BMW CHARGEFORWARD

Electric Vehicle Smart Charging Program

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GLOSSARY

BEV: Battery electric vehicle

DDV: Distribution Deferral Value

EV: Electric vehicle

GHG: Greenhouse gas

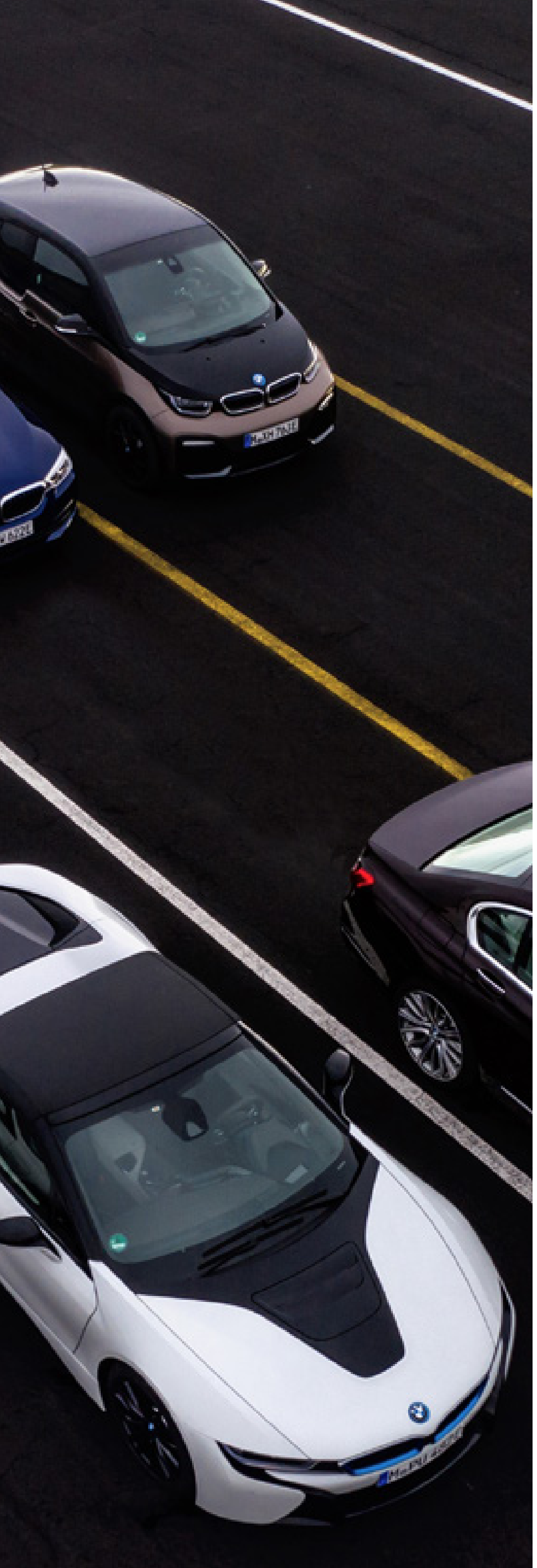
i3 REx: Battery electric vehicle with range extender (small gas tank)

NGO: Non-governmental organization

PHEV: Plug-in hybrid electric vehicle

VGI: Vehicle grid integration

V2G: Vehicle-to-Grid



INTRODUCTION

In 2017, BMW of North America (BMW[1]) launched a new phase[2] of ChargeForward, an electric vehicle (EV) program that explored how EV charging can be intelligently managed to maximize the environmental and grid benefits of vehicle charging. The primary goals of ChargeForward were to reduce the overall cost of electric vehicle ownership, support renewable energy integration into the electric grid, and help reduce greenhouse gas (GHG) emissions in the transportation sector.

BMW partnered with Pacific Gas and Electric Company (PG&E), a local Northern California utility, throughout the ChargeForward program. The partnership represents a unique collaboration between an automaker and a utility, working to combine two primary tools to fight climate change – vehicle electrification and renewable energy. ChargeForward demonstrated that smart charging can capture synergies between EV customers, automakers, and utility companies to accelerate decarbonization of our transportation and energy sectors and reduce the impact on grid infrastructure during the transition.

ChargeForward was the largest smart charging optimization program that featured real drivers. Over 400 real BMW drivers in Northern California participated, providing real-world experience to understand how smart charging can fit into the lives of our customers. BMW included both battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) to understand how different vehicle types performed with smart charging. BMW also sought to evaluate the role incentives and education could play in engaging customers to use smart charging. Participants were provided digital tools, such as a smart phone app and a customized web portal, to facilitate their participation.

Working with grid experts at PG&E, BMW organized a series of smaller studies aimed at understanding different aspects of smart charging, including:

- Customer engagement and retention strategies
- Away-from-home charging
- The role of incentives
- Micro-targeting of grid requirements
- The impact of optimizing charging with various grid signals

Interviews, focus groups, and surveys provided insights into participant behavior and attitude, which, along with charging data, informed what tools and techniques were most effective.

Summary of Conclusions

BMW partnered with UC Berkeley's Transportation Sustainability Research Center to evaluate and report results from the program. The Berkeley research team identified the following conclusions:

- Smart charging EVs can reduce greenhouse gas emissions by an additional 32% on average in Northern California.
- Smart charging can enable EVs to accept an additional 1,200 kWh of renewable energy per vehicle per year- equivalent to 3,500 to 5,000 miles of additional zero carbon travel.
- Telematics data from automakers are a critical enabler of smart charging programs as it provides a holistic view of a driver's mobility needs, helping facilitate daily charging during hours when GHG emissions are lowest.
- ChargeForward vehicles can create an average of $325 in estimated grid savings annually per vehicle in California.

This project was made possible thanks to funding from the California Energy Commission's Electric Program Investment Charge (EPIC). The full research report will be available on the California Energy Commission website (https://www.energy.ca.gov/energy-rd-reports-n-publications).

[1] All references to BMW as an entity in this document refer to BMW of North America, LLC. See imprint page for contact information.

[2] Results of the previous phase of BMW ChargeForward can be found here: https://www.pgecurrents.com/wp-content/uploads/2017/06/PGE-BMW-iChargeForward-Final-Report.pdf

KEY FINDINGS

REAL DRIVERS

400+ participants across Northern California

50% have access to workplace charging

87% plug in at home at least once a week

42% have rooftop solar

61% spend more than 45 minutes in their car each day

GHG SAVINGS

Smart charging can reduce GHG by an **additional 32% over unmanaged EVs**

RENEWABLE ENERGY ABSORPTION

1 Million Miles
were powered by 100% renewable energy between the 2018 and 2019 Earth Days

Each smart-charging vehicle can absorb up an **additional 1,200 kWh of renewable energy per year**

PHEV SUSTAINABILITY

A smart-charging PHEV can help **integrate more renewable energy** than a normal-charging BEV per unit of battery capacity

CUSTOMER FEEDBACK

90% cited charging with more renewable energy as a primary reason to participate in a smart charging program

79% have a better understanding of how charging impacts their carbon footprint

75% prefer cash incentives to non-monetary rewards

DISTRIBUTION VALUE

83% fully shifted their load away from high congestion hours, demonstrating EVs can be a distribution deferral resource

01

WHY SMART CHARGING?

The Transitioning Grid

In the US and other parts of the world, the electricity grid is undergoing a massive shift as it seeks to transition from fossil fuels to renewable generation. An increasing number of states and local governments are setting new and increasing renewable energy generation targets aimed at reducing carbon emissions. Utilities are seeking technological solutions that are highly flexible, low cost, dispatchable, and responsive to the variability of renewable energy.

Renewable energy integration presents new challenges to utilities and grid operators who are responsible for delivering reliable electricity to customers while maintaining the balance of supply and demand on the grid. If electricity supply and demand are out of balance, the grid frequency can change, risking blackouts and equipment damage.

Traditionally, grid operators maintain this balance by increasing or decreasing generation in response to daily, hourly, and minute-to-minute changes in customers' electricity consumption. However, large quantities of renewable energy disrupt traditional grid management because most renewable generation (such as wind and solar) cannot be controlled the same way as fossil fuel generators. Instead, wind and solar generation are dependent on weather conditions. While renewable energy generation does follow somewhat predictable weather patterns, these patterns do not necessarily align with energy consumption, challenging utilities and grid operators who must align demand with supply. Further, renewable energy generators are not readily available at all hours and cannot be ramped up or down as demand rises and falls without using expensive stationary batteries.

In a phenomenon first described by the California Independent System Operator (CAISO) as the 'duck curve,' the chart on the next page outlines the new reality of net demand for grid operators: a sharp decrease after sunrise followed by a period of low net demand during the day when the sun provides most of the energy required by Californians. At times, this demand is actually less than the renewable energy being supplied, leading to hours of "overgeneration." This period is followed by a very steep ramp up in the early evening as people return home from school and work just as the sun is setting and the system reaches peak demand for the day.

