# WORLD RESOURCES INSTITUTE

# USING RENEWABLES FOR ELECTRIC VEHICLE DEMAND:
## A REVIEW OF UTILITY PROGRAM DESIGNS & IMPLEMENTATION STRATEGIES

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## EXECUTIVE SUMMARY

### Highlights

- Traditional methods of renewable energy procurement can be used to match electric vehicle (EV) demand with renewables annually; however, approaches that incorporate the timing of charging have the potential to enable demand to match renewable energy supplies more closely and offer greater grid benefits.

- Although programs to date have primarily focused on residential EV owners, time-based elements of EV charging could be incorporated into existing renewable energy offerings for large energy users, such as corporations and cities, to help meet their clean energy goals.

- Program structures that offer financial incentives are more likely to yield higher participation rates and thus may be more effective in providing grid benefits.

- Charging programs for employees and fleets can be designed to maximize utility and customer benefits through managed charging, which can match renewable energy availability with EV loads.

- Network charging with renewable energy has the advantage of ease of use but may be more difficult to implement in a way that closely matches charging times with renewable energy generation, relative to other approaches.

- Although a limited number of programs currently offer the ability to charge EVs with renewable energy, approximately a third of customers expressed interest in the handful of programs for which data were collected.

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## Background

**The use of EVs in the United States is growing rapidly, with adoption expected to reach nearly 20 million EVs on the road in the coming decade**. EVs are, on average, two to three times more energy efficient than traditional internal-combustion engine vehicles. Although the improved efficiency alone contributes to significant reductions in greenhouse gas (GHG) emissions, the energy sources on the grid, or the grid mix, used for charging determines the overall emissions. As electricity generation continues to transition toward carbon-free sources, electric transportation can provide even greater contributions toward decarbonization goals.

**Large energy users, particularly those with renewable energy procurement goals, are increasingly interested in using clean energy sources to meet new EV demand and are establishing goals to push these efforts forward**. Goals are typically designed to cover new EV loads associated with fleet vehicles and in some cases EV loads associated with employee workplace charging or public charging, such as at retail stores.

**Aligning EV charging with the availability of renewable energy generation can also provide benefits for the grid, particularly in areas that currently have or anticipate having large amounts of solar or wind generation on the grid.** Programs that encourage customers to charge midday, such as through workplace charging, can align well with peak solar output; nighttime EV charging can align well with the availability of wind generation.

### About This Working Paper

Various approaches can be used to match EV loads with renewable energy sources but can differ in terms of how closely the renewable energy generation matches the timing of EV charging and how customers are compensated for adjusting their charging times to help with grid management. This working paper explores the range of approaches and emerging program designs currently being used in the United States to match EV loads and renewable energy, with an emphasis on methods that more closely link the timing and location of the EV demand with renewable energy supply. On the basis of early experience with these programs (and where data

were available), this paper examines the structure of these offerings, pricing, the link between customer charging and the availability of renewable source power generation, and customer response. The objective is to inform both customers seeking choices and utilities interested in offering programs about the range of different approaches available, lessons from experience to date with utility programs, and considerations for program design and implementation.

## 1. INTRODUCTION

In 2018, more than 2 million electric vehicles (EVs) were sold, bringing the total number of EVs globally to more than 5 million—a 63 percent increase from the prior year (IEA 2019). In the United States alone, more than 1 million EVs have already been deployed and, with today's rapid improvements to vehicle technology and declining battery costs, EV ownership is expected to continue growing at unprecedented rates. By early 2021, the Edison Electric Institute has predicted that EV sales in the United States will double, reaching 2 million; by 2030, this number is expected to grow almost tenfold, reaching nearly 19 million EVs on the road. Thus, in the coming decade, 7 percent of all vehicles in the country are expected to be electric (Cooper and Schefter 2018).

On average, EVs convert 60 percent of their spent energy to moving the vehicle, compared with 20–30 percent for internal-combustion engine vehicles, according to the U.S. Department of Energy (DOE) (Denning 2019). Although the improved efficiency alone contributes to significant reductions in greenhouse gas (GHG) emissions, the grid mix used for charging determines the overall emissions. As such, large energy users, such as corporations and cities, particularly those with established GHG reduction targets, are increasingly interested in using clean energy sources to meet new EV electricity loads. Over the past year, more than 53 multinational companies in the United States have committed to procuring 100 percent renewable energy for electric loads (RE100 2018), joining the more than 130 cities that have already pledged to meet this same goal in the coming years (Sierra Club 2018). These goals are typically designed to address new loads associated with electric fleet vehicles, and potentially loads associated with employee workplace charging or public charging, such as at retail stores.

Recognizing that 30 percent of national emissions comes from the transportation sector, some cities and states have also established EV-specific clean energy charging goals for public transportation or other uses. Some examples are the following:

- **Cambridge, Massachusetts.** Cambridge has committed to transition to 100 percent clean and renewable energy community-wide, including energy for building energy use and transportation, by 2035.

- **Honolulu, Hawaii**. Honolulu has committed to a 100 percent renewable-fueled municipal fleet by 2035, in addition to a goal to power the city's entire public and private ground transportation system with 100 percent renewables by 2045.

- **Portland, Oregon**. Portland has committed to using 100 percent renewable energy to power community-wide transportation needs by 2050.

Utilities can play a key role in offering renewable energy options for EV charging and can benefit from programs that are aligned with grid needs, including peak load management and renewable energy integration. As EVs proliferate, wind and solar energy are among the fastest-growing technologies, expected to account for 35 percent of the country's electricity generation by 2050, up from 9 percent today (BNEF 2019). This growth, along with the falling cost of renewable energy (NREL 2018), means the case for integrating renewables into the grid is stronger than ever before. In areas where there is significant solar energy deployment, and there can be excess solar energy midday, workplace EV charging programs could be designed to help use this excess generation when it is available. In regions with significant wind energy capacity on the system, there can be excess wind generation at night, which aligns well with overnight charging.

