours, such as 3:00 p.m. to 7:00 p.m. during July, for example. Or the peak period might be defined as the moment the entire system experiences the greatest load, which is referred to as “coincident peak.”38

A peaking power plant can start generating electricity almost immediately, as additional power is needed. Because peaking power plants are used for less time over the course of a year, it’s not as crucial that the cost of generation be low. Peaking power plants have traditionally been fueled by natural gas. Despite low natural gas prices, peak power remains more expensive per kilowatt than base load.

Serving loads during peaks can result in financial losses for co-ops. This is especially true in the residential sector, where higher wholesale costs for peak power are generally not passed through to end-users.

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The cost for dispatching the next increment of electricity production—or the marginal generation cost—varies greatly depending on the time of day and whether base load or peaking power resources are drawn on. The generation on the margin is a key driver for determining how expensive it will be to fuel PEVs in your service territory. Most distribution co-ops and utilities charge more for peak electric use in the commercial or industrial sector by setting a demand charge or a time-of-use (TOU) rate. But few co-ops employ these types of rates in the residential sector.

Increased revenue in the residential sector due to load growth is usually a simple calculation of the additional kilowatt-hours used multiplied by the residential rate per kilowatt-hour. But the lack of time-differentiated rates or demand charges in the residential sector results in many co-ops selling kilowatt-hours at a loss during peak periods because those peaking kilowatt-hours cost more than base load kilowatt-hours. On the other hand, nighttime PEV charging flattens demand, allowing for full-power operation of cheaper base load power plants, lowering the cost of electricity for everyone.

PEV batteries can also be used for load shaping as PEV owners can set a timer to schedule off-peak charging. Volume 3 of this report will discuss in detail the strategies used by utilities and co-ops around the country to promote and ensure off-peak charging. Off-peak charging is often referred to as “valley-filling,” because it increases the load during the hours when the load is lowest, flattening the load curve at night (see Figure 3.1).

A more stable level of demand enhances grid efficiency by enabling base load power plants to operate more steadily. Steadier demand means less reliance on more expensive peak power sources. In the future, co-ops may be able to remotely control PEV charging to help optimize load shaping and control.

In the near-term, early evidence suggests that grid impacts and the need for new generation resources as a result of PEVs will be a nonissue. An October 2014 report analyzing the potential financial impacts of PEVs in California found that—even if PEV charging does not occur during off-peak hours—revenue from PEV charging will exceed the marginal cost of generation to serve the load and the additional costs incurred by electricity

![FIGURE 3.1: Load Shaping Benefits of PEVs](source: E Source)

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If charged overnight, 73% of the current U.S. light-duty car fleet could be supported as PEVs without adding a single power plant. Providers to serve PEV load even under the “worst-case” assumptions for grid impacts. In the long term, fears about needing to build costly new generation facilities and distribution infrastructure to power the PEV fleet are unlikely to materialize if co-ops and utilities are able to manage when PEV charging occurs (see Volume 3 of this report for more information about charge management). The Pacific Northwest National Laboratory found that, if charged overnight, 75 percent of the current U.S. light-duty car fleet could be supported as PEVs without adding a single power plant.

At this time, PEVs represent less than one percent of the current U.S. light-duty car fleet. In other words, it is unlikely that new generation facilities will be needed as a result of PEVs. Rather, current generation facilities may be more highly utilized, resulting in a higher return on investment from those fixed costs and assets.

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Eddie Webster, the Load Management Coordinator at Great River Energy, a Minnesota G&T, shares a growing sentiment among those in the electric industry that PEVs are a significant opportunity, as long as electricity providers can manage PEV charging well.

“PEVs are an amazing load to have,” said Webster. “They can show up like having a new house on the system. But, you have to keep that load off-peak. If you can educate customers about when to charge them—and why—they are great loads to have on your system. But there is that looming fear that loads won’t be charged off-peak. We are asking ourselves, ‘How can we help our distribution co-ops keep PEV charging off-peak?’”

At this time, PEVs represent just 0.38 percent of all vehicle registrations in the United States and PEV adoption is highly concentrated in urban areas. Unless PEV adoption rates increase dramatically, it is possible that PEVs will have almost no grid impact on co-ops in the near future. While there is a possibility that PEV adoption rates will fail to increase or falter, there is also a good chance that electricity will become a mainstream transportation fuel.

Forecasts about future PEV adoption rates vary considerably. If bullish forecasts materialize, understanding and accounting for the possible grid impacts of PEVs in planning and operations procedures will be imperative for co-ops in order to reliably supply this new load. Furthermore, one of the most essential ways that co-ops can help promote PEVs is by assuring consumers and other stakeholders that a safe and reliable electricity grid can be maintained even as electricity consumption grows due to PEVs.

42 Personal communication with Eddie Webster, Load Management Coordinator at Great River Energy, on September 9, 2014.
PEV charging can place localized stress on existing distribution infrastructure; however, system-wide generation and transmission impacts are unlikely at this time. Eddie Webster explains:

“At the generation and transmission level, grid impacts from PEVs are not something we are concerned about. It is the distribution co-ops that need to think more about this. At the distribution level, co-ops need to know where the hot spots are going to occur, what transformers and substations will be impacted. We anticipate that PEVs will start impacting the transmission in about a decade.”

Studies from academic and research institutes reinforce the view that system-wide impacts from PEVs are unlikely, given the current trajectory of PEV growth. An MIT report on the grid impacts of transportation electrification found that the existing generation and transmission capacity of the nation could accommodate five to 50 million PEVs, depending on which strategies are used to manage the charging demand. There are currently less than a quarter of a million PEVs connecting to the grid in the United States.

At the localized level, distribution infrastructure is typically sized to meet current peak electricity needs. PEVs, if charged during peak periods, could overload elements of the local distribution system and necessitate local upgrades.

Different types of PEVs will place different incremental peak demands on the local distribution system, depending on the EVSE level used for charging. Charging capacity is determined by circuit pressure (volts) and the level of electric current (amps). Peak charging loads commonly range from 1.4 kW to 6.6 kW, but can be much higher if fast charging is employed. (See Table 4.1.)

At this time, Level 1 charging—which is as simple as plugging into a standard 120-Volt home outlet—is a popular option for PEV drivers. Chevrolet reports that as many as 70 percent of Volt drivers opt for Level 1 charging and Nissan reports that 10 to 20 percent of LEAF drivers opt for Level 1 charging. In a 2013 analysis, Southern California Edison found that about 50 percent of plug-in hybrids (PHEV) drivers use Level 1 charging.