Already in California, the impact from large quantities of renewable energy is being felt on the grid. According to a report by S&P Global Market Intelligence, CAISO had to curtail 961,343 MWh of solar and wind in 2019 in order to balance the grid's supply and demand. This was more than double the curtailment amount seen in 2018, and more than triple the amount in 2016.[3]

[3] In California, renewable electricity cuts more than doubled in 2019. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/in-california-renewable-electricity-cuts-more-than-doubled-in-2019-56695560

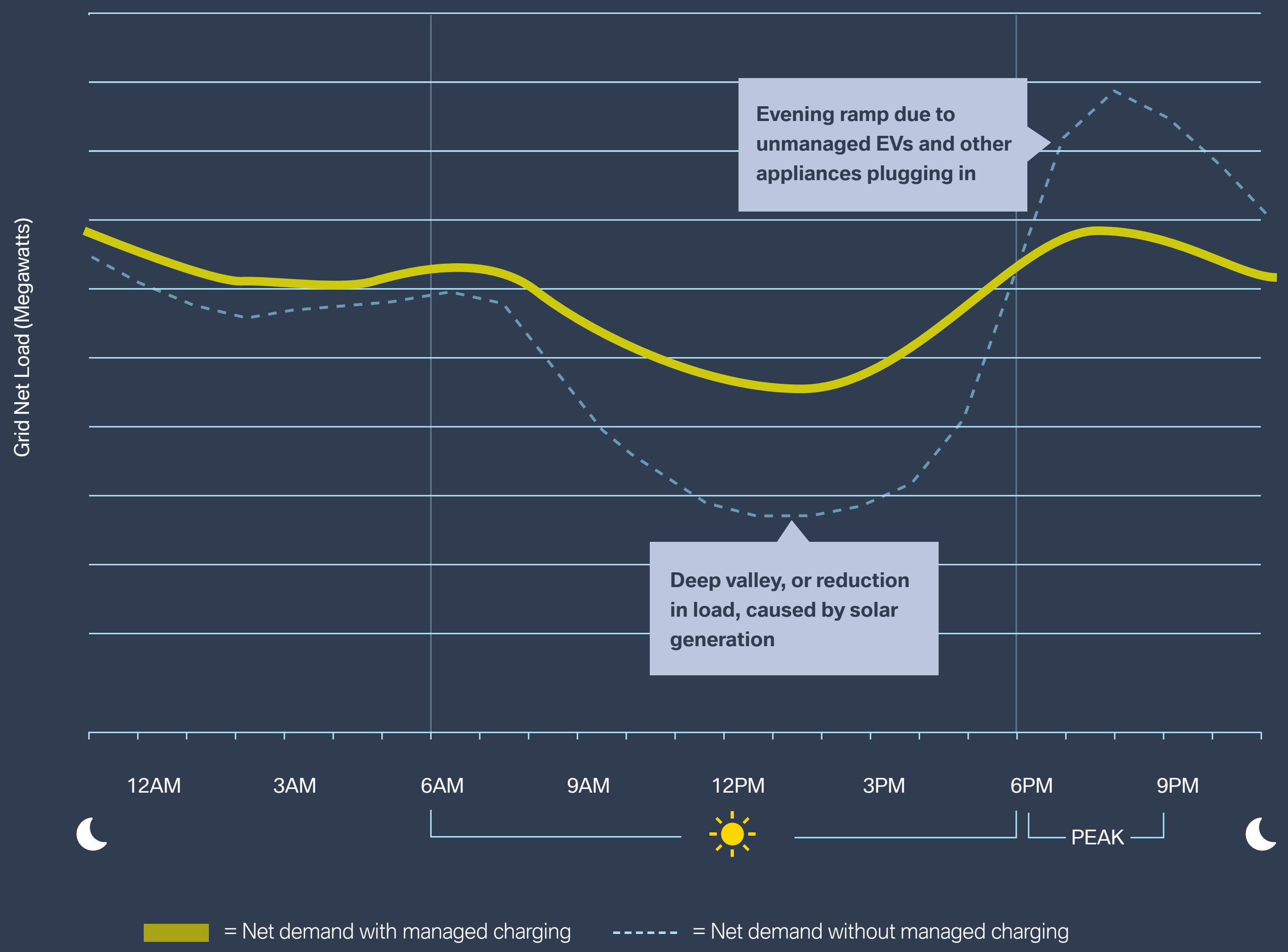
https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/022520-curtailments-rising-with-renewables-increasing-on-the-cal-iso-grid

[4] According to the National Household Transportation Survey

[5] For a BMW i3 with a 33 kWh battery, a full charge takes about 4-5 hours with a Level 2 charger. Typical daily charging requirements are 2 hours or less as they do not require a full charge each day. For PHEVs, the charging times are much shorter due to the smaller battery size. https://www.pluglesspower.com/learn/bmw-i3-charging-ultimate-guide/

HOW MANAGED CHARGING CAN HELP TO BALANCE THE GRID (THE 'DUCK CURVE')

Illustrated daily net load for California



Managed charging can help balance the grid by smoothing the disruptive peaks and valleys. The valleys, caused by solar energy, shown here as the noontime valley, can be shallowed by increased daytime charging. The peak shown here in net demand, caused by a simultaneous increase in residential power use and decrease in solar and in the evening, can be reduced by increased daytime and middle-of-the night charging. These changes also benefit the stability and operability of the grid; the steeper the ramps in the net load curve, the more unstable the grid becomes.

How Smart Charging Helps the Changing Grid

Smart charging can help integrate renewable energy into the grid. With smart charging, EVs can charge at times when the grid needs more consumption to align with renewable generation, or when electricity is inexpensive. Charging during hours of high ramp rates, peak use, or a high mix of fossil fuels can be avoided- with no impact on the drivers' mobility needs.

EVs are unique among household energy devices because the timing of their energy use is extremely flexible- most vehicles are parked over 22 hours per day[4]. This is an ample amount of time to meet daily charging needs.[5] For people that charge at home at night, charge can be shifted away from evening ramping and peak hours to low-cost overnight hours, while still achieving a full battery in time for the morning commute. The opportunity for creating grid benefits is even greater for commuters who can plug in at work. Smart charging vehicles during the day aligns charging with solar energy generation (the hours with the most renewable energy in Northern California). Smartly managing daily charging needs into high renewable energy generation hours creates powerful synergy between renewable energy and EVs; as EV adoption increases, we create a flexible load resource that helps utilities incorporate more renewable energy generation and supports our long-term climate change goals.

Smart charging is also the first step toward integrating bi-directional (V2G, or 'vehicle-to-grid) charging as a grid resource. V2G capable vehicles have the ability to both charge from and discharge to the grid, serving as a battery storage resource when the vehicle is parked. Currently, smart charging focuses solely on shifting the charging of a vehicle across time, to allow charging to happen at the best times and locations for the electric grid.

How Smart Charging Works

When a driver plugs in, instead of immediately starting to charge, the vehicle sends its current state of charge and projected unplug time to BMW. BMW simultaneously receives information from CAISO and the utility about energy prices and current grid and renewable energy conditions for the vehicle's specific location. The BMW system considers the driver's cost of charging the vehicle, i.e. the utility peak and off-peak hours. Finally, the driver provides input to the optimization based on their preference for lowest charging cost or highest renewable energy.

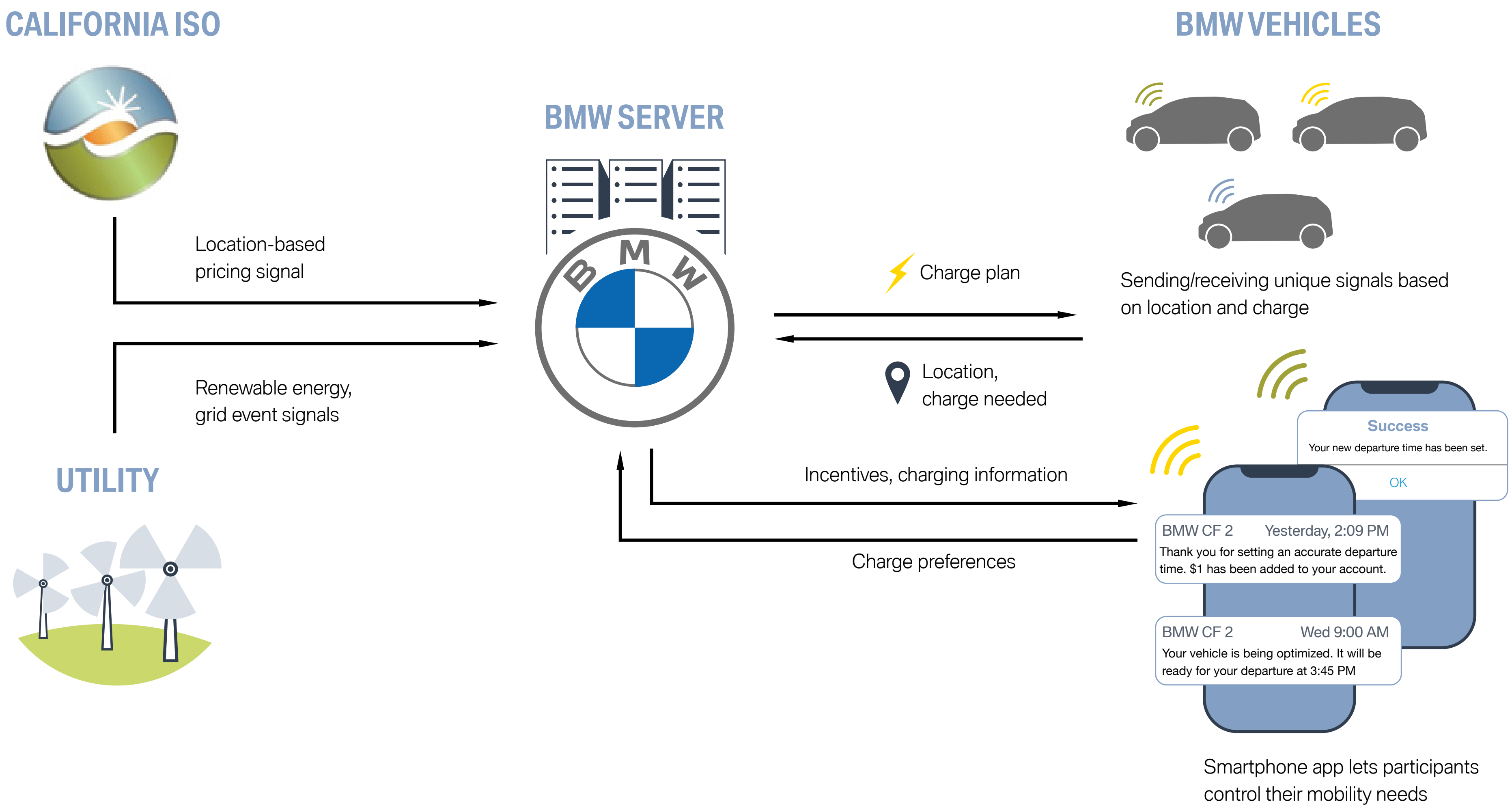
Using vehicle, driver, utility, and grid inputs, BMW calculates the optimal charge window(s) for each vehicle. BMW sends the optimized charging signals to the vehicle through its vehicle telematics system. The longer a vehicle is plugged in, the more the charge can be shifted, and the greater the benefits that the grid and customer see.