This paper was prepared for the Special Clean Power Council for Customers and Utilities—a two-year collaboration of large utilities and large energy buyers interested in mutually beneficial solutions that help meet clean energy goals. The paper explores the range of different approaches and emerging program designs that are now being used to match EV loads with renewable energy sources, with an emphasis on methods that more closely link the timing and location of the EV demand with renewable energy supply. On the basis of early experience with these programs (and where data were available), the paper explores the structure of these offerings, pricing, and customer response. The objective is to inform both customers seeking choices and utilities interested in offering programs about the range of different approaches available, lessons from experience to date with utility programs, and considerations for program design and implementation.

## 2. APPROACHES TO MATCHING EV LOADS WITH RENEWABLES

Depending on the type of vehicle, whether a battery-only electric vehicle or a plug-in hybrid electric vehicle, a single light-duty EV consumes anywhere from 500 to 4,350 kilowatt hours (kWh) annually (Table 1).

Table 1 | **Annual EV Electricity Consumption by Vehicle Type**

| VEHICLE[a] | PERCENTAGE OF ALL-ELECTRIC MILES USED | ANNUAL ELECTRICITY CONSUMPTION (KWH)[b] |
|---|---|---|
| PHEV10 | 10–15% | 500 |
| PHEV20 | 33% | 1,400 |
| PHEV40 | 75% | 3,500 |
| BEV100 | 100% | 3,500 |
| BEV300 | 100% | 4,350 |

*Notes:*
[a] PHEV denotes a plug-in hybrid electric vehicle; BEV denotes a battery-only electric vehicle. Numbers denote the range of all-electric miles a vehicle type can travel before switching over to fuel or needing additional charging.
[b] It is assumed that all vehicle types would be driven 12,000–13,000 miles annually, except a BEV100 at 10,000 miles because of the range restrictions of the battery.
*Source:* Adapted from data compiled by ICF, the EV Project, Ford Motor Company, and SEPA, cited in SEPA 2019.

For electric buses and medium- to heavy-duty trucks, energy consumption can be substantially higher, ranging anywhere from 0.56–3.34 kWh per mile (Table 2).

Table 2 | **EV Electricity Consumption by Vehicle Type**

| VEHICLE | AVERAGE ELECTRICITY CONSUMPTION (KWH/MILE) |
|---|---|
| Passenger light-duty vehicle | 0.32–0.42 |
| Light commercial vehicle | 0.49–0.67 |
| Minibuses | 0.56–2.39 |
| Medium-duty trucks | 1.40–1.78 |
| Buses | 1.93–2.80 |
| Heavy-duty trucks | 2.34–3.34 |

*Source:* IEA 2019.

By 2030, the increase in share of EVs will add anywhere between 58 and 336 terawatt hours (TWh) of energy to the grid, according to models by the U.S. National Renewable Energy Laboratory (NREL).[1] Navigant Research estimates that energy demand will be closer to 93 TWh by the same year (SEPA 2019).

With this expected increase in demand for EVs, electricity, and clean energy, utilities are responding with new rates and programs designed to enable charging with renewable energy sources. For many years, utility and third-party offerings have existed in the United States to enable customers to procure renewable energy on an annual basis to match their overall electricity needs, such as through green pricing programs, green tariffs (which allow large customers to buy bundled renewable electricity at a special rate), community solar programs, direct power purchase agreements with renewable sources, or renewable energy certificates (REC)–based offerings.[2] However, these offerings have not typically been tailored specifically to EV loads, which vary by vehicle type and charging patterns, and do not capture all of the benefits that utilities and customers can reap by more closely linking the time when EVs are charged and the production of renewable energy.

New utility programs have emerged, mostly focused on light-duty vehicles, that more effectively capture the grid benefits that EV charging programs can provide. Some new programs are designed to link EV charging to the time of renewable energy generation, such as when solar production is available midday or when excess wind generation is available on the system, often at night. Although charging patterns vary by vehicle type, use, and customer needs, some EV charging demand can be flexible and can be shifted to align with grid needs or with clean energy availability. Residential customers and some vehicle fleets, for example, may have the ability to shift charging to preferred times, particularly if they receive financial incentives to do so. For other vehicle types, including buses and medium- to heavy-duty vehicles, it is likely that there will be limits on the ability to shift charging times, as the vehicles are needed to meet service obligations. Utility programs that address these shifts in demand can help customers meet their clean energy goals and benefit utilities in the transition to a low-carbon grid as vehicle electrification and renewable source deployment grow in coming years.

This paper explores five different approaches that utilities and third parties have used to enable customers to match EV charging demand with renewable energy generation (Table 3). These offerings are designed to

- enable customers to access renewables for EV charging through a network charging arrangement;

- offer renewables and encourage charging during beneficial times for the grid;

- use time-based rates that match renewable energy supply;

- incorporate managed charging to align EV charging with grid needs and renewable generation; and

- couple on-site renewables with EV charging infrastructure.

Each is examined in turn and recent examples given. Key differences in the ability to tie customer loads directly with renewables, the extent to which customers are credited financially for aligning their EV charging with grid needs, and the considerations for designing and implementing programs, are also examined.

Table 3 | **Approaches to Matching EV Loads with Renewables**

| APPROACH | EXAMPLES | DETAILS |
|---|---|---|
| EV network charging using renewables | Austin Energy, EVgo | Network charging model is used; customers pay per use, or a monthly flat fee, to use public chargers and charge with renewables. |
| Utility offerings that shift charging times and provide access to renewable energy | Great River Energy, Xcel Energy, Sacramento Municipal Utility District, Potomac Electric Power Co. | EV charging is encouraged during off-peak periods or when renewable energy generation is high. |
| Rates that match EV charging with the timing of excess renewables | Hawaiian Electric Co., San Diego Gas & Electric | Discounted rates encourage customers to charge EVs when excess renewables are on the grid. Customer cannot claim the renewables. |
| Managed charging | San Diego Gas & Electric, Pacific Gas and Electric, BMW | Managed charging programs can align EV charging with renewable energy output or grid needs. |
| Coupling EV charging with on-site renewables | Google LLC, DirecTV, Tesla, San Diego Gas & Electric | On-site solar panels and sometimes batteries charge EVs; can incorporate communication between the charger and the photovoltaic system. |

## 2.1. EV Network Charging Using Renewables

One approach to enabling customers to charge EVs with renewables is to incorporate the option within the network charging agreement. Typically, customers can take part in EV network charging under several different cost models: pay-as-you-go plans, fixed-cost monthly subscriptions, or, in some cases, free network access offered as part of pilot programs or to employees through a workplace contract. Network charging programs can also be designed to encourage customers to charge at times that are beneficial for the grid or align with renewable energy production.