Although Level 1 charging is the slowest method of charging, it requires no special equipment other than a dedicated electrical cable that comes with the PEV and can meet most daily commute fueling needs with overnight charging. The prevalence of Level 1 charging helps minimize grid impacts.

### TABLE 4.1: Peak Charging Loads by EVSE Level

<table>
<thead>
<tr>
<th>EVSE Levels</th>
<th>Voltage</th>
<th>Amps</th>
<th>Charging Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Level 1</td>
<td>120 V, 1-Phase AC</td>
<td>12 A–16 A</td>
<td>1.4 kW–1.9 kW (Typically 1.4 kW)</td>
</tr>
<tr>
<td>AC Level 2</td>
<td>208 V–240 V 1-Phase AC</td>
<td>12 A–80 A</td>
<td>2.5 kW–19.2 kW (Typically Either 3.3 kW or 6.6 kW)</td>
</tr>
<tr>
<td>DC Fast Charging</td>
<td>200–480 V (Typically 480 V) 3-Phase DC</td>
<td>&lt;200 A Circuit (Typically 125 A)</td>
<td>&lt;90 kW (Typically &lt;50 kW)</td>
</tr>
</tbody>
</table>

Sources: AFDC46, EEI47

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Utilities in early adopter markets that have higher-than-average levels of PEV penetration have experienced minimal grid impacts to date. (However, please note that the examples below are from two large California utilities that may not represent the norm for other utilities and co-ops.)

- Representatives at Pacific Gas and Electric (PG&E), a utility which serves large PEV populations, report that a grid service check is conducted every time a customer purchases a PEV to ensure there is enough power to charge it. Out of the 10,000 checks conducted by PG&E, only 12 local grids have had to be upgraded as a result of PEVs.50

- A recent report by Southern California Edison (SCE) also found that grid impacts in its service territory were minimal, despite being home to 12 percent of the nation’s PEVs. “Since 2010,” states an SCE report, “of all the nearly 400 upgrades [SCE] made to (or identified for) circuits that serve PEV customers, only one percent of that work was required due to additional power demands from PEVs. The rest of the work was required under [its] regular infrastructure upgrade and maintenance schedule.”51

However, the SCE report also noted that an increasing number of all-electric vehicles with higher charging capabilities coming online could have implications for grid reliability and necessitate more upgrades to distribution transformers. For example, the new BMW i3 all-electric vehicle released in 2013 comes with 7.2-kW AC capabilities. Most Tesla models come standard with a 10-kW AC charger but can be configured with a 20-kW AC charger on-board. These charging capabilities are significantly higher than the Nissan LEAF, which is now typically being configured with a 6.6-kW AC charger, or the Chevy Volt, which comes with a 3.3-kW AC on-board charger.

There are many different components to the grid; certain components will be more impacted by PEVs than others. As discussed in the previous section, generation and transmission components of the grid are unlikely to be impacted in the near future. It is distribution components of the grid (shown in green in Figure 4.1) that will require the most attention from grid operators.


Understanding how certain components of the distribution system work will help provide context for understanding how PEVs may impact the distribution grid. While most co-ops have engineers who understand how the distribution system functions, it may be helpful for employees in member services, marketing, and finance to also have a basic understanding of how increased load from PEVs may impact grid components. Basic descriptions of select distribution system components—as well as possible impacts as a result of PEVs—are below.

**TRANSFORMERS**

**Transformers** are the workhorse of the distribution system. They transfer electrical energy from one system level (e.g., transmission) to another (e.g., distribution) by converting electricity from one voltage to another. Every home and business connects to the power grid through transformers. They are one of the most important components of the power grid.

There are different kinds of transformers. Substation transformers are much more expensive and impact many more consumers; because of this, they are usually closely monitored. Secondary, or distribution transformers, on the other hand, are not always monitored and are more likely to see overloading from PEV charging. However, advanced metering infrastructure (AMI), coupled with wireless distribution grid sensors, are changing this by facilitating the monitoring and analysis of distribution system performance data.

Most residential distribution transformers are rated to serve between 10 and 50 kVA of load, or one to eight typical homes. In some cases, a single 15–25 kVA transformer will serve just one home, especially in regions of the country with high heating and cooling loads. A single PEV using Level 2 240-V EVSE will consume about 7 kVA (one kVA is 1,000 volt amps). Three all-electric vehicles will use nearly the entire capacity of a 25-kVA transformer.

A DTE Energy study evaluated the impact of plug-in hybrid electric vehicles (PHEVs) on distribution system components. Figure 4.2 shows the impact of three PHEVs on a 25-kVA transformer versus a 50-kVA transformer charging at

![Figure 4.2: Impact of Three PEVs on Transformer Loading](source:DTE, 2011)

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52 Personal communication with Robert Harris, Principal, Transmission and Distribution Engineering at the National Rural Electric Cooperative Association, on October 28, 2014.


54 Ibid.
two different charging loads (1.4 kW and 3.3 kW) on a warm summer day. The 3.3-kW installation on the 25-kVA transformer resulted in approximately 28 percent additional load to the transformer’s design rating. Therefore, a transformer loaded at 73 percent or greater at peak, would become overloaded (in terms of its design rating) if three 3.3-kW PHEVs were installed and charged at the same time.

When a transformer meets or exceeds its rated capacity, this is called overloading. Transformers are built to accommodate a certain amount of overloading. For example, a 50-kVA-rated transformer can handle 30 to 50 percent overloading for a short period of time and during colder ambient temperatures. However, overloading a transformer shortens its life, wearing down insulation and emitting gases and chemicals. Warmer outside temperatures compound overloading effects.

Transformers are among the most costly components in the medium- and low-voltage distribution system and are designed to last for about 50 years. Frequent or persistent overloading from PEV charging—or other loads—can contribute to transformer aging and should be a key consideration when evaluating the grid impacts of PEV charging.55

In addition to aging and possible failure, when a transformer exceeds its peak capacity, it can also lead to low voltage, higher losses, and service interruptions.

Overloading is sometimes also referred to as thermal overloading. The temperature of transformers will become elevated when the rated capacity is exceeded. When a transformer—or nearly any part of the distribution system—operates at elevated temperatures, the result is accelerated aging of those components. How much a transformer is aged by overloading varies, depending on the frequency of overloading, the degree to which the transformer exceeds its rated capacity, and other factors, such as ambient temperature.