Vehicle telematics data offers compelling advantages for smart charging relative to other data sources:

- Telematics data is mobile. Unlike wall outlets or charging stations, which are stationary, the innate mobile nature of vehicles means that their telematics data follows the vehicle wherever it goes. The advantages of a telematics approach to smart charging is that it is not geographically limited to a particular location and does not require additional hardware. Telematics provides a complete charging picture and charging can be managed holistically, wherever the vehicles are. Customers can set preferences that follow them from charging station to charging station and their charge can be managed optimally to meet their mobility needs across time and locations.
- Telematics data provides the necessary level of data granularity. Household utility meters provide an incomplete picture of vehicle charging. An earlier UC Berkeley study[6] indicated that it was not possible to accurately detect nor quantify Level 1 or Level 2 charging data from household energy data. Thus, in order to effectively manage and evaluate a smart charging program, vehicle charging data needs to be directly accessible, across all times and locations.

[6] Elpiniki Apostolaki-Iosifidou, Soomin Woo, and Timothy Lipman (2019), "Challenges and Opportunities for Electric Vehicle Charging Detection Using Utility Energy Consumption Data," Transportation Research Board #19-05695, Poster Presentation, Washington DC, January.

CHARGEFORWARD SYSTEM ARCHITECTURE



CHARGEFORWARD STUDIES SUMMARY

Study Name	Description	Timeframe	Highlights
Demand Response	Opted in vehicles automatically stopped charging during pre-determined event hours	July 2017 - Jan 2018	Demonstrated demand response capabilities of vehicles over 70 demand response events
Home Overnight	Shift charging out of evening peak	Apr - Jun 2018	First study testing the charge shifting optimization signal; 700 signals sent to 288 unique vehicles
Earth Week Renewable Energy	Bonus incentives for daytime charging; first time testing daytime charging against renewable energy signals	April 2018	55% of participants' charging came from renewable energy, compared to national average of 23%
Home 24 Hour	Tested updated optimization signal	Jun - Oct 2018	Improved optimization signal qualifying more vehicles for charge shifting; 85% increase in optimized charging
Driver Cohort Plugin Goal	Bonus incentive for increased plug-ins	Sep - Oct 2018	Increased daily plug-ins to over 4 plug-ins per week
Overgeneration Away from Home	Optimizations expanded to include all locations with bonus incentives for day-time plug-ins	Oct - Nov 2018	234% more daytime charging than the Earth Week study due to expanding to charging to include any location
Transactive Energy Signal	Optimizations against EPRI transmission signal instead of price	Dec 2018	Successfully updated optimization engine to use EPRI's transactive energy price signal

CHARGEFORWARD STUDIES SUMMARY

Study Name	Description	Timeframe	Highlights
Sub-LAP Decrease	Optimizations using day-ahead LMP pricing; load decrease events called (location-based demand response)	Jan - Feb 2019	Results show that drivers respond better to events telling them when to charge, instead of when not to charge
XSP Signals	Load increase events called (excess supply signals)	Apr 2019	Vehicles are able to absorb excess energy
HESS: Event-Based; Load Increase (excess supply)	Home Energy Storage System (HESS) pilot; testing home battery charge/discharge signals for customer and grid benefit, in addition to ongoing vehicle optimization signals	Mar - Jun 2019	Household batteries can be reliably used for frequency regulation, and homeowners can save money by charging their batteries during low-cost hours and discharging during high-cost hours
HESS: Event-Based: Load Decrease (DR)		Mar - May 2019	
HESS: Frequency Regulation		Jun - Jul 2019	
HESS: Energy Arbitrage		Jul 2019	
Advanced Distribution Deferral	Fixed daily no-charge windows with bonuses paid out for 100% participation; distribution deferral proof of concept	Dec 2019 - Feb 2020	Over 80% of participants reliably provided distribution deferral value

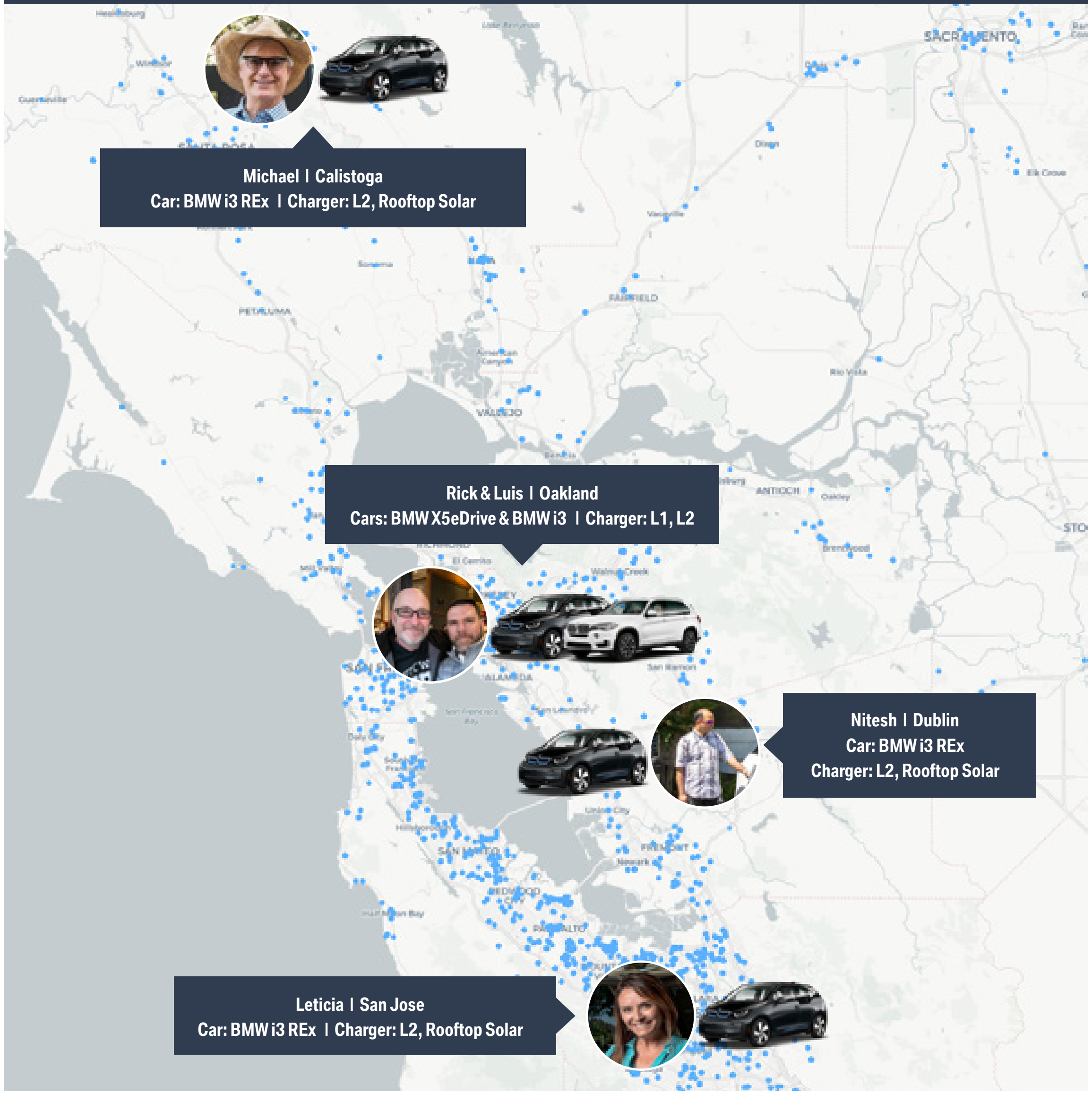
OUR PARTICIPANTS

ChargeForward was the largest smart charging program with real drivers — over 400 BMW drivers in the San Francisco Bay Area participated. The program included the BMW i3, an all-electric vehicle, and BMW plug-in hybrid electric vehicles (PHEVs). This product mix provided a unique opportunity to recruit a high volume of both BEV drivers and PHEV drivers, allowing ChargeForward to evaluate driver behavior and opportunities for both vehicle types.

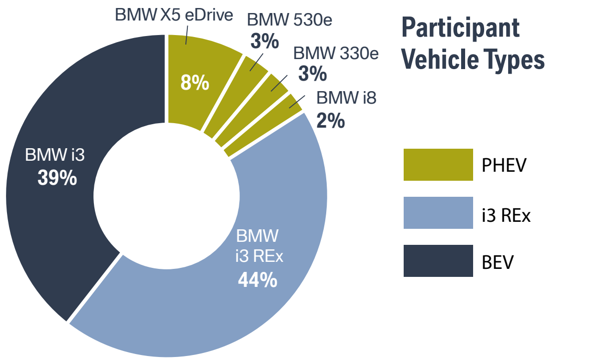
BMW developed a simple, entirely electronic recruitment process designed to reduce customer touch points. Applicants were also registered with PG&E, the local utility, and a Demand Response Provider (DRP). This approach provided a test for a scalable enrollment process for future vehicle grid integration (VGI) programs. Upon successful enrollment with ChargeForward, the utility, and the DRP, participants downloaded the ChargeForward smartphone app and began smart charging.

PARTICIPANT MAP

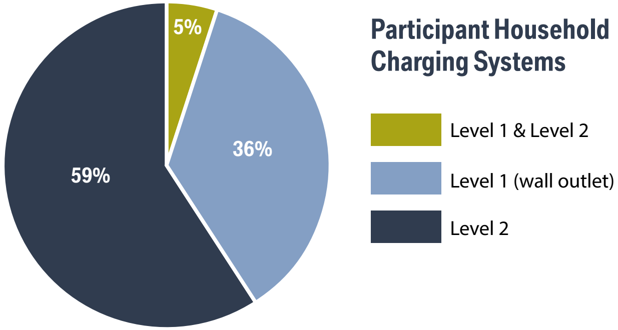
400+ PARTICIPANTS



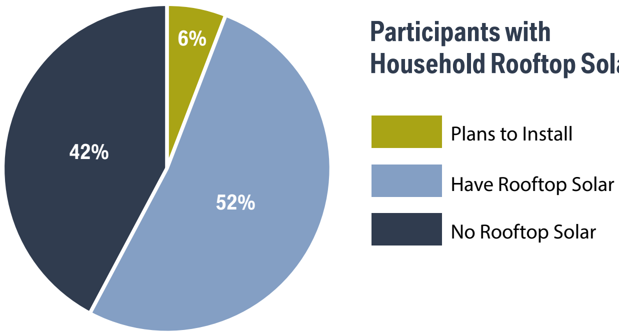
Participant Vehicle Types



Participant Household Charging Systems



Participants with Household Rooftop Solar



Real Drivers and Real Households

ChargeForward conducted over a dozen studies aimed at better understanding and managing the interaction between participant charging and driving behavior as it relates to the grid. The studies tested the impacts of various charge optimization signals (including price and renewable-energy based signals), charging locations (home and away), increasing plugging times, varying incentive levels, and customer messaging.