Although approximately 20,000 public charging stations are currently available throughout the country (Wagner 2019), only a small fraction of these chargers allow customers to source their electricity exclusively from renewable energy options. Programs that do offer this option usually allow customers to subscribe to a fixed amount of EV charging that is guaranteed to be matched with renewables, essentially providing volume pricing to customers who want to see an itemized reflection of these charges on their utility bills. Wherever this happens, the best practice is to ensure that RECs associated with the utility option are retired, or taken out of circulation, on behalf of the customer, which allows customers to claim that they are using renewable energy instead of helping utilities meet specific renewable energy mandates.

To participate, customers can sign up either through a utility program or, alternatively, through an EV charging network provider. Currently, Austin Energy (Box 1) and EVgo, a fast-charging network company (Box 2), offer programs that allow customers to source 100 percent of their electricity from renewable energy sources. Launched in 2012, Austin Energy's program was the first of its kind; it gave customers the option to charge with renewable sources in exchange for paying a fixed rate. For US$4.17 a month, customers have unlimited access to all charging stations within the Austin Energy network. At the same time, the utility launched a time-of-use (TOU) pilot program that encouraged charging during otherwise low-load periods on weekends and at night, when wind energy is plentiful on the grid.

Austin Energy allows its customers to source 100 percent of their electricity from off-site wind farms under its green pricing program, GreenChoice, at a premium of $0.0075 per kWh on their utility bill (Austin Energy 2018).

With direct funding from DOE, Austin Energy has expanded the reach of its GreenChoice program. In 2012, the utility launched the Plug-in EVerywhere™ network. For $4.17 per month, this network gives EV customers unlimited access to the more than 834 charging ports installed at 237 locations around Central Texas and enables customers to charge EVs with wind power (Austin Energy 2017).

As of 2017, Austin Energy reported that 2,480 customers, more than 35 percent of their EV customers, were subscribed to the Plug-in EVerywhere™ Network. Since the program's inception, 4.69 GWh of renewable energy have been consumed through 550,442 charging sessions, displacing approximately 22 million petroleum miles (Austin Energy 2019).

As part of the Plug-in EVerywhere™ Network, Austin Energy jointly launched a time-of-use pilot program for EV charging in 2016. For a flat fee every month, the 100 customers involved in the pilot had access to unlimited charging at any Plug-in EVerywhere™ station and unlimited off-peak charging at home (off-peak hours ran from 7 PM to 2 PM on weekdays and anytime on weekends). In the program, EV drivers requiring a demand of less than 10 kW had a flat $30 monthly fee, while customers with a demand greater than 10 kW were subject to a $50 fee (Mitsubishi Motors 2019).

## 2.2. Utility Offerings That Shift Charging Times and Provide Access to Renewable Energy

In an effort to match the timing of renewable energy generation and EV charging, some utility programs have been developed to encourage EV charging at times that are better for the grid, either during off-peak periods or at times when renewable energy generation is high. In exchange for charging during these preferential times, utilities offer customers discounted rates, which can offset any potential premium for renewable energy.

On May 7, 2019, EVgo announced plans to match the electricity needs of its network—the nation's largest public fast-charging network—with 100 percent renewable energy. The company currently owns and operates more than 1,200 direct current (DC) fast chargers and 1,000 Level 2 chargers across 66 metropolitan markets. Founded in 2010, EVgo currently serves more than 150,000 customers nationwide.

Across the country, EVgo purchases a combination of Green-e® certified wind and solar energy through its electricity suppliers and REC partners. Under a newly announced commitment, EVgo will contract with its energy suppliers and partners to ensure that each GWh delivered financially supports a renewable energy generator. To form part of the EVgo charging network, customers have the option to enroll either in a pay-as-you-go plan that allows for 45-minute charging sessions at $0.27–0.35 per minute, depending on location, or a membership plan, for $7.99 per month, that includes the first 29 minutes of fast charging and average rates of $0.27 per minute (EVgo 2019).

In 2018, EVgo is estimated to have powered more than 75 million electric miles, an 88 percent growth from the prior year; by the end of 2020, the company plans to more than double its network capacity. Currently, EVgo opens new stations every six to eight weeks and continues to expand exponentially through strategic partnerships with companies such as Nissan, through which EVgo plans to install 200 additional chargers in the next few years.

## Integrated Programs to Enable EV Charging with Renewables

Currently, Great River Energy offers special rates for Minnesota customers who are willing to charge at night, when wind is abundant in Minnesota. The savings of using excess wind generation allow the utility to offer 100 percent renewable charging at no extra cost to the customer (Box 3). This example, in particular, is mutually beneficial for both the utility and its customer—while the utility saves on system management costs, customers are allowed to charge with renewables without paying a premium. This is similar to the Austin Energy pilot that offered unlimited off-peak charging to encourage charging when wind energy was readily available.

Box 3 | **Great River Energy's Revolt Program (Minnesota)**

In 2015, Great River Energy designed and launched Revolt, a program that allows members to meet EV loads with wind energy charging that is offered at no additional cost to the customer.

Revolt is the first program of its kind in the United States to offer a renewable energy alternative free of charge. It also offers special discounted nighttime rates for those who participate (Noble 2016). Revolt's goal is twofold: to encourage the adoption of EVs and to use excess wind at night, when it is most abundant on the grid.