A recent study performed in Phoenix, Arizona, and Burlington, Vermont, looked at how ambient temperature impacted transformer overloading and aging as a result of PEVs. In all cases, the warmer climate of Phoenix resulted in notably more transformer aging than the cooler climate of Burlington. In cooler climates, a moderate amount of overloading from PEV charging may not substantially decrease transformer life.56

FEEDERS
A feeder is a medium-voltage power line delivering power from a distribution substation to distribution transformers. Feeders represent a unit of a local grid, often serving between 100 and 500 homes or businesses. The impact of PEV load on this grid component will depend on the feeder topography.

There are two main kinds of constraints on feeders: thermal limits and voltage limits. Thermal limits refer to the maximum amount of current that can flow through a conductor before overheating it.

Feeders are also designed to maintain certain voltage levels; at a certain point, as load increases, voltage can drop to the point where end-users are no longer receiving adequate service. This can be addressed by upsizing wires or installing extra components, such as capacitors or voltage regulators, to adjust voltage as needed.

Most co-ops have some combination of feeders that are thermal-limited and some that are voltage-limited. Feeders in suburban areas tend to be shorter and built to carry a heavier load, while feeders in rural areas tend to be longer and more sparsely loaded.

In 2010, the Pacific Northwest National Laboratory (PNNL) conducted an analysis of PEV charging impacts on a sample of 40 feeders located within three different utility territories.

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56 Ibid.
The PNNL analysis assumed hypothetical PEV penetration rates of 50 percent and 100 percent and evaluated a range of six different charging scenarios—from 120 V to 240 V, at peak and nonpeak periods, and at work and home.

The analysis showed that, for the most part, the rated capacity of individual distribution system components was not exceeded due to PEV charging. This was true over a range of six scenarios with different charging strategies. The study found that the most common component prone to failure from overloading was overcurrent protection, such as a fuse.

OVERALL POWER QUALITY
As with all new loads, distribution system engineers should monitor how PEVs may impact voltage harmonics, voltage drops, and line losses. Many of the manufacturing standards for electronic equipment are voluntary, meaning that certain models of EVSE may not be designed to prevent power quality issues.  

An Institute of Electrical and Electronics Engineers (IEEE) research team conducted a simulation with low PEV penetration levels (20 percent) and Level 1 EVSE to explore power quality issues resulting from PEV adoption. The simulation results showed “acceptably low harmonic levels and voltage deviations with the least amount of losses.”

On the other hand, the IEEE simulation with high PEV penetrations (80 percent) using DC fast charging resulted in unacceptable and severe voltage harmonics and power losses. Because the PEV penetration rate remains very low at this time (less than one percent)—with Level 1 EVSE as the primary mode of charging—issues with voltage harmonics and line losses resulting from PEVs are unlikely to be a serious problem in the near term for co-ops.

According to Mike Smith, Director of Corporate Strategy and Emerging Technologies at Central Electric Power Cooperative, the design of EVSE also has a significant impact on power quality. “One small charger (like a phone charger) with a poor design and high harmonics doesn’t have an impact on the system because it is so small,” he said. “Lots of poorly designed chargers on a circuit will. Similarly, a DC fast charger can have either low or high power quality impact simply by its design.”

Clustering effect, described in Section 2, can have problematic local impacts on a distribution system, especially in residential settings. In some high-adoption neighborhoods, there may be more than one household with a PEV on the same transformer.

Multiple PEVs charging at high power levels on one transformer can increase load on distribution feeders and potentially overload the rating of the transformer or deprive the transformer of its normal cool-down period. Stress on one transformer can affect the quality of power at other houses receiving power from the same distribution substation.

Performing an analysis of where residential charging stations are likely to be installed in a cooperative’s service territory can help a co-op proactively identify vulnerable electrical infrastructure and plan for upgrades. Methods for identifying PEV clusters will be discussed in Volume 3 of this series.
In This Section:  
Quantifying the Risks

The previous two sections describe the possible financial and grid impacts of PEV charging. PEVs present both opportunities and risks to co-ops. To summarize, these benefits and opportunities include the following.

• **Opportunities Presented by PEVs**
  - Overnight PEV charging can provide “valley-filling” benefits by flattening the load curve at night.
  - PEV load is highly malleable. Unlike lights or air conditioning, PEV drivers don’t have a preference about when energy is flowing to the car, as long as charging is complete at a certain time. On average, vehicles are typically parked for more than 12 hours per day at a residence.
  - New electricity generation will likely not be needed to fuel PEVs if they are charged overnight. A DOE report found that nearly 75 percent of the current U.S. light duty car fleet could be supported as PEVs without adding a single power plant.\(^{59}\)
  - Co-ops can expect a 13 to 40 percent increase in electricity consumption among households that own a PEV.
  - At the median co-op residential rate of 12 cents per kilowatt-hour, co-ops could expect to collect between $340 and $515 a year from all-electric PEV owners.
  - Cooperative-run PEV programs can be an opportunity for member engagement and could boost member satisfaction.
  - PEVs represent a form of new load that may be environmentally and politically acceptable.

• **Risks Presented by PEVs**
  - PEV load growth, if it happens during peak periods, could result in a co-op purchasing power from the wholesale market at a cost that exceeds what the co-op is charging residential end-users, resulting in a financial loss.
  - Early data show that PEV adoption is often geographically localized and can create pockets of higher electricity consumption among households that are connected to the same transformer. In some cases, this leads to transformer overloading.
  - Frequent or persistent overloading from PEV charging—or other loads—can contribute to transformer aging. Transformers are the most costly component of the distribution system.
  - High rates of both PEV adoption and use of DC fast charging could compromise power quality.

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There are six primary variables that dictate how these opportunities and risks will impact co-ops. Each cooperative will have varying degrees of control over these variables. They include:

1. **Wholesale Power Costs.** The financial impacts of serving PEV charging will be determined by the wholesale costs of generation capacity in your regional market.

2. **Distribution System Capacity.** Both the financial and grid impacts of PEV charging will also be heavily influenced by the degree to which your distribution system is constrained.

3. **Time of Day of Charging.** The time of day that PEV charging occurs is a variable that more and more co-ops and utilities are trying to manage. Utilities and co-ops around the country are launching charge management programs aimed at educating PEV drivers about the benefits of charging during off-peak hours. These programs are often accompanied by special time-of-use rates that incentivize drivers financially to charge their PEVs off-peak.

4. **PEV Adoption Rates.** While it is difficult to know how many PEV drivers will be on the roads in the future, there are many ways that co-ops can not only forecast and track PEV adoption but encourage it as well.