On the ChargeForward app, participants were asked to provide their vehicle's departure time. Participants were primarily notified about studies through email and push notifications to their phones, while the program website provided a more in-depth resource for those who were interested.

90% of participants would recommend ChargeForward to others.

About 50% of participants have access to workplace charging, although they don't all use it consistently. Participants primarily rely on charging their cars at home.

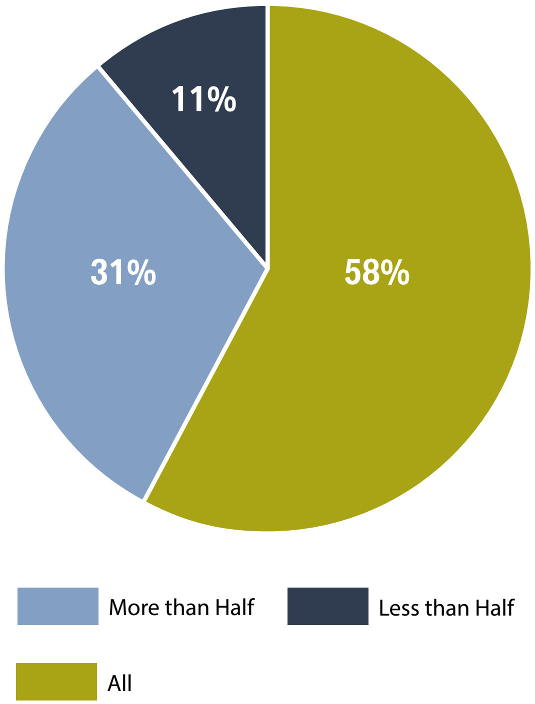
50% charge their EVs at home during the day on weekdays at least 3 times per week, compared to 23% who charge their vehicle away from home at least 3 times per week.

80% primarily use their car for commuting.

65% of all plug-ins occur at home, and 60% of all plug-ins occur on weekdays.

Over half (58%) of ChargeForward's PHEV drivers reported a 100% electric commute, and 31% have at least half their weekly miles covered by the battery.

REPORTED % OF PHEV WEEKDAY MILES COVERED BY ELECTRIC BATTERY



ChargeForward engaged participants through targeted emails, push notifications, and the ChargeForward web portal. Participants provided feedback in surveys and focus groups — often resulting in new features such as the option to have their vehicles charged during either lowest cost or highest renewable energy windows.

Participant Charging Behavior and the Daytime Charging Challenge

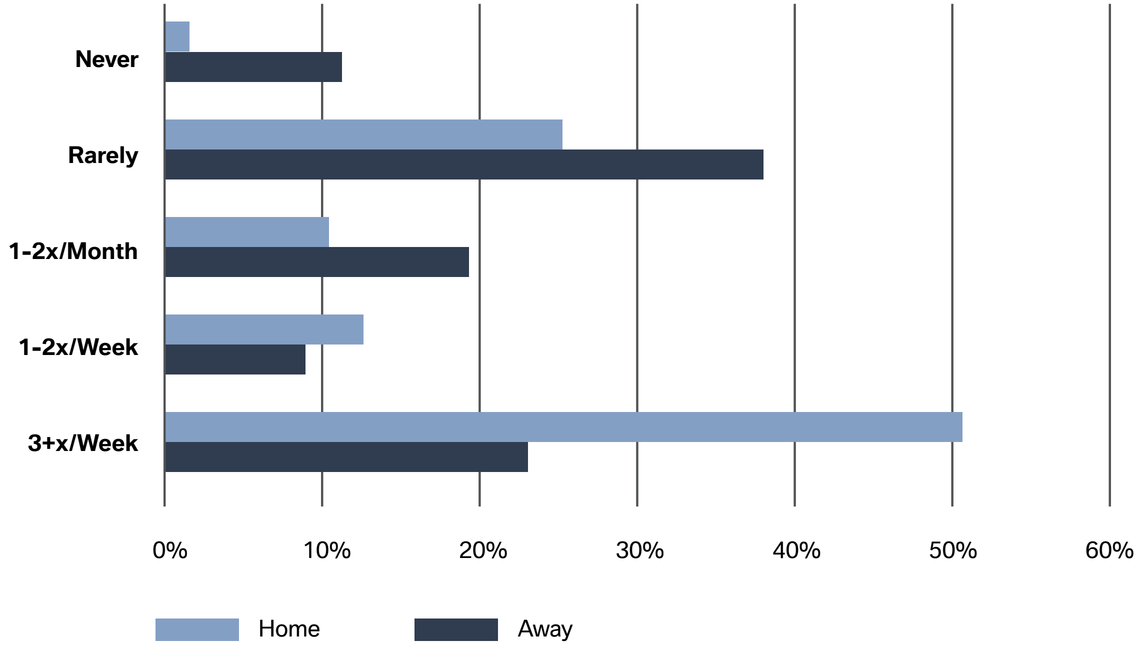
Although close to half the participants were able to charge at work at least once a week, workplace charging came with its own set of challenges. These included the following:

- Rates are based on amount of time plugged in, not energy consumed, leading to a high daily rate.
- Lack of consistently available stations

For participants that could charge at home on weekdays, 58% indicated that they prefer not to charge during the day due to more expensive utility rates. Given a choice between nighttime only optimizations and a comprehensive smart charging program that optimizes vehicles at any time, 67% of participants would choose a comprehensive smart charging program. Several studies tested what level of incentives and other awards would offset these barriers to motivate more charging more during the daytime (Section 3).

The long-term challenge with electric vehicles will be to **shift charging from nighttime hours to daytime hours** when solar energy is abundant!

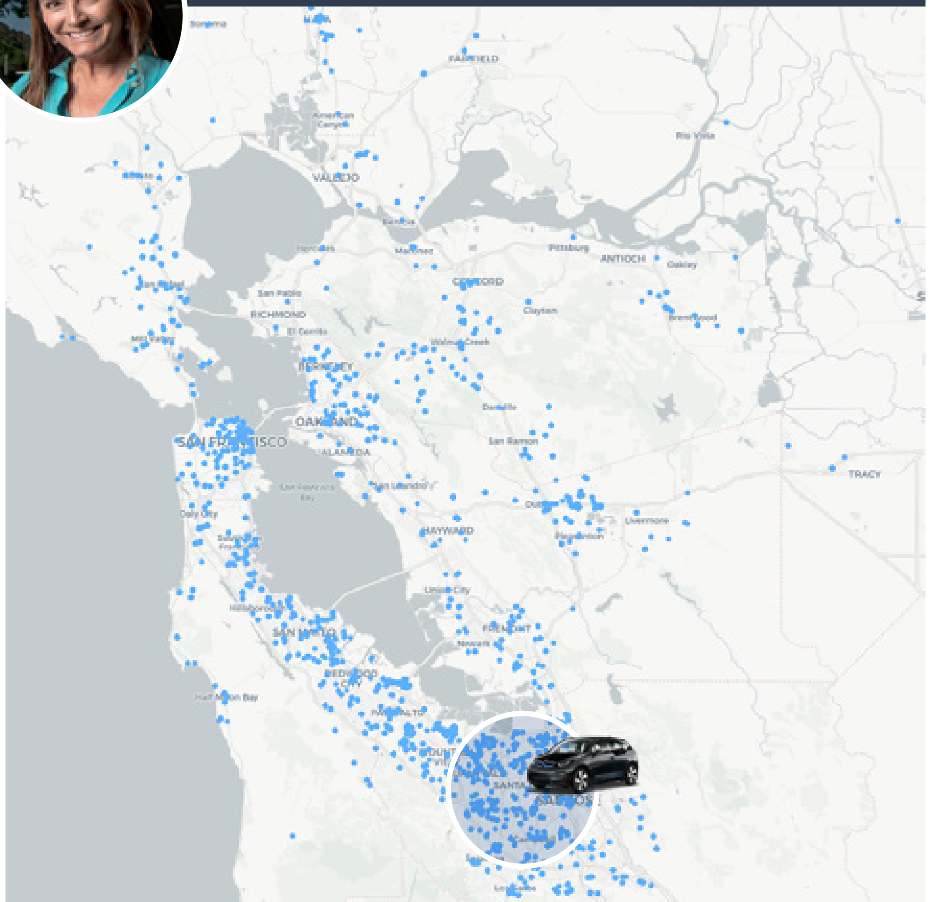
REPORTED FREQUENCY OF WEEKDAY DAYTIME CHARGING BY CHARGEFORWARD PARTICIPANTS



DRIVER SPOTLIGHT

OPTIMIZING RENEWABLE ENERGY USE FOR THE VEHICLE AND THE HOME

BMW CHARGEFORWARD AND HESS PARTICIPANT



Leticia

Leticia is one of the four ChargeForward participants who also took part in the household energy storage system (HESS) sub-studies. She was interested in both ChargeForward and HESS as an opportunity to earn smart charging incentives, save money on utility bills, and use more renewable energy. In the HESS studies, from January – August 2019, BMW explored how residential battery systems and EVs can work together as a single resource to support renewable energy integration and generate electricity bill savings. Participating households demonstrated that battery systems can offer grid services such as frequency regulation and on-demand load increases, while also saving customers money by charging with solar or during low-cost hours and discharging to meet home demand during high-cost hours.