The program was available to 400 EV owners in Great River Energy's service area and retired each customer's RECs to cover every kWh consumed charging: 5,000 kWh annually per customer during the lifetime (up to 10 years) or lease (up to 3 years) of the vehicle (Trabish 2015). Although Revolt was initially scheduled to end the same year it was launched, the program has been extended each year, because of its popularity, and continues to be offered to customers.

## Coupling EV TOU Rates with Renewable Energy Options

Other programs are designed to link TOU rates for EV customers with renewable energy options. TOU rates allow utility customers to pay different prices for their electricity, depending on their time of consumption—typically, higher rates are charged during peak hours when electricity demand on the grid is high, and lower rates are charged during off-peak hours. TOU rates encourage EV owners to shift their loads away from peak demand hours, helping to avoid the construction of additional power plants to meet demand, or toward hours when there is excess renewable energy on the grid. Although TOU rates are not novel, utilities are increasingly making them available to EV owners, offering them either as a residential rate where all household energy is measured on a single meter or as a separate metered rate specific to EV charging.

In some cases, utilities offer EV TOU rates alongside a green pricing program or offer EV customers the option to charge their EVs with renewable energy. These approaches are similar to the Austin Energy example, but do not include use of a charging network.

### TOU RATE COUPLED WITH UTILITY GREEN PRICING PROGRAMS

Under this approach, customers sign up separately to participate in an EV TOU rate and a green pricing program. In combining programs, customers can typically offset the premium cost associated with participating in a green pricing program if they charge their EVs at off-peak periods, because the TOU rate provides lower off-peak rates. Therefore, the customer provides grid benefits by charging at preferred grid times, although these programs do not necessarily ensure that the EVs are charging at the time of the renewable generation. However, once the availability of renewable sources reaches high enough levels on the system, the preferred grid times could be modified to when excess renewables are available.

The Sacramento Municipal Utility District (SMUD) (Box 4) and Xcel Energy (Box 5) offer separate EV-specific TOU rates and voluntary renewable energy offerings, or green pricing programs, that can be combined. Customers might not be able to combine these TOU rates with a utility's green tariff option, depending on the tariff structure.

### TOU RATE WITH RENEWABLE ENERGY OPTION

Under this approach, which is a variation on the above approach, customers interested in participating in a TOU rate and adding renewable energy sign up for the TOU rate first and then choose to add renewable energy charging. This approach differs from the green pricing examples in that it does not rely on a pre-existing utility renewable energy program and can be implemented in an electricity market with retail competition.

For example, Potomac Electric Power Company (PEPCO) offered a pilot TOU rate for EV customers with a renewable energy option in its Maryland service area (Box 6). In its pilot, PEPCO found that approximately one-third of EV customers switched over to renewable energy, despite incurring an additional charge of $0.02 per kWh. In some cases, utilities might allow customers to add renewable energy without paying a premium, if the off-peak charging hours align with renewable energy production.

SMUD allows EV owners the opportunity to source 100 percent or 50 percent of their charging needs from renewables for an additional monthly fee of $6 or $3, respectively, by enrolling in SMUD's voluntary green pricing program, Greenergy.

In 2017, the entire Greenergy Program accounted for roughly 4 percent of SMUD's total annual load; it currently has more than 74,000 enrolled customers from the total service area population of 1.5 million. To date, the program has supplied approximately 750 GWh of renewable energy (SMUD 2017). Yet, the exact number and percentage of EV owners who participate in this program remains unknown, making it difficult to analyze the impact they have on Greenergy's overall numbers.

In addition to Greenergy, SMUD also offers EV owners a special residential TOU rate—termed a time-of-day (TOD) rate—to incentivize off-peak charging. Starting January 1, 2019, TOD rates became mandatory for all SMUD residential customers in order to encourage energy use before 5 PM and after 8 PM Monday through Friday. For customers who charge their EVs between the hours of midnight and 6 AM, SMUD provides an additional incentive of $0.015 per kWh credit every day, all year long (SMUD 2019).

Box 5  |  **Xcel Energy's EV-Specific TOU Rates (Colorado, Michigan, Minnesota, New Mexico, and Wisconsin)**

Under Xcel Energy's voluntary green pricing program, Windsource, residential customers have the option to charge their EVs with energy derived from wind either entirely or partially. Windsource subscriptions are available in 100 kWh blocks for a premium of $1.50 per block, or $0.0150 per kWh, added to a customer's monthly electricity bill (Xcel Energy 2019). Although information on the current percentage of EV owners who participate in the Windsource program is not available, Xcel Energy has seen a high correlation among both factors—in 2013, 35 percent of EV owners were also Windsource customers (Haskard 2013).

In August 2018, Xcel Energy also launched a new two-year EV pilot program, the EV Service Pilot Program, for up to 100 residential customers in Minnesota. To participate in the program, Xcel Energy installs charging equipment with embedded energy-monitoring capabilities at customers' homes, and customers can either pre-pay for the charger and installation ($886 one-time fee + $7.10 per month) or bundle the cost as a monthly fee ($17.47 per month). Once customers are enrolled in the EV Service Pilot Program, they gain access to the utility's EV electric pricing schedule, which encourages off-peak overnight charging (9 PM to 9 AM weekdays and all hours on weekends) at a rate of $0.0426 per kWh (Xcel Energy 2018b). Customers enrolled in the pilot program can also concurrently participate in Xcel Energy's Renewable*Connect program, which allows residential customers to source 100 percent of their electricity from wind and solar. The additional premium averages $5 to $7 per month (Xcel Energy 2018a).

Box 6  |  **PEPCO's Pilot Program (Maryland)**

Between 2013 and 2015, PEPCO ran a voluntary pilot program for EV owners in its Maryland service area. To study the impact home charging had on the grid's demand response, PEPCO enrolled 101 customers to test two different TOU rate structures—an EV-specific rate and a whole-home rate—and offered optional renewable charging options. Of the participants, 86 percent chose to participate in the EV-specific rate; the remaining 14 percent opted to enroll in the whole-home rate.