5. **Location of PEV Adoption.** Co-ops have minimal control over where PEV clusters form in their service territory, but clusters can be monitored so that negative grid impacts can be prevented.

6. **EVSE Levels.** Although Level 1 EVSE (which presents very minimal impacts to the grid) may not be visible to co-ops, permits are required in many places for Level 2 EVSE and some utilities request that their customers provide a notification when installing any level of charging equipment. The Level 2 permitting process generally involves new load calculations to determine whether the residence’s service supply is sufficient to safely add the new load.60

Although the financial impact of PEV load is influenced by all of the above, the first three variables—regional wholesale electricity prices, the capacity of your co-op’s distribution system, and managing, or controlling, the time of day that PEV charging takes place—will typically have the most significant impacts on a co-op’s Cost to Serve figures. As these six variables will look different for each co-op, the financial impact of PEV load can vary widely, even if the amount of PEV load is the same (in terms of kilowatts).

### Quantifying the Risks

The subsections below quantify the opportunities, risks, and controlling variables described above.

All costs are from the distribution co-op perspective and use Midwest market-based costs. Calculations were completed by Integral Analytics.

Figures 5.1 and 5.2 illustrate the financial impacts two different co-ops may experience from serving one PEV for a year. These two scenarios are intended to represent co-ops with distinct wholesale energy cost characteristics and approaches to charge management:

- **Co-op 1:** low wholesale capacity charge, average transmission and distribution costs;
- **Co-op 2:** high wholesale capacity charge, average transmission and distribution costs.

In these scenarios, a co-op with high wholesale capacity costs pays $200/kW to a wholesale supplier for delivering a kilowatt during system peak, while a co-op with low wholesale capacity costs pays just $9.73/kW during system peak.61 Controlled charging means the co-op gets to choose when PEV charging occurs by implementing a charge management program or PEV time-of-use rates. Controlled charging will often mean that PEV charging happens off peak, while uncontrolled charging can occur during system peak.

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61 Personal communication with Mike Smith, Director of Corporate Strategy and Emerging Technologies at Central Electric Power Cooperative, Inc., on October 23, 2014.
In all the scenarios presented below, PEV demand is assumed to be 3.9 kW, which is a weighted average based on the typical demand (kW) of a PEV, taking into account the respective market share of the three standard levels of EVSE. The estimated end-user energy use for charging this 3.9-kW PEV for one year is 3,600 kWh, which assumes that the PEV is driven 12,000 miles/year.62

Costs for these two scenarios are broken down into three separate components: transmission and distribution (T&D) costs, wholesale generation “capacity” costs, and energy costs.

Figure 5.1 demonstrates that uncontrolled PEV charging can result in a significantly higher cost of service for this load. In locations with high wholesale capacity costs and average transmission and distribution costs, uncontrolled charging can increase the cost of service by over 250 percent. In contrast, uncontrolled charging in locations with low wholesale capacity costs and average distribution capacity increases the cost of service for the PEV load by just over 120 percent.

Although this cost is not incorporated in the Cost to Serve graphs above, some co-ops may need to provide a financial incentive to help defray cost of Level 2 EVSE installation to enable use of time-of-use (TOU) rates and controlled charging.

WILL A PEV RESULT IN A LOSS OR GAIN FOR YOUR CO-OP?

Controlling the PEV load will also influence whether the new PEV load will result in net losses or gains for your co-op. While, in some cases, the Cost to Serve PEV load will result in financial losses, in other cases the cost of serving PEV load will be offset by PEV revenue. Figure 5.2 illustrates the net losses (in red) and gains (in blue) of serving the same 3.9-kW PEV for one year for Co-op 1 and Co-op 2. Net income calculations are based on the assumption that end-users pay a standard residential rate of $0.12/kWh to charge their PEVs, and does not factor in time-of-use rates or demand charges.

Figure 5.2 shows the impact that controlling PEV, or charge management, can have on net income. By offering time-of-use rates or using education and outreach to motivate members to shift charging off peak, co-ops can minimize the revenue losses resulting from serving PEV load.

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and maximize financial gains. Volume 3 of this series will provide more in-depth guidance on methods co-ops can use to manage PEV charging and real-world examples of co-ops with PEV charge management programs.

**COST TO SERVE ANALYSIS AT THE CIRCUIT LEVEL**

The inputs for the graphs in Figures 5.1 and 5.2 were calculated using system-wide transmission and distribution (T&D) averages. Using system averages is the simplest method of determining the Cost to Serve a load. However—due to circuit loading—Cost to Serve figures vary circuit by circuit throughout a co-op service territory. System averages don't provide co-ops with locational distribution costs.

The graphs in Figure 5.3 and Figure 5.4 show four Cost to Serve scenarios with the same two co-ops (Co-op 1 with a low wholesale capacity charge and Co-op 2 with a high wholesale capacity charge) and the same 3.9-kW PEV. The difference is that these graphs show Cost to Serve figures at the circuit level.

A distribution circuit with “excess” capacity refers to a circuit that is operating below its rated capacity; a “constrained” circuit refers to a distribution circuit that is operating at or near its rated capacity and an upgrade to the circuit is required. All Cost to Serve calculations assume that the cost to upgrade a circuit is amortized over a 15-year period.

The two graphs in Figures 5.3 and 5.4 show that, in addition to the importance of managing the timing of PEV charging, the location of the PEV load can be a key driver of a co-op’s financial costs to serve PEV load. If a member-owner is connected to a constrained circuit, his or her co-op will have much higher costs to serve new PEV load because of the increased stress on the

### FIGURE 5.3: Estimated Annual Cost to Serve One 3.9-kW PEV (Circuit-Level Analysis)
distribution transformers and other components. Likewise, PEV load served by a circuit with excess capacity will cost far less, especially if PEV charging is managed so that it occurs off-peak.

While system averages can be helpful, it is important that your co-op closely monitor the distribution system to determine where circuits may be at capacity. For nearly all co-ops, some fraction of the distribution system will be constrained. These constrained circuits will result in higher Cost to Serve figures than represented in the system average.

However, because many co-ops are not experiencing load growth at this time, it is likely that many co-ops will only have a small number of constrained distribution circuits. If PEV adoption or clusters are likely to occur on distribution circuits that are constrained, co-ops should proactively upgrade transformers and other key infrastructure.

To summarize, the key financial implications new PEV loads could present for co-ops include the following.