During ChargeForward, Leticia generally stuck to her usual routine. She primarily charged her BMW i3 REx at home overnight in order to avoid expensive daytime rates. Once the HESS was installed, this routine also allowed her to take advantage of charging with solar energy from her battery that had been generated that day in excess of her household load.

Other HESS Participant Feedback:

"The best part of having a home battery system is that **I am doing something positive for the environment.** I like being able to store energy from my solar panels for later use."

"The most surprising aspect of the system is that we don't really think about it on a day-to-day basis. **It has been happily running in the background,** aside from the initial setup."

"Being able to discharge the battery during peak times has **allowed me to save on my electricity bill.** I would absolutely recommend a home battery storage system to friends and neighbors."

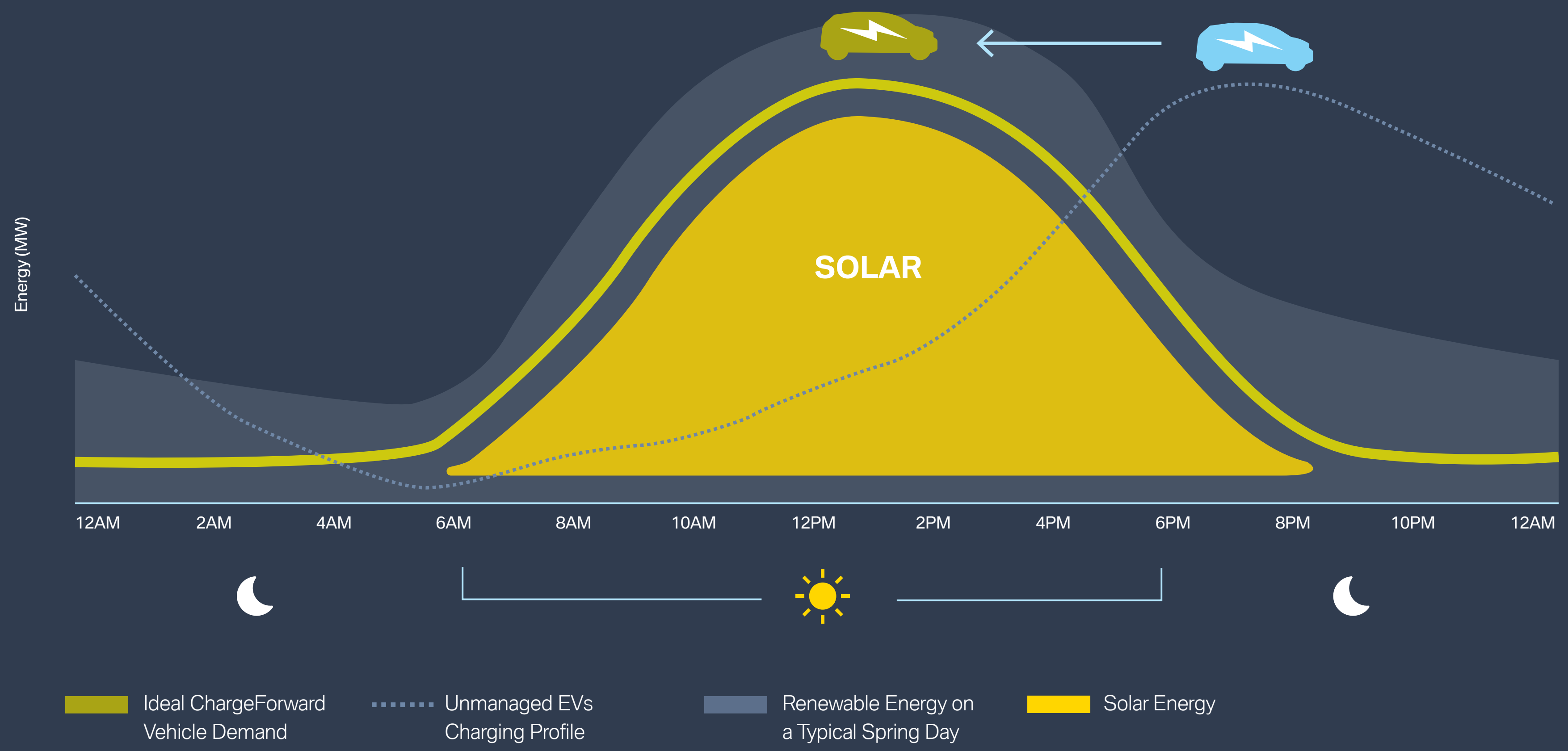
03

MAXIMIZING RENEWABLE ENERGY

ChargeForward explored how smart charging can deliver more renewable energy to EVs, and in turn help the grid incorporate more renewables. BMW partnered with PG&E to receive a renewable energy forecast; the first such partnership ever between a utility and an automaker. This forecast included a day-ahead hourly profile of renewable energy in the generation mix. BMW then fed this data into its optimization engine and shifted participants' charging to the hours with the highest renewable energy.

90% of participants would be interested in a smart charging program for the ability to charge with renewable energy.

MANAGED VS UNMANAGED CHARGING



Managed charging at scale allows the grid to support more renewables without adverse consequences. While the earlier graph in Section 1 showed how much power is being drawn from the grid overall (by EVs as well as other equipment and appliances), this graph represents the typical charging profile for EVs alone, and how it can be matched with solar generation (the shaded area represented above).

Two sub-studies in particular helped illuminate the advantages of incorporating more renewable energy with smart charging EVs: The Earth Week study and the Overgeneration study. In addition to these two studies, BMW's project partner, UC Berkeley, developed a model to calculate the potential renewable energy and greenhouse gas (GHG) savings from smart charging in a future scenario with more abundant charging stations.

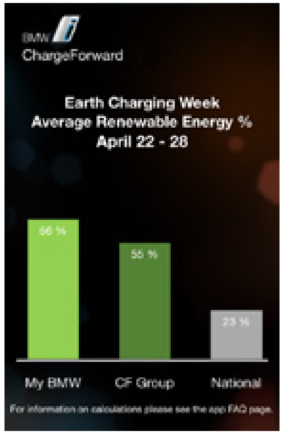
Earth Week Study, April 2018

Over Earth Day 2018 and the week that followed, BMW developed a study to determine if participants could incorporate more daytime charging into their routine. If they could, BMW also sought to understand what the primary motivation for changing their routines was — a general goodwill to fully participate in the program, a desire to drive with more renewable energy, or to earn more incentives. During Earth Week, BMW educated participants on the benefits of daytime charging to maximize renewable energy with special messaging on some days and offered participants bonus incentives for charging between 10AM-2PM on others.

The results showed that participants were able to incorporate daytime charging. During Earth Week, over 55% of ChargeForward participant charging came from renewable energy, compared to the 2017 national average of 23%. Although incentives proved to be the greatest motivator based on participation rates, survey results indicated that participants also wanted to charge with more renewable energy.

In a post-study follow-up survey, 21% of participants indicated they were primarily motivated to charge during the day to drive with more renewable energy, while 17% said they participated in order to earn more incentive money; other reasons were 'to fully participate in ChargeForward' and 'to do what's best for the grid'. Participants also reported the following:

- **79%** had a better understanding of how their charging behavior has an impact on their carbon footprint
- **67%** better understood how EV charging impacts the grid
- **56%** agreed that charging an EV during the day can have potential benefits compared to charging at night.



Screenshot of the renewable energy results from ChargeForward's phone app

Between Earth Day 2018 and Earth Day 2019, ChargeForward participants drove over **1 million miles powered by 100% renewable energy.**

'Overgeneration - All Locations' Study, Fall 2018

BMW and PG&E developed the Overgeneration study which explored managing charging beyond just the home, and offered incentives to plug in during hours when solar overgeneration was most likely, typically at or around 11AM during event days. Participants were notified of an event by 5PM the evening before, which gave them time to plan ahead and change their nighttime charging behavior to take full advantage of the bonus incentives that were offered.

During this study, daytime charging between 10AM and 2PM jumped 155%, with 14% of all charging occurring during these hours (compared to an average of just 6% before). A total of 36% of daytime charging was done away from home.

Modeling the Renewable Energy and GHG Savings Potential

Another partner, UC Berkeley, sought to answer the following two questions:

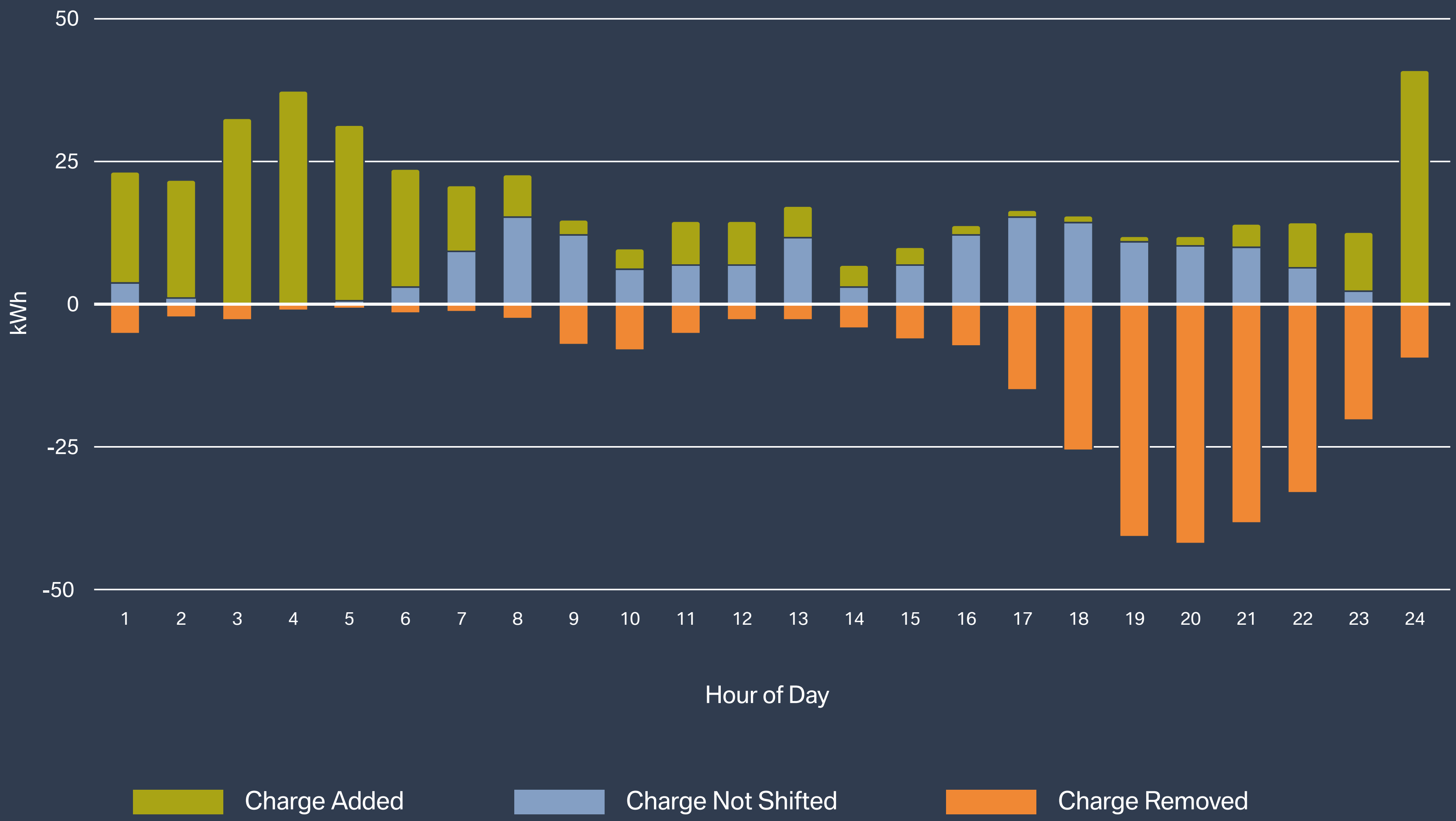
- If charging was optimized for renewable energy, how much more renewable energy could ChargeForward vehicles use with their current driving patterns?
- If charging was optimized for greenhouse gas reductions, how much could greenhouse gases be reduced with current driving patterns?