For the EV-specific rate, peak charging times ran noon to 8 PM, Monday through Friday, at a rate of $0.23 cents per kWh, while off-peak rates declined to $0.05 per kWh. On top of this, customers on this rate could choose to pay an extra fee of $0.02 per kWh to charge with renewable energy, claim zero tailpipe emissions, and have PEPCO retire their corresponding RECs.

When the pilot ended, about 34 percent of customers in the EV-only rate had opted to pay the premium to guarantee renewable energy charging, signaling customers' interest in continued implementation of renewables into the grid (Walton 2017).

## 2.3. Rates That Match EV Charging with the Timing of Excess Renewable Energy

Other programs (i.e., rates) focus on aligning EV charging with the availability of renewables to help with renewable grid integration. These programs differ from the ones described earlier because customers do not procure the renewable energy equivalent to their EV consumption, regardless of when the renewable energy is generated. Rather, these rates are designed to shift loads to times when there is excess renewable energy generation on the grid.

In regions where the penetration of renewable sources is high and curtailment is necessary, utilities are using TOU rates to address renewable energy integration. By improving overall grid flexibility and shifting load demand, TOU rates can help address some of the concerns associated with the daily and seasonal patterns of renewable energy generation (e.g., solar generation at midday in summer and wind generation at night in winter and spring). Currently, these issues occur in only a few regions, such as Hawaii and California, where there can be excess solar generation midday. However, as solar capacity is expected to double over the next five years, topping 100 GW by 2021 (SEIA 2019), and wind capacity is similarly expected to grow substantially, reaching more than 110 GW by 2020 (DOE 2019), more utilities may be interested in linking EV demand and renewable supplies.

For example, TOU rates recently introduced by Southern California Edison (SCE) (Box 7) and the Hawaiian Electric Company (HECO) (Box 8) do not directly provide renewable energy for an EV's load but instead try to match the timing of customers' EV loads with excess solar generation on the grid. The TOU rates are designed to encourage charging when solar energy is most available on the grid, even though participation in this rate does not allow customers to claim use of renewable energy. If customers did indeed want to make such claims, the renewable generation attributes, or RECs, would have to be transferred to or retired on behalf of the customers.

Box 7 | **SCE's TOU-D-PRIME Rate (California)**

In an effort to use excess renewables on the grid, SCE's TOU-D-PRIME Rate (California) recently introduced a TOU rate—TOU-D-PRIME—available to EV owners and lessees, customers with energy storage systems, and customers with electric heat pumps. Eligible customers were able to enroll in this rate until April 30, 2019, and there was no minimum commitment period for participation.

The TOU-D-PRIME rate encourages customers to charge on weekdays and weekends during off-peak hours when solar power is abundant (8 AM to 4 PM) and then again at night (9 PM to 8 AM) when wind power can be abundant. Enrollment in the TOU-D-PRIME rate has a fixed charge of $0.40 per day—a higher cost when compared with other similar programs—but also offers lower off-peak variable charges to offset cost at $0.13 per kWh (SCE 2019b). Prior to this, EV owners who owned charging stations with a dedicated meter already had access to another TOU rate program, TOU-EV-1, which has now been closed to enrollment and has rolled over to a grandfathered rate plan (SCE 2019a).

Today, more than 150,000 SCE customers drive EVs. In 2018, the utility filed for approval of a program known as Charge Ready 2, a $760 million investment that focuses on financing electrification and infrastructure to support 48,000 additional charging ports throughout Southern California.

Box 8 | **HECO's Schedule TOU EV Rate (Hawaii)**

In 2010, the Hawaiian Electric Company (HECO)—including its subsidiaries Hawaiian Electric, Hawaii Electric Light, and Maui Electric—introduced a TOU rate for EV charging, known as Schedule TOU EV, that provided customers with a lower price for energy that was used overnight. Although participating customers can stay on the TOU EV rate indefinitely, the program was closed to new enrollments in September 2016.

To replace the Schedule TOU EV program, two new sets of TOU-RI rates were recently introduced in October 2016: a residential rate where all household energy is measured on a single meter and a separate meter rate for EV charging only.

Available to up to 5,000 customers, this new TOU-RI rate has three different energy charging periods, including on-peak (5 PM to 10 PM), midday (9 AM to 5 PM), and off-peak (10 PM to 9 AM) (Public Utilities Commission of Hawaii 2016). Although rates vary by island and are subject to monthly adjustment changes, costs are lowest during the midday period, when solar and other renewable energy is most abundant and at an excess on the grid (HECO 2019). Under these terms, customers can save anywhere between $0.33 per kWh and $0.50 per kWh when compared to base rate plans (Coffman et al. 2016).

## 2.4. Managed Charging Programs

Another approach is to design programs that control the timing of EV charging, either at work or at home, to link EV charging more closely to renewables. Managed charging—also known as controlled, smart, or V1G[3] charging—allows utilities or other third parties to control EV charging remotely by adjusting the rate of charging to correspond more closely with grid needs or manage rate impacts.

Managed charging requires a communications system between the EV, the charger, and the utility or third party. This communication occurs through wireless networking, cellular communications, or another telecommunication system. Generally, Level 1 and Level 2 chargers (Box 9) are more suitable for load management as systems can be turned down or off without major effects on the customer, who is likely to charge for hours at a time.

Box 9 | **EV Charging Levels Available**

Three different levels can be used to charge EVs. When designing managed charging programs, the charging times, cost to consumers, and load management capabilities of each option vary.

- Level 1: 120-volt charge that uses a standard wall outlet. Charging rates average 2–5 miles per hour.

- Level 2: Either a 220- or 240-volt charge, with a rate of up to 25 miles per hour. Most common chargers found in households and workplaces are Level 2.

- DC fast charging: Fastest way to charge EVs that have the capability. DC fast charging typically charges up to 80 percent capacity in less than 30 minutes.

DC fast charging is less suitable than other levels for load management, given that the average use case is limited and ranges from 5 to 45 minutes. Managed charging interruptions could disrupt fueling and transportation costs.