- The financial impacts of PEVs on co-op systems depend on the co-op’s wholesale purchase contracts, as well as what circuits PEVs are located on within the distribution system.
- Co-ops should develop an accurate understanding of their circuit level transmission and distribution cost of service.
- If properly managed, the negative financial impacts of PEVs for co-ops with constrained distribution systems can be decreased significantly. Even for co-ops with excess distribution system capacity—such as Co-op 1—charge management can be the difference between a financial loss and a gain. Charge management strategies are a key way to reduce the financial risks of PEVs.

63 Personal communication with Robert Harris. Op cit.
Co-ops with a high wholesale capacity charge should consider managing PEV charging through time-of-use rates or load management switches to prevent PEVs from charging at the time of system peak. A new Consumer Electronics Association standard in the United States, CEA-2045, specifies a modular communications interface (MCI) for energy management signals and messages exchanged among devices in a home and the smart-grid system. CEA-2045 was designed specifically so that EVSE and other household appliances with large energy loads can interface with a range of utility load management systems. Currently, Siemens produces the only EVSE unit that is based on the CEA-2045 standard; it works with utility demand response programs, giving utilities the ability to directly shift PEV loads. Direct load control programs are costly; co-ops should evaluate the economic costs and benefits of a direct load control program for PEVs based on PEV adoption rates, wholesale capacity charge costs, and the viability of other less costly charge management strategies.

Integrating PEVs with the Smart Grid

As grid mechanisms become more automated and computerized, and more devices are equipped with sensors and two-way communication capabilities, the smart grid is becoming more and more of a reality. PEVs have the potential to play an important role in the smart grid.

In the long term, successful PEV-smart grid integration could improve the services offered by both. Integration would allow grid operators to modulate the power flowing to and from PEVs to match power supply and demand. Individual and commercial PEV owners could generate revenue by using their vehicles to provide market services to the grid.

**SMART GRID TECHNOLOGY STILL DEVELOPING**

Connecting PEVs to the smart grid will require the integration of a wide range of systems, devices, and applications. Although many of the components are ready for use, the absence of standards is limiting their adoption. Standardizing these technologies presents a significant challenge, as PEVs, EVSE, and utilities all use proprietary systems and technologies, and integration will need to incorporate legacy utility systems (e.g., customer information systems) for utility billing.

Integration is further complicated by the fact that the PEV is a mobile technology with the ability to cross jurisdictions, networks, and service territories. Successful integration will require standardized communication protocols that enable vehicles from more than a dozen automakers to exchange data with thousands of energy providers.

These protocols are still being tested and developed and include the Open Automated Demand Response (OpenADR) standard (used for standardizing demand response signals between utilities, ISOs, energy management and control systems, and power-using devices) and
the ZigBee Smart Energy Profile (SEP2) standard, used to standardize home area network (HAN) energy management.

As part of the Clean Cities Electric Vehicle Readiness project, Texas utility Austin Energy partnered with a number of other stakeholders to outline a roadmap for facilitating PEV interoperability with the grid. The roadmap inventories the necessary devices (e.g., EVSE and smart meters), systems (e.g., PEV on-board telematics systems, advanced metering infrastructure), and software applications (e.g., EVSE payment and transformer load monitoring software) needed. The project also identified key integration points between all of the above, and an estimated timeline for the process. Figure 6.1 displays the priority integration points required in the two-to-five-year stage of the roadmap.

Co-ops can refer to the Texas River Cities report for more details on the integration of the technologies listed above.65

### SMART CHARGING AND DEMAND RESPONSE (DR)

The term “smart charging” generally refers to charging based on two-way communication between energy providers and PEVs. Smart charging is closely related to using PEVs for demand response (DR); both terms refer to slowing, delaying, or turning PEV charging off based on utility signals.

PEV-smart grid integration would allow for more sophisticated charging that incorporated EVSE location and a driver’s charging requirements, such as minimum charge required and requested charge completion time. PEV charging could be prioritized based on which PEVs needed a charge most urgently, and charging speed and power level could be dynamically controlled. According to a report by Navigant Research, by 2022, DR programs will be able to control nearly 640 MW of PEV load.66

Smart charging and DR programs would allow energy providers to better manage PEV load during peak periods, maximize the load shaping capabilities of PEVs, and further minimize PEV impacts on grid infrastructure. Charging based on both real-time and forecasted grid conditions would also allow utilities to use PEVs to better utilize intermittent renewable energy supply, such as wind or solar power.

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Smart grid technology is still developing and there are many unresolved questions around exactly how smart charging/DR should be implemented. No single approach has yet to emerge as the best choice, and the optimal solution will likely differ for each utility.

Charging will need to be managed through some form of centralized coordination, likely either through a utility or third-party energy management services company or “aggregator.” Utilities or the aggregator could manage charging directly, either through a PEV’s onboard telematics system, a smart meter, or EVSE.

There are additional questions about compensation for the parties involved in charge-control programs. Utilities or aggregators might compensate either EVSE site owners or vehicle owners themselves in exchange for participation. Employers could provide free or discounted charging to workers who opted into charge-control programs.

Depending on what systems were used to manage the process, other parties might be compensated as well: auto manufacturers might take a cut for use of a vehicle telematics system, EVSE network or PEV charging software providers might charge for use of networked charging stations.

A number of PEV and EVSE manufacturers, utilities, and third-party organizations are currently researching smart charging and demand response programs.

- IBM worked with Honda and California utility PG&E to develop a cloud-based software platform that synchronizes PEV battery level data with real-time utility data on grid conditions to create an optimized charge schedule. The IBM EV platform also aggregates historical PEV charging data to forecast the location and duration of PEV charge loads for a specific area, such as a neighborhood, helping utilities optimize grid operations and infrastructure planning.67

- Greenlots, a company that builds software for EVSE, released the first software platform compliant with the OpenADR 2.0b standard in 2014. Utilities can use EVSE equipped with this platform to provide customers with DR programs.68

- Austin Energy has tested an automated DR program with about 60 residential customers with PEVs. The utility used AutoGrid’s cloud-based Demand Response Optimization and Management System platform to notify PEV owners of upcoming DR events, allowing them to either participate or opt out. The utility incentivized participation by providing rebates for home chargers. Early results suggest the program is successful.69

- In 2013, PG&E began a DR pilot in order to evaluate the feasibility of utilizing the batteries of commercially owned PEVs—both when they are in the vehicle and when they are removed—to provide grid stabilization services.70

- The Electric Power Research Institute is working with 16 utilities, eight automakers, and Sumitomo Electric Industries, Ltd., to build an open communications platform that will allow for bidirectional information exchange between utilities and PEVs. The program aims to develop a cloud-based, central server that will relay and translate utility information (such as demand response signals) to nearby PEVs. The platform would create a single standards-based interface that would allow PEV drivers to conveniently participate in utility demand response programs, and could also make it easier for drivers to use parked PEVs for vehicle-to-grid applications. It would integrate a number of communication networks—including automated

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meters, infrastructure (AMI), home area networks (HAN), building energy management systems, and energy management companies—and would allow utilities to track and manage EV load in specific geographic locations. For example, utilities would be able to distinguish how much load is coming from a PEV versus a residence. The Open Vehicle-Grid Integration (VGI) Platform software system was demonstrated for the first time at the Sacramento Municipal Utility District’s Customer Service Center in October 2014.