To answer these questions, UC Berkeley built an optimization model and incorporated PG&E renewable energy data, California electricity GHG hourly data, and charging and parking data from ChargeForward participants.

Key highlights from the model results include:

- **Smart charging could reduce carbon emissions for EVs by 32% on average.** Extrapolating a year's worth of ChargeForward participant vehicle data, UC Berkeley calculated the potential environmental benefits of smart charging in a future scenario where vehicles are able to plug-in and charge wherever they are parked. By matching 2019 California-specific hourly marginal emission rate (MER) data with each vehicle's time and location, the model projected that smart charging can reduce greenhouse gas emissions up to 300 kg per vehicle per year.
- **Smart charging allows the grid to support 1,200 kWh additional renewable energy per vehicle per year in Northern California.** UC Berkeley calculated the capacity of vehicles to incorporate renewable energy by modeling charging against hourly renewable energy profiles, assuming vehicles had easy access to charging both home and away. This can increase grid capacity to support more renewable energy integration, helping utilities meet renewable energy standard portfolio goals. In Northern California, the average 1,200 kWh increase more than doubles the amount of renewable energy for ChargeForward drivers and equates to approximately four months of annual charging, or 3,500 to 5,000 miles of additional zero carbon travel.

OVERGENERATION: ALL LOCATIONS RESULTS



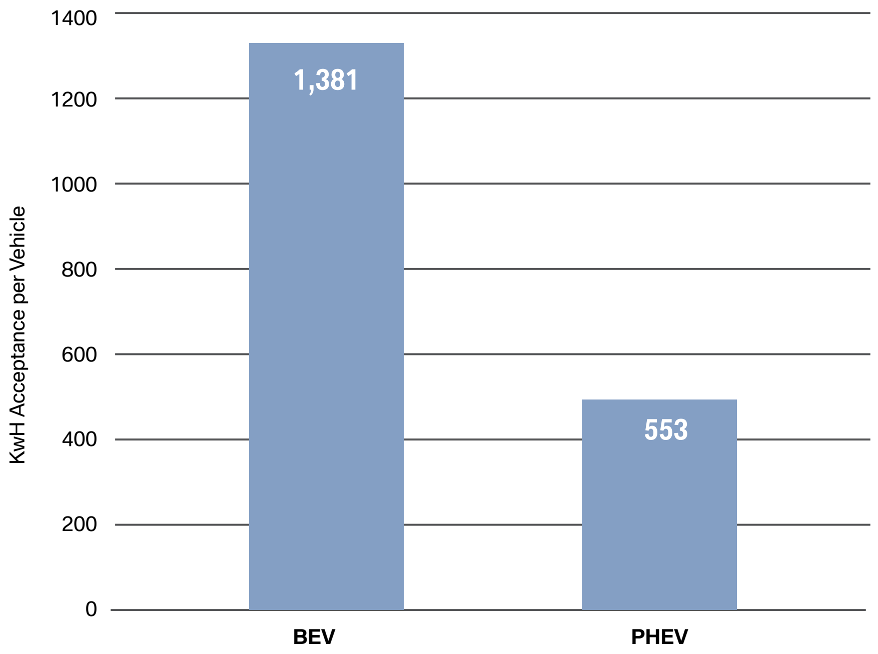
PARTICIPANT QUOTES

"It was eye opening to see the data. More importantly, **it shows the potential that this program has once the awareness increases** amongst i3 (and other EV) owners down the road."

"Very cool program to understand **how to maximize** use of renewable energy."

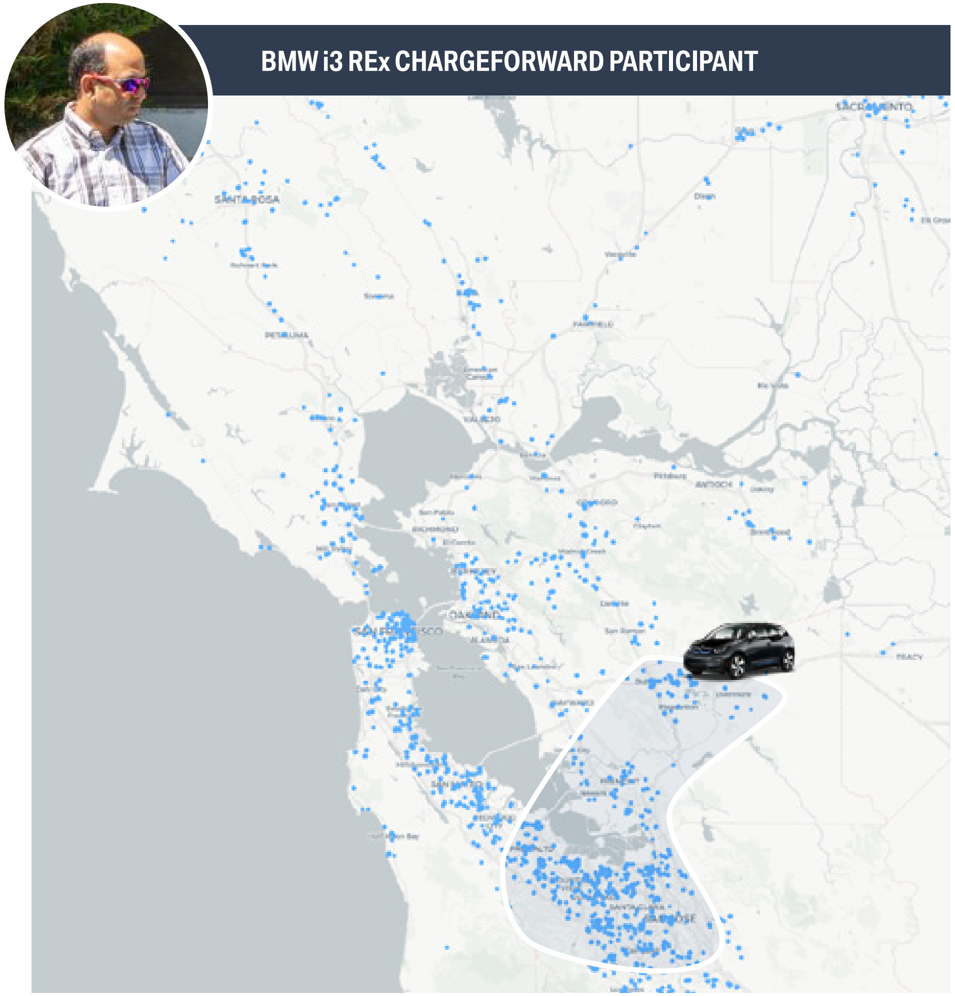
"Daytime lower charging rates would **definitely help increase the adoption.** People depend on night charging given the economics of it."

ANNUAL ADDED RENEWABLE ENERGY ABSORPTION (KWH) POTENTIAL BY VEHICLE TYPE



DRIVER SPOTLIGHT

SMART CHARGING INCREASES THE 'GREEN FACTOR' OF ELECTRIC VEHICLE CHARGING



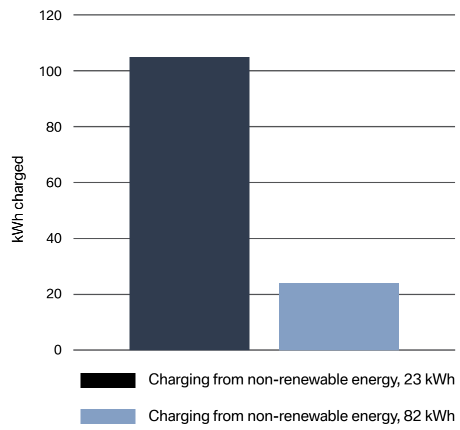
Nitesh

ChargeForward participants were excited to learn that they can make their transportation choices even more sustainable. For the 2018 Earth Week Challenge in BMW's ChargeForward program, participants had the option to shift their charging to times when the grid was powered by more renewable energy. This meant plugging in more during the day, and taking advantage of workplace charging if available. By participating in 10AM - 2PM charging during Earth Week, 78% of the charging for Nitesh's car came from renewable energy (compared to 23% nationwide).