Managed charging can offer benefits to both the customer and utility by shifting the timing of EV charging according to grid needs, matching the timing of renewable generation, or enabling customers to manage the cost of their electricity bills. Like other load management programs, managed EV charging is automated and customers can reap benefits without having to manage the time of charging manually. With respect to bill savings, commercial customers could manage EV charging with the objective of minimizing utility demand charges, for example. Managed charging programs could feature a mix of Level 2 and Level 1 charging—dropping EV users to the lower level of charging depending on grid conditions, rather than ceasing charging for a period of time. Generally, corporations interested in installing charging infrastructure should consider whether to purchase equipment or to host equipment owned and operated by charging companies, as well as whether to add charging load to existing meters, which may improve load profiles, or install new meters for incremental charging demand.

As of May 2019, the Smart Electric Power Alliance (SEPA) reported that 38 utility-run managed charging pilot and demonstration programs were available in the United States, of which only 3 programs (or 7 percent) offered renewable energy options (SEPA 2019). For example, Pacific Gas and Electric (PG&E) has offered a managed charging pilot in conjunction with BMW (Box 10) that offered participating customers the option to charge with renewable energy and found that approximately two-thirds of customers were interested; however, interest dropped with strict limits on daytime charging unless financial incentives were offered. San Diego Gas & Electric (SDG&E) also introduced a pilot program at workplaces and multifamily housing to encourage charging during times of high renewables generation at preferred rates (Box 11).

Box 10 | **BMW and PG&E's Managed Charging Program (California)**

From July 2015 to December 2016, BMW and PG&E ran Phase 1 of a managed charging pilot program—known as ChargeForward—to demonstrate the technical feasibility and grid benefits of controlled EV charging. During this time, BMW was required to provide PG&E with 100 kW of grid resources when necessary, through a combination of delaying charging for 100 BMW i3 vehicles and drawing from a second-life stationary battery system, for one hour.

Throughout Phase 1, 209 demand response events totaling 19,500 kWh were dispatched. On average, 20 percent of the grid resources were from the 100 participating EVs and 80 percent came from the energy storage system. The vehicle response rate was highly correlated with PG&E's residential TOU rates, which offer lower electricity prices at night from 11 PM to 2 AM. PG&E reported that a high percentage of EV drivers plugged in their vehicles as soon as they got home but delayed actual charging until later in the evening, when rates declined. Ultimately, this showed that the vehicles had flexibility as a grid resource, given that they were plugged in for longer periods of time and customers effectively responded to the rate structure.

In Phase 2 of the pilot program, BMW aligned its EV charging with PG&E's forecasted renewable energy generation peak period. To do this successfully, PG&E provided BMW with daily projections of renewable energy generation a day in advance in order to optimize charging and maximize the amount of renewables that were used to power participating vehicles.

In a survey conducted by BMW and PG&E, customers interviewed were 68 percent more likely to participate in a managed charging program if presented with the option of charging EVs with solar or wind energy. This number dropped significantly to less than half (41 percent) when participants were told they would need to adjust their charging to the core daytime hours (9 AM to 4 PM) to take advantage of solar energy. However, the presence of an additional monetary incentive (such as lower off-peak rates) approximately doubled the likelihood of participation from 41 percent to 83 percent, indicating a clear interest in charging with renewable sources in exchange for an additional monetary incentive.

Box 11 | **SDG&E's Power Your Drive Program (California)**

Starting in 2016, SDG&E launched a three-year managed charging pilot program, Power Your Drive, which tested making EVs available as dispatchable, distributed energy resources.

To carry out this program, SDG&E installed 3,500 Level 2 charging stations at 350 apartment buildings, condominiums, and workplaces across its service territory. The company is currently testing the influence and viability of real-time pricing structures available via a mobile app (SDG&E 2019). During times with high renewable energy generation, denoted "grid-friendly" times, customers have incentives to charge their vehicles in exchange for lower electricity rates. These dynamic hourly rates are posted a day in advance and attempt to reflect both the system and local grid conditions.

To participate, customers were asked to set a maximum electricity price they were willing to pay for charging. Charging stations are automatically programmed to stop charging once the hourly price exceeds the maximum price set.

On average, dynamic pricing ranges from $0.18 per kWh in "super off-peak" summer rates (midnight to 5 AM) to $0.46 during on-peak hours (noon to 6 PM). Customers are billed separately; these charges do not appear on household electricity bills.

Box 12 | **Dutch Consortium's Solar-Controlled V2G Charging Stations (Utrecht, The Netherlands)**

In March 2015, a Dutch consortium—including General Electric, Nissan, Vidyn, LomboXnet, LastMile Solutions, Stedin, Upp Energy, New Solar and 15 Utrecht cities—developed a pilot program, Smart Solar Charging, and tested the world's first solar-controlled V2G charging stations for EVs.

During the initial phase of the program, 22 of these chargers, with the capacity to charge and discharge approximately 40 EVs, and 100 kW of new solar power capacity were installed throughout Utrecht province. Program participants were asked to charge their EVs during the day and to connect to the bidirectional charger later in the day to discharge any solar energy that had not been used. Results from the program showed cost savings averaging $131 to $820 annually per customer, depending on the vehicle type (De Brey 2017).

In 2016, plans to test a Renault fleet of 150 Zoe vehicles with V2G functionality and install 1,000 additional V2G chargers and 10,000 solar PV panels by 2021 were announced. To date, preliminary results from the pilot program have demonstrated an increase in self-consumption from 49 percent to 62 percent to 87 percent and a decrease in peak demand of 27 percent to 67 percent (IRENA 2019).

A second, more advanced managed charging approach is known as vehicle-to-grid (V2G)—a bidirectional system in which energy not only flows from the grid to the vehicle during charging, but also from the vehicle's battery back to the grid under certain circumstances. Under this arrangement, utilities or other transmission system operators can purchase energy stored in EV batteries during peak demand periods or use EV batteries themselves for ancillary services, such as frequency or voltage control.