Vehicle-to-Grid (V2G) Applications of PEVs

Electric vehicle batteries offer a large energy storage reservoir that can potentially be used to perform a number of vehicle-to-grid (V2G) applications, such as absorbing excess power from renewable sources or providing backup power to homes in emergencies. PEVs are one of many demand-side resources that can be used for balancing the grid in place of power plants.

ANCILLARY SERVICES (A/S)

Ancillary services (A/S) support the stable operation of the electric system; these services account for five to 10 percent of electricity cost, or $12 billion a year in the U.S. The highest value A/S is frequency regulation. Frequency regulation, or “regulation,” balances load and generation and keeps system frequency at or near 60 Hz.

Frequency is too high when too much power is being generated in relation to load; load must be increased or generation must be reduced. If frequency is too low, there is too much load and system operators must increase generation or remove excess load.

These adjustments to the system are typically made by dispatching local generators or loads for just a few minutes at a time. PEVs can provide this temporary service while slower power sources ramp up capacity, charging to remove excess load when there is too much generation or discharging when there is too much load on the grid (see Figure 6.2).

FIGURE 6.2: V2G Ancillary Services

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Compared with other storage resources, PEV batteries are advantageous due to their fast response time and low total energy demand. PEV batteries can respond to grid imbalances significantly faster than traditionally used power plants and can serve as a generator or load at any time.

It is important to note that PEVs are currently faster at removing excess load than providing/ramping up power. Also, there are concerns around the effect of bidirectional power flow on battery longevity.

PEVs can also provide an A/S called spinning reserve, which refers to generation capability that can reach full capacity within 10 minutes of a signal and provide power during unplanned outages of base load generators. However, cycling is less frequent for this A/S and it is less valuable than regulation.

Another A/S is peak shaving, where aggregated PEVs could act as generators to reduce system peak.

PEV A/S applications have been successfully tested in a number of pilot projects. One project—a collaboration between utility NRG Energy and the University of Delaware, known as eV2g—proved real-world V2G capabilities for the first time in early 2013. Each PEV communicates with the grid and the other PEVs in the project via a control board which costs between $200 and $300 and uses about $40 of electricity a month. The project demonstrated that a fleet of PEVs could sell power services to the Pennsylvania/New Jersey/Maryland (PJM) Interconnection grid (see Figure 6.3).

The vehicles currently earn a monthly profit of about $110 a car. NRG Energy has yet to commercialize the eV2g technology.

In another successful 2013–2014 Texas pilot program, Frito Lay’s fleet PEVs provided regulation services to the Electric Reliability Council of Texas (ERCOT)-managed grid via a V2G system developed by the Southwest Research Institute. PEV regulation is especially useful in this region as wind supply constitutes 20 to 25 percent of ERCOT network peak load, resulting in significant intermittent power generation.

The Frito Lay PEV delivery trucks were hooked up to two-way Level 2 chargers and a device monitoring grid frequency; charger power input was adjusted when frequency deviated. Vehicles successfully removed charge loads from the grid in less than one second, responding to real-world ERCOT signals.

At this point, both economic and technical barriers are slowing the use of PEVs for A/S. V2G business models are currently being developed; energy aggregators and major fleets will likely be the first to use PEVs for market services. However, both regulated and deregulated electricity markets make the barrier to entry high for energy management companies.

Regulated markets governed by vertically integrated utilities provide ancillary services.

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76 Ibid.


internally, which limits the participation of independent power producers, energy service companies, and fleets. Although deregulated markets are more accessible, participating in the ancillary services market can require high, potentially prohibitive upfront investments in vehicles and equipment.

A recent change in regulations may make participation easier. In 2013, the Federal Energy Regulatory Commission (FERC) updated regulations (Orders 784 and 755) to recognize and compensate faster, more accurate ancillary services and open up the ancillary services market to new technology, such as PEVs and other fast-responding energy storage technologies.79

There are also technological barriers preventing A/S. PEVs currently available on the market are not equipped with bidirectional on-board chargers, and modifying existing vehicles and EVSE with V2G capability would be expensive. Also, control boards necessary for managing the connection with the grid and other PEVs are not yet commercially available.80 There are concerns around what impact increased cycling and bidirectional power flow will have on battery longevity and manufacturer warranties.

V2G applications are further complicated by the fact that batteries always need to be sufficiently charged to drive. Business models which inconvenience or harm drivers in any way are unlikely to scale; drivers will be less willing to volunteer their vehicle for A/S services if there is a risk of being stranded with a dead or worn-out battery.

As battery technology and charge management scheduling systems improve, more PEVs may be equipped with V2G functionality. A 2013 report by Navigant predicts that PEVs will be able to participate in grid services in the second half of this decade.81 Co-ops may want to wait to invest in integrating PEV A/S into their system until market and technological forces converge to make these applications more feasible.

**VEHICLE TO HOME (V2H) AND VEHICLE TO BUILDING (V2B)**

Vehicle to Home (V2H) and Vehicle to Building (V2B) are V2G applications that typically involve using PEV batteries to export power to a household, building, or microgrid. V2H and V2B can be used for “peak shaving,” charging during nighttime periods and releasing stored energy to “shave off” peak demands in the energy use of a home or building. PEVs can also be used to provide backup power in emergencies.

At this point, PEVs are unlikely to be used for V2H or V2B at scale, due to concerns about bidirectional power flow on PEV battery life. However, V2H technology is currently being implemented in Japan and several PEV manufacturers are experimenting with technology that enables bidirectional capability.

After the 2011 Fukushima nuclear accident, Nissan worked with Japanese company Nichicon to develop the “LEAF to Home” power supply station. The station serves as a two-way charger and power inverter based on the CHAdeMO quick-charging protocol, turning the LEAF into a back-up power source in the event of a power outage (see Figure 6.4).