Previously, Nitesh only plugged in at home. After learning about the increased environmental benefits from charging during the day, Nitesh now also charges at work or when getting groceries. This helps power his car with more renewable energy that is abundant during in daytime hours.

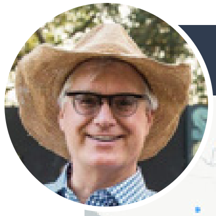
"Normally I would just charge at home at night. For Earth Week, I made sure to split charging both at home and at work. **It was interesting to see what a little bit of awareness can do,** and see how the ChargeForward participants' charging [with renewable energy] compared to the rest of the nation!"

Nitesh's Total Charging During Earth Week

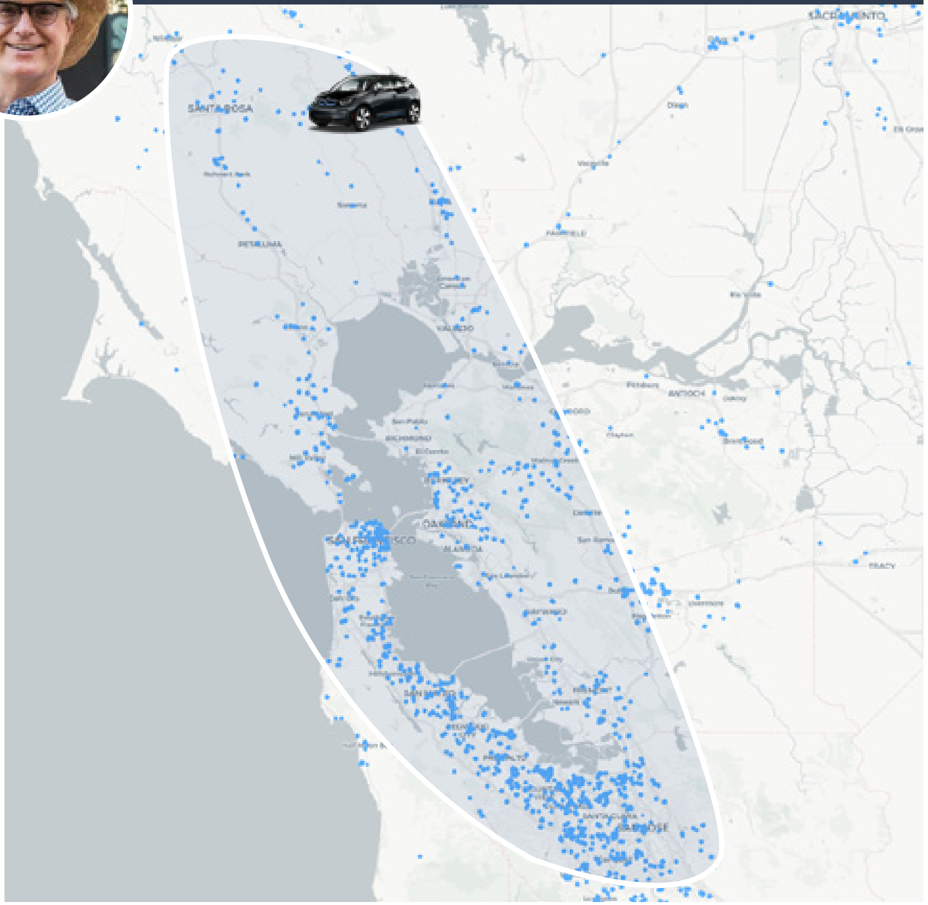


DRIVER SPOTLIGHT

SMART CHARGING SIMPLIFIES SUSTAINABLE CHOICES



BMW i3 REx CHARGEFORWARD PARTICIPANT



Michael

A resident of Napa County, Michael was initially drawn to ChargeForward for environmental reasons, so that he can use more renewable energy while charging. ChargeForward taught him to plug in more frequently in order to get more flexible charging windows and better understand the best times to charge. Since joining, Michael has referred several of his colleagues to the program. “It’s attractive to tell people that they can make money while doing the right thing, and the nature of the program is quite simple — just plug in your vehicle and have it ready when you need it.”

> “It’s easy to just plug in and have the car be ready, **knowing that ChargeForward will optimize the car.** I no longer have to worry about how best to charge efficiently and inexpensively”

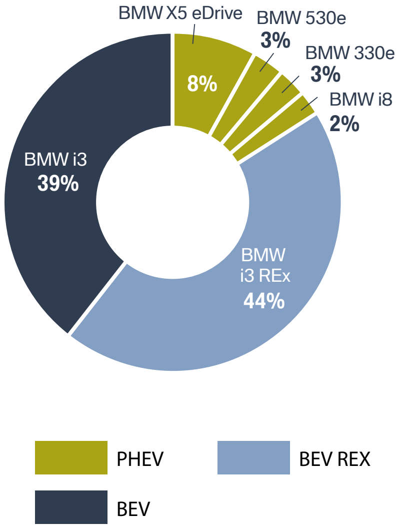
04

THE POTENTIAL OF PHEVs

The ChargeForward program featured both battery electric vehicles and plug-in hybrids. While 86% of the participants drove BEVs, the program included 82 PHEVs, which provided a robust set of vehicles to evaluate how PHEVs perform with smart charging.

Our results demonstrate that the environmental benefits of PHEVs can be greatly enhanced through smart charging.

Participant Vehicle Types

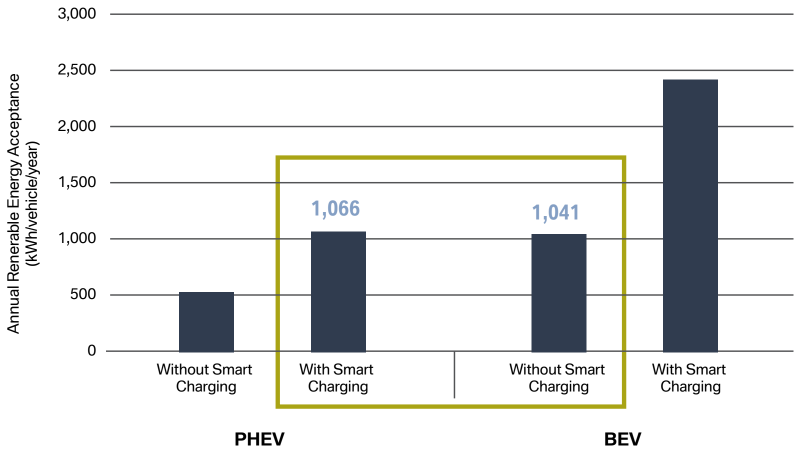


A smart-charging PHEV can utilize more renewable energy than a normal-charging BEV

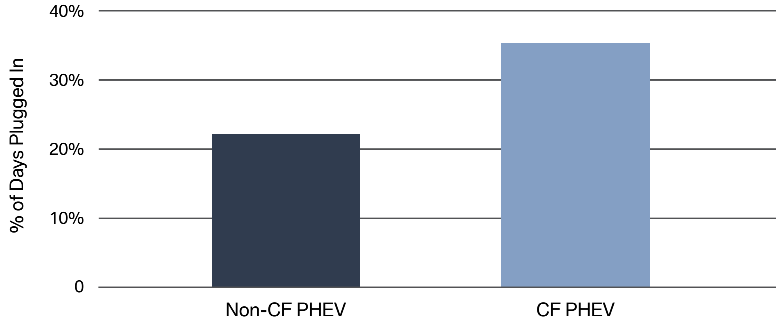
In the UC Berkeley modeling scenario where charging infrastructure was abundant[7], the average PHEV could utilize 1,066 kWh of renewable energy, an increase of 108% over the average PHEV without smart charging-more than double. In fact, the amount of renewable energy used by a smart-charged PHEV exceeded that of a BEV without smart charging, demonstrating the high potential of a smart charging PHEV.

Viewed from an efficiency perspective, PHEVs also utilize more renewable energy per unit of battery capacity than a BEV in a smart charging scenario. While the average BEV battery (with smart charging) uses 89 kWh of renewable energy annually per kWh of battery capacity, a PHEV with smart charging utilizes 124 kWh of renewables annually per kWh of battery capacity, a difference of 39%.[8]

CHARGEFORWARD INCREASES RENEWABLE ENERGY 108% FOR PHEVS, 133% FOR BEVS



CHARGEFORWARD PHEVS PLUG IN 67% MORE DAYS THAN NON-CHARGEFORWARD PHEVS



[7] Based on UC Berkeley model using ChargeForward participant parking and charging data, this future-case model assumed that each vehicle was able to charge any place it parked

[8] This is based on a weighted average BEV battery capacity of 27.2 kWh, and an average PHEV battery capacity of 8.6 kWh, based on ChargeForward participant data

Smart charging incentives increased participant plug-in behavior, improving the carbon savings associated with PHEVs. The charging habits of ChargeForward PHEV drivers were compared to that of non-participant BMW PHEV drivers in California. ChargeForward PHEV drivers were found to plug in 67% more days than non-ChargeForward PHEV drivers. The increased plug-in behavior of PHEV drivers has a direct impact on increasing the electric miles driven by PHEVs and the corresponding environmental benefits.

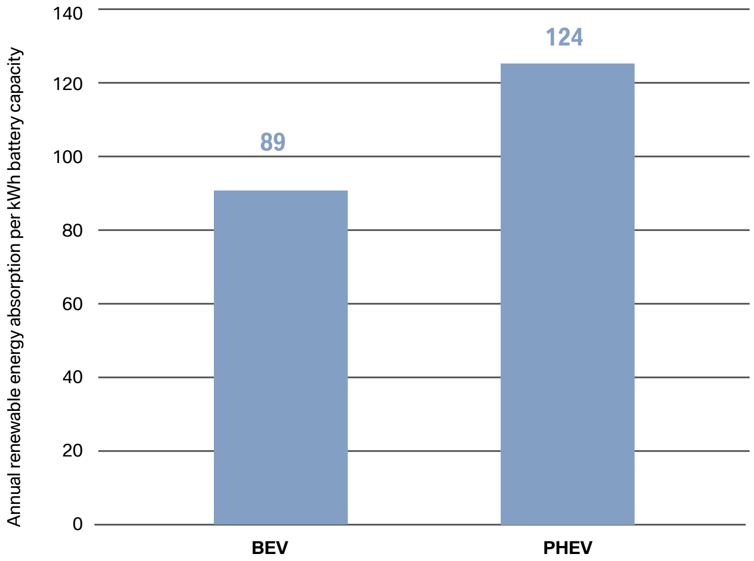
In the UC Berkeley model, PHEVs realized similar rates of increase in GHG savings as BEVs, 30% and 32% respectively, when smart charging. However, when measured on a battery capacity basis, the GHG savings were significantly higher for PHEVs. With an average battery size of 8.6 kWh (weighted average for the participants), PHEVs averaged 18.3 kg of GHG savings per unit of battery capacity (kWh), while BEVs averaged 12.2 kg of GHG/kWh. This means a smart charged PHEV gets 50% more GHG savings per unit of battery capacity.