V2G can be used as a way to address renewable energy variability and make it more readily available to customers. EVs charged with solar and wind energy can discharge that electricity back onto the grid during times when renewable energy generation is low. For example, in 2015, during a pilot program conducted by a consortium of partners in the Netherlands (Box 12), local solar photovoltaic (PV) systems were combined with V2G chargers. Participants were asked to charge during the daytime, when solar energy was most abundant, and to discharge any energy not consumed later in the day, to provide access to renewable energy outside times when power was generated.

## 2.5. Coupling EV Charging with On-Site Renewables

EV charging can be paired with on-site renewable energy generation, typically solar energy, for residential or commercial applications, with or without managed charging. When EV charging is paired with on-site renewable energy, several approaches can be used. These include co-locating the systems without direct control of loads so as not to affect charging times, using managed charging systems to control load and match the renewable generation, and integrating battery storage into the system. For managed charging applications where EV charging is controlled to match renewable energy generation, a Level 2 EV charging station can use software that manages EV charging to align it with the PV system output (and, in some cases, with a battery as well).

Both Google and DirecTV have offered workplace EV charging for their employees that is at least partially supplied by on-site solar (Box 13). Other companies are starting to offer renewable energy charging options in the workplace, often providing their employees with EV charging infrastructure and beneficial charging rates—or, in some cases, free employee charging.

Aside from coupling EV infrastructure with solar energy, offering workplace charging can have benefits for companies interested in reducing their operations' GHG footprint. The DOE collected data on employers offering workplace charging; findings indicated that their employees were six times more likely to drive a plug-in EV than were employees that did not have access to charging at work. The study also found 80 percent of these employers offered EV charging as a benefit to retain and attract employees (DOE 2016).

Box 13 | **Workplace Charging with On-Site Solar (California)**

Google has quickly become one of the largest EV charging station operators in the United States. It currently offers more than 750 charging stations at no cost to employees on the Mountain View campus. Some of these charging stations are powered by the company's own PV systems. As part of its environmental sustainability initiatives, Google has committed to having 5 percent of its parking spaces equipped with EV charging stations. Similarly, DirecTV currently provides its employees with more than 30 charging stations, 4 of which are entirely powered by solar energy.

For example, the Tennessee Valley Authority (TVA) and the Electric Power Board have installed several solar canopies for EV charging throughout Chattanooga (Box 16). Similarly, San Diego has installed several solar canopies, paired with battery storage systems, at the San Diego Zoo parking lot (Box 14). During the day, the solar canopy charges the EVs that are directly connected with solar power and stores any excess renewable energy in connected batteries. The stored energy can either be used to continue charging EVs at a later time or to export energy to the grid during times when it is most valuable. Tesla has also rolled out several EV charging programs coupled with solar and batteries (Box 15).

Although coupling EV charging with on-site renewable generation might be beneficial and relatively easy to manage for residential customers, the instantaneous load when multiple EVs are charging at the same time may make it difficult to scale up this model for larger commercial customers dealing with large fleets. For such customers, PV panels may not always be sufficient to satisfy the spike in load and it might become increasingly difficult to serve multiple vehicles with on-site renewables.

Box 14 | **San Diego's Solar-to-EV Pilot Project (California)**

In 2012, a solar-to-EV pilot project was launched as part of a public-private partnership between the City of San Diego, the University of California-San Diego, General Electric, CleanTECH, and SDG&E. As one of the nation's cities with high levels of EV drivers, San Diego chose to install 10 solar photovoltaic canopies, with 90 kW of capacity, in the San Diego Zoo parking lot.

The first project of its kind, this solar-to-EV program gives San Diego residents access to five charging stations for $0.59 per kWh (or $0.49 per kWh if the resident has subscribed to the Blink charging network). When cars are not being charged, the system stores solar energy in a 100 kW system that is used by SDG&E to offset power demand on the grid, particularly during peak times.

Well into their seventh year of service, the charging stations are estimated to offset approximately 189,216 pounds of carbon dioxide in the atmosphere per year.

Box 15 | **Tesla and LomboXnet's Smart Solar Charging Project (Utrecht, The Netherlands)**

Following Tesla's launch of two rechargeable lithium-ion battery storage systems—the Powerwall and the Powerpack—in October 2016, the company's involvement with utilities and solar companies across the United States and Europe has skyrocketed.

In June 2018, a Dutch company known as LomboXnet partnered with Tesla to deploy a Smart Solar Charging project equipped with 20 charging points connected to a 200-panel solar array and a 400 kW, 800 kWh Tesla Powerpack battery system. During the day, EV owners can charge with solar power while excess solar is stored in the battery packs. At night, customers looking to charge their EVs with renewables can use the battery system's energy.

Following this project, Tesla announced its plan to help a Volkswagen subsidiary, Electrify America, to fit more than 100 of its electric charging stations with Powerpack batteries over the course of 2019. By 2027, Electrify America plans to invest $2 billion in EV infrastructure, access, and education programs throughout the country. The partnership with Tesla will enable Electrify America to use its charging ports more effectively, without fear of overloading the grid.

Box 16 | **Tennessee Valley Authority and Electric Power Board Solar Charging Stations (Tennessee)**

In 2017, the Chattanooga Area Regional Transportation Authority, the Tennessee Valley Authority, Green Commuter, Prova Group, the Electric Power Board, and the City of Chattanooga launched a partnership to install public charging stations throughout Chattanooga, available to EV customers free of charge.

Over two years, several solar systems have been installed across the city. Chattanooga Airport offers a 10 kW solar canopy co-located with six charging ports; Southern Adventist University has a 20 kW canopy with eight chargers. A third location, the Chattanooga Area Regional Transportation Authority's main depot, has a 50 kW solar system, but no charging ports to accompany it. All solar systems are currently tied to the grid and are sized to offset the charging locations' electricity demand in aggregate (annually).

As of 2018, the program has expanded to include 64 EV charging ports across 22 locations. Collectively, the stations have helped power more than 55,000 vehicle miles directly with solar energy.