Using the LEAF’s V2H interface, the unit charges or discharges the vehicle at up to 6 kW,
connecting to a household distribution board via a power control system. Owners can also use the LEAF to Home system as a money-saving energy storage unit, sending cheaper off-peak electricity stored at night back to their home during daytime peak-demand periods.

Although Nissan has sold more than 2,000 LEAF to Home systems in Japan, the system is not available in the U.S. In 2012, Mitsubishi released a similar power inverter called the MiEV power BOX, which exports up to 1,500 W of AC power using the i-MiEV battery; this unit is also only available in Japan.

One challenge to U.S. deployment is that Americans use significantly more electricity; the average American residence consumes 32 kWh a day, whereas the average Japanese household only consumes 10 kWh. The LEAF’s 24-kWh battery can power a Japanese home for two days but would only power an American home for one day.

Furthermore, most Americans are unfamiliar with using PEVs for backup power and may view gas-powered generators as a cheaper, simpler alternative. However, some PEV owners are experimenting with this capability; several LEAF owners hacked their cars to power several appliances during 2012’s Hurricane Sandy.

Nissan recently completed preliminary testing of a vehicle-to-building (V2B) system, which allows companies to use employee-owned LEAFs to regulate office building electricity consumption. The LEAFs are charged when electricity is cheaper, and the building draws power from the cars during peak periods when electricity is more expensive. Up to six Nissan LEAFs can be connected to a building’s power distribution board and charging is phased such that each vehicle is fully charged by the end of the work day. The testing showed that power use was cut by 2.5 percent during peak hours, providing an estimated annual $4,900 in net savings when six LEAFs were connected to the building’s power distribution board. Businesses and buildings could use this kind of system to curtail demand charges.

The U.S. Department of Defense is a major supporter of V2G technology. In 2013, the Defense Department announced it would invest $20 million in a multiyear pilot study on V2G energy storage capacity led by Sandia National Laboratories, the largest demonstration of V2G to date. This investment may accelerate the spread of V2H and V2B technology.

The project aims to transition military bases to “microgrids” in which local generation and storage assets—such as solar panels and battery systems—provide on-site generation for local loads. Research will explore what role PEVs can play in these microgrids, with a focus on their ability to provide backup power to keep mission-critical loads in operation in case of grid outages. The project will also study the use of PEVs in integrating on-site renewable assets.

**PEVS AND SOLAR**

EV batteries can serve as distributed energy storage for the excess output of highly variable renewable energy sources such as wind power, then providing this power back to the grid during peak periods. As more renewable generation is integrated into the grid, there may be a greater demand for PEV energy storage and controllable load capabilities.

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In particular, PEVs and residential solar are closely intertwined; advances in one technology benefit the other. Increased demand for PEVs is expected to accelerate production of lithium ion batteries, cutting the cost of home energy storage systems that could be used with residential solar. A report by investment bank UBS predicts that home solar will be cost-competitive with power generated by utilities by 2025.89

Moreover, there is significant crossover between PEV owners and home solar users. Opower, a utility software company, recently analyzed 2,000 PEV owners in the Western U.S. who were enrolled in discounted PEV charging programs. The study found that, relative to the typical household, PEV households were 6.6 times as likely to own solar panels that routinely send surplus electricity back to the grid; one in 13 PEV-rate-plan subscribers regularly spin their electric meter backwards via solar, compared to just one in 86 households without PEVs.90

SolarCity—the largest solar power provider in the U.S.—has developed a home energy storage system in selected California markets that utilizes Tesla batteries to provide emergency backup power as well as peak-usage cost shaving (Figure 6.5).91

The combined demand for batteries for both solar systems and Tesla vehicles may accelerate battery production in Tesla’s planned Gigafactory, resulting in lower battery costs.

There is some concern among utilities that homes using a combination of solar panels, energy storage technology, and PEVs will become completely independent from the grid, operating as energy islands. Peter Rive—SolarCity’s cofounder and CTO—refutes this concern.

“One of the more polarizing ideas going around is that battery storage will lead to mass defections from the grid,” said Rive. “Needing only their solar and their batteries, the story goes, Americans will simply cut the cord. While this is technically feasible, SolarCity has no interest in this scenario. While cutting the cord enables one household to be 100 percent renewable and self-sufficient, it limits what these technologies can do. In short, the grid is a network, and where there are networks, there are network effects. When batteries are optimized across the grid, they can direct clean solar electricity where (and when) it is needed most, lowering costs for utilities and for all ratepayers. This is true of homeowners’ behind-the-meter storage units, and it’s also true of larger commercial and utility-scale units.”92

Although the combination of PEVs, solar, and storage may not currently pose a threat to grid operators, it is important that co-ops assess the implications of these technologies and find ways to accommodate them into their business models.

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SECONDARY USE OF PEV BATTERIES FOR GRID-RELATED STORAGE

PEV batteries can be used for energy storage applications both while in the vehicle and after they have degraded to the point where they are no longer usable in the vehicle. In general, after about 10 years of driving, PEV batteries degrade to around 70 to 80 percent of original capacity, diminishing both driving range and the ability to use regenerative braking energy to deliver power to the electric motor. At this point, many drivers are likely to want to upgrade to a new battery.

There are currently more than 246,000 PEVs on the road. As these vehicles age, a secondary market for used PEVs and used PEV components will mature. The market for used PEV batteries is currently minimal, due to a low rate of failure and the high cost of replacement batteries.

However, as the cost of replacement batteries drops due to increased manufacturing know-how and economies-of-scale, the used PEV battery market will likely grow. One analysis predicts that up to 100,000 second-hand batteries will become available in the U.S. on an annual basis.93 PEV owners will be able to trade in or sell old batteries to either PEV manufacturers or other third parties.

Used PEV batteries can be repurposed as stationary energy storage units able to store cheap power for a long time. According to an analysis by John Holmes, head of technology innovation and deployment at San Diego Gas and Electric, even after PEV battery capacity falls below 70 percent, batteries may have about 10 years of useful life as storage devices.94 Both in-vehicle and used PEV batteries can be used for A/S, load shifting, or for storing excess power output from volatile renewable generation.

However, there are still some technical barriers to using afterlife PEV batteries. A report from the University of California-Davis notes that: “Little is known at the present time regarding the variability of the cell characteristics in spent batteries and how the batteries continue to age on test cycles appropriate for second-use applications.”95

Moreover, not all PEV batteries are equally conducive to repurposing and it is difficult to combine batteries from different automakers. There are further concerns about the cost of integration: batteries may need new thermal management and electronics systems for second-life applications.