## 3. CONCLUSIONS

To date, the limited number of utility programs in the United States market that offer EV charging with renewable energy options have focused on residential customers. Opportunities remain for innovation in offerings focused on commercial customers that maximize customer and utility benefits. Different approaches may be needed to serve medium- and heavy-duty vehicles, fleets of vehicles, employee workplace charging, or the public charging loads of retail customers. Optimal program designs may also vary depending on how much EV charging capacity is required for employees or retail customers and the regional utility grid mix.

Traditional methods of renewable energy procurement can be used to match customers' EV electricity demand with renewables annually. However, approaches that incorporate the timing of charging have the potential to enable demand to match renewable energy supplies more closely and offer greater benefits to utilities and customers. Utilities can benefit from utilizing EV loads to integrate higher amounts of renewable energy and manage system peaks; customers can reap greater cost savings when providing benefits to the grid.

Employee EV charging programs can be designed to maximize utility and customer benefits through the use of managed charging. Managed charging programs may be most beneficial, from a renewable energy standpoint, in regions where substantial renewable energy capacity has been installed or is planned. In jurisdictions with high proportions of solar generation at midday, workplace charging can be largely coincident with renewable generation and yield system benefits, even without implementation of managed charging.

Some considerations in determining the structure of workplace charging programs are the expected rate of uptake of EVs among employees, the average commute range, and regional grid considerations, which can influence a utility's interest in establishing incentives for time-based charging. Where adoption of solar energy is expected to grow, early rollout of workplace charging programs can help customers develop the habit of charging at work and influence their charging practices. It may also be beneficial to incorporate capabilities for managed charging at the outset when infrastructure is deployed, to eliminate the need for retrofits later and facilitate future V2G charging. Another consideration is that there may be valid reasons to implement managed charging systems aside from renewable energy integration, such as mitigating potential demand charges at hosting facilities.

Large customers and utilities could collaborate on network solutions for serving retail customers, employees, or vehicle fleets with renewable sources. Network solutions, such as those implemented by Austin Energy and EVgo, could be implemented for commercial customers under different infrastructure ownership arrangements and contract structures between the utility, the potential third-party network provider, and the commercial customer. Network solutions hold the promise of enabling customers to rely more easily on renewable energy for all or most of their charging needs but may be more challenging to implement in a way that matches renewable energy output with EV charging, relative to other approaches. However, networks can be designed to include on-site renewable energy systems or incorporate financial incentives for charging at preferred times.

Program structures that share savings with customers who provide benefits to the grid are likely to yield greater customer uptake and more effectively address grid challenges. A common theme among new program designs is the use of financial incentives to encourage charging during preferred times of the day—for example, some link the timing of EV charging with renewable generation on the grid. In their pilot program, PG&E and BMW found that customers were more likely to alter their charging behavior if given financial incentives to do so.

Although a limited number of programs have offered customers the ability to charge EVs with renewables to date, in the handful of programs for which data were available, a third or more of customers opted for using renewable sources. Factors that can influence participant interest include the pricing of renewable energy options and constraints on the time of charging (Table 4). For commercial customers, response to these programs can provide a potential indicator of interest among employees and retail customers.

Time-based elements of EV charging could be incorporated into existing renewable energy offerings for large customers. To date, some green pricing programs have been coupled with TOU rates to enable residential and small commercial customers to use renewables for EV charging while obtaining cost savings for charging at off-peak periods or during periods of excess renewable generation. Green tariffs could potentially be modified or coupled with other rates or mechanisms to enable EV charging with renewables at preferential times for the grid. Such programs could also focus on installing new renewable energy sources to serve EV loads.

With expected growth in the adoption of EVs in coming years, exploring methods of charging EVs with clean energy sources is imperative for addressing transportation sector GHG emissions. Although EV adoption is still nascent, rapid growth is under way and likely to accelerate over the next decade. New solutions for meeting EV demand by commercial customers are required to encourage charging at beneficial times and to integrate renewable energy sources into the grid cost effectively.

Table 4 | **Customer Response to Programs Enabling Charging EVs with Renewables**

| UTILITY | PROGRAM | PARTICIPATION | COST OF RENEWABLES |
|---|---|---|---|
| Austin Energy | Plug-in EVerywhere™ Network Charging Program | As of 2017, 1,400 customers, or more than 40% of EV owners in the service territory, subscribed to the network, which supplies 100% wind energy charging. | $4.17 per month or $2 per hour |
| Potomac Electric Power Co. | EV Pilot Program in Maryland | In the pilot program, 34% of customers enrolled in the utility's EV-specific charging TOU rate also opted to pay $0.02 per kWh more for renewable energy. | $0.02 per kWh more for renewable energy |
| Great River Energy | Revolt Program | Program was initially available to 400 EV customers in utility area, enabling customers to charge with 100% wind energy at no extra cost; was extended each year, because of its popularity, and is still offered to customers. | No extra cost for wind energy |
| Pacific Gas & Electric/BMW | ChargeForward Pilot Program | The option to charge with renewables interested 68% of customers; dropped to 41% when charging was limited to 9 AM to 4 PM to match solar generation; increased from 41% to 83% with financial incentives. | Cost varied by pilot |
| Xcel Energy | Windsource green pricing program (used for EVs) | As of 2013, 35% of EV owners in the utility's service area subscribed to Xcel's Windsource program, which enables charging with 100% wind power at a premium. | Varies: 0.9–1.5 per kWh |

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## ENDNOTES

1. For additional details on NREL's modeling, see the laboratory's Electrification Futures Study (https://www.nrel.gov/docs/fy18osti/71500.pdf).

2. For additional details on utility offerings and other approaches customers can use to procure renewable energy, see U.S. EPA's "Guide to Purchasing Green Power" (https://www.epa.gov/greenpower/guide-purchasing-green-power) and NREL's status report on green power markets (https://www.nrel.gov/docs/fy19osti/72204.pdf).

3. V1G refers to one-way charging from the electricity grid to the EV, in contrast to V2G charging, where the vehicle can supply energy back to the grid.

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