There are a number of efforts to develop new financial and ownership models for used PEV batteries. PEV manufacturers, in particular, are researching reuse programs as a way to recoup the high financial and environmental costs of manufacturing PEV batteries and lower PEV total cost of ownership.

Some PEV manufacturers are leasing, rather than selling batteries. Nissan recently announced a LEAF battery pack trade-in program. Replacement batteries are priced at $5,499, including a credit of $1,000 for the required return of the old battery pack.96 Nissan is obtaining the used batteries for likely less than $100/kWh, which is far less expensive than purchasing new batteries for grid-related storage.

In February 2014, the world’s first large-scale PEV battery energy storage facility—installed by the 4R Energy Corporation (a collaboration between Nissan and Sumitomo Corporation)—began operating in Osaka, Japan.97 The power storage system consists of 16 used PEV battery packs linked with a 10-MW solar PV farm (Figure 6.6). 4R’s system is built to accommodate a range of PEV batteries, as PEV battery deterioration varies by how it was used. 4R is testing the storage system’s ability to smooth intermittent solar output, and expects to make...

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the results of the project commercially viable in around five years.

In 2012, General Motors and ABB—a power and automation technology group—demonstrated the use of a modular unit made of five used 16-kWh Chevrolet Volt batteries. The unit can provide about 25 kW of electricity for about two hours, enough to power three to five average American homes. The hope is that these units will one day serve as “community energy storage units,” used to power homes or small commercial buildings during a power outage.98 Duke Energy is testing one of these units with a transformer that supports about four customers, communicating with the unit via the ABB inverter.99

BMW North America is testing a 100-kW peak shaving and load shifting system using second-hand PEV batteries in its Mountain View, Calif., location.100 BMW is collaborating with Vattenfall, an energy company, to further investigate the use of afterlife PEV batteries for fast-charging stations, solar arrays, and grid stability.

Implications for Co-ops

For now, most PEV smart grid and V2G technology is still in the trial phase and may not be deployed for some time. However, it is important that co-ops stay up-to-date on research in this area. While it is difficult to establish an exact timeframe for the adoption of this technology, in the long-term, PEVs may facilitate the rise of demand-side management and the use of distributed generation technologies, which could significantly impact co-op business.

Proactive assessment and planning will help co-ops address PEVs and other disruptive technologies as they arise. Some co-ops and G&Ts may want to get involved in research efforts to gain experience with these technologies and gather information on their performance. For example, in the late 2000s, a number of co-ops participated in a General Motors/EPRI/utility collaborative partnership that studied V2G technical interfaces and other topics.101

Some utilities are taking concrete steps toward planning for, developing, and deploying the technology and infrastructure needed to enable V2G benefits of PEVs. The New York City grantee of the Clean Cities Electric Vehicle Readiness project analyzed the economics of V2G and began installing longer electrical conduits to accommodate future V2G technologies.102

Others are waiting for the market to evolve organically before investing in research efforts. Co-ops can stay current on these technologies by watching utilities in early adopter markets, participating in a working group such as the EPRI Infrastructure Working Council (IWC), or joining one or more of the OpenADR, ZigBee, WiFi, HAN, or HomePlug alliances exploring smart grid technology and standards.

PEVs offer co-ops many potential benefits. They represent a unique opportunity for co-ops to grow load and increase revenue in a way that is environmentally and socially acceptable. The load from PEVs is also highly malleable and early evidence shows that electricity providers can successfully encourage off-peak charging with charge management programs. Off-peak charging can help flatten and stabilize a co-op’s load profile and ensures that new generation resources will not be needed to serve the PEV load.

However, if co-ops do not manage the timing of PEV charging, they may experience negative financial and grid impacts. PEV charging during peak periods could result in a co-op purchasing power from the wholesale market at a cost that exceeds what the co-op is charging residential end-users. This scenario could result in financial losses for co-ops.

Although the impacts of PEVs on the distribution grid are almost non-existent at this point, as PEV adoption increases, it is likely that PEV clusters will form. PEV clusters have the potential to overload transformers and can result in accelerated transformer aging.

Managing the timing of PEV charging is essential if co-ops want to reap the potentially significant financial benefits from the PEV load. Tracking the location of PEV adoption is also important to prevent stressing the distribution grid. If co-ops can manage these two key variables, PEV adoption is likely to result in increased profit.

Volume 3 of this series provides an array of policy and program options to help co-ops manage the timing of PEV charging and track PEV cluster formation. It also provides suggestions about ways that co-ops can encourage PEV adoption.
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<td>AFDC</td>
<td>Alternative Fuels Data Center (DOE)</td>
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<td>AMI</td>
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<td>A/S</td>
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<td>BEV</td>
<td>Battery Electric Vehicle; also referred to as an all-electric vehicle</td>
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<td>CHAdeMO</td>
<td>Japanese DC Fast Charging standard developed by Tokyo Electric Power Company</td>
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<td>Clean Cities</td>
<td>DOE-sponsored program supporting reduction of petroleum use in transportation</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>DC Fast Charging</td>
<td>Direct-Current Charging; fastest level of charging, providing full charge in under 30 minutes (480-V 3-Phase AC input)</td>
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<td>EVSE</td>
<td>Electric Vehicle Supply Equipment (aka charging station)</td>
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<tr>
<td>Frequency Regulation</td>
<td>Matching generation and load levels through adjusting generation output, using reserve capacity to reduce peak demand, etc.</td>
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<td>Gigafactory</td>
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<td>IEEE</td>
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<tr>
<td>kWh</td>
<td>Kilowatt-hour</td>
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<td>MCI</td>
<td>Modular Communications Interface</td>
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<td>MIT</td>
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<td>PEV</td>
<td>Plug-In-Electric Vehicle (aka plug-in vehicle, plug-in); includes PHEVs and BEVs</td>
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<td>PG&amp;E</td>
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<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle (aka plug-in hybrid)</td>
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<td>PNNL</td>
<td>Pacific Northwest National Laboratory (DOE)</td>
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<tr>
<td>Regenerative Braking</td>
<td>Converting the kinetic energy produced by a stopping PEV into electricity that can be used to recharge the car's batteries (stepping on the brake pedal of a PEV converts the electric motor into a generator, slowing the car's wheels; this drag produces electricity that's then fed into the vehicle's batteries)</td>
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<td>RTO</td>
<td>Regional Transmission Organization</td>
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<td>Smart Charging</td>
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