PHEV batteries, while smaller than BEV batteries, get more GHG savings and renewable energy usage out of every kWh of battery capacity when they participate in smart charging. Incentives are effective at encouraging participants to plug-in more frequently, and the smaller battery size captures significant benefits from optimizations.

PHEV Drivers Adapt Behavior to Smart Charging Requirements

PHEVs hold a lot of potential to unlock renewable energy integration if managed well. ChargeForward aimed to find a balance between educating participants and motivating them to reconsider their charging behavior, while keeping any disruption to their daily routines to a minimum. Surveys of ChargeForward PHEV participants confirm this. The vast majority (92%) were able to follow their regular charging routines without having to think too much about the program rules. 67% also indicated that ChargeForward changed their approach to charging by helping them become more sustainable, and 85% indicated they now have a better understanding of renewable energy's impact on the grid.

ANNUAL ADDED RENEWABLE ENERGY ABSORPTION (KWH) AS MEASURED PER UNIT OF VEHICLE BATTERY CAPACITY

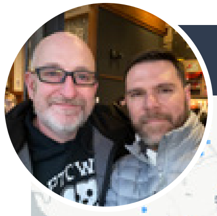


"ChargeForward developed more sensitivity toward charging times and grid usage. Because I own a plug-in hybrid, I was not as bothered by demand events as others might have been. **I try to maximize electric driving, but I always have a backup."**

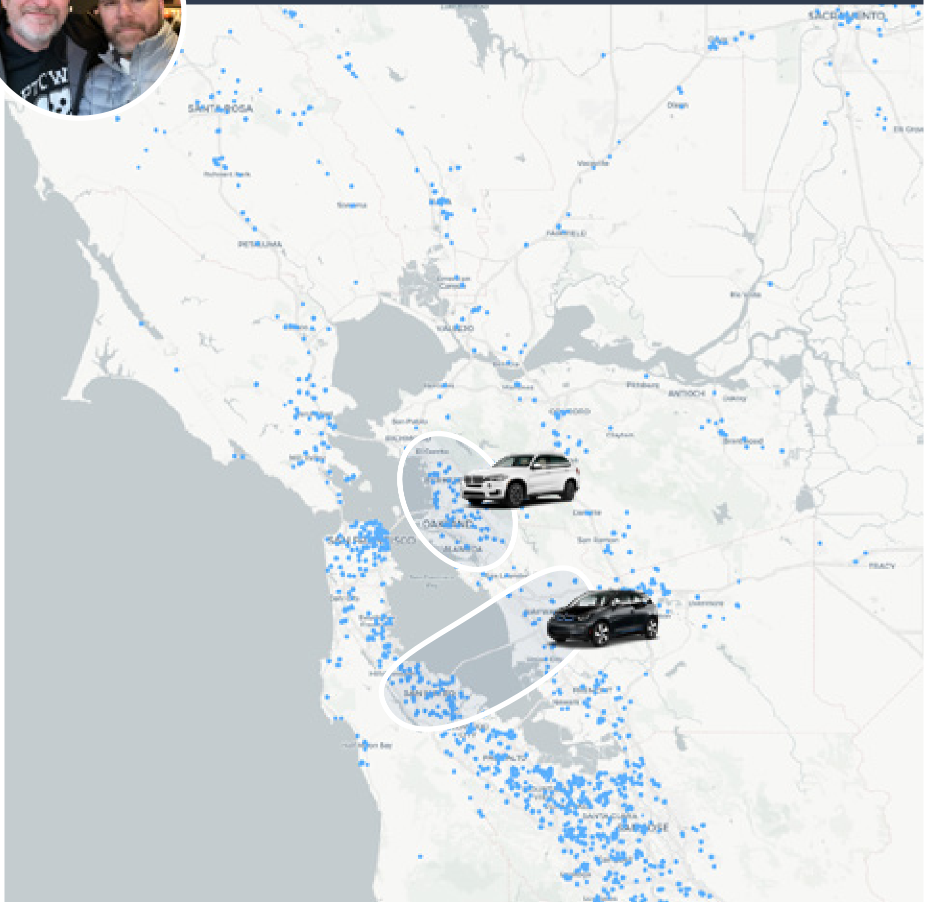
– ChargeForward participant

DRIVER SPOTLIGHT

MAXIMIZING HOUSEHOLD ELECTRIC COMMUTE MILES



BMW CHARGEFORWARD PARTICIPANTS



Rick & Luis

Rick and Luis initially signed up for ChargeForward for the opportunity to earn cash incentives, but found that their greatest takeaway from the program was gaining awareness of charging with renewable energy.

Already focused on maximizing their electric commuting miles, the main behavioral adjustment was to remember to set an accurate departure time so their cars are fully charged when needed. Rick, who has the shorter commute, likes to make a point of maximizing his X5 eDrive hybrid's electric miles during the weekdays by charging daily. On the weekends, the hybrid SUV gives this household the flexibility for longer trips to the mountains or wine country, while otherwise keeping gas costs to a minimum.

> "I drive a BMW X5 eDrive because I wanted an SUV that lets me **maximize my electric miles."**
>
> -Rick

05

BEHAVIORAL CHANGE THROUGH INCENTIVES

Incentives are the biggest behavioral change motivator when it comes to smart charging. Results from three studies that tested how people respond to various forms of incentives all revealed the highest response rates when incentives were increased.

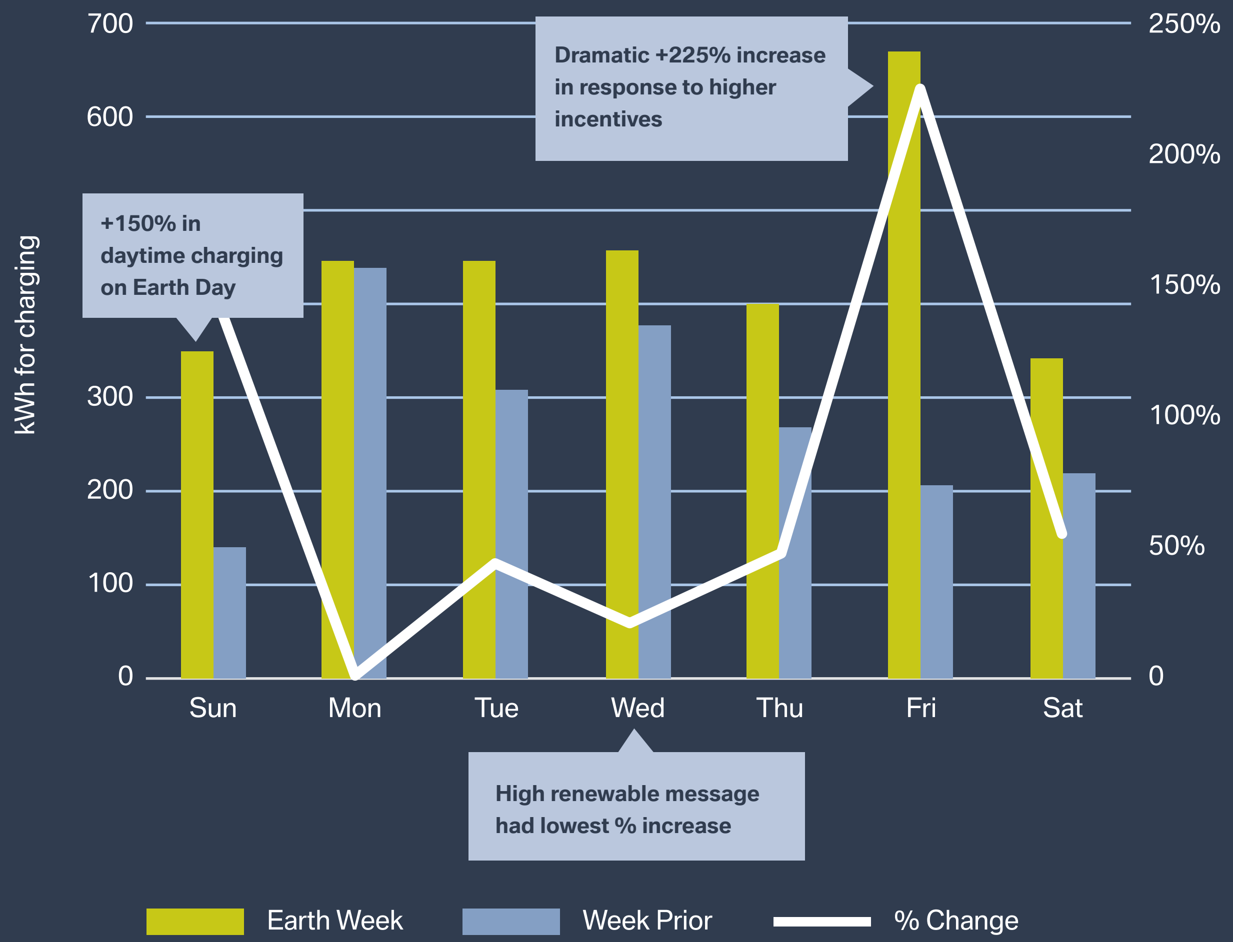
The Earth Week Study

The Earth Week study is the most notable example of the impact financial incentives can have. The 'Double Incentive' day saw a dramatic 225% increase in daytime charging, compared to a 21% increase during the 'High Renewable message' day. Survey results indicated that customers were more motivated by the incentives (31%) relative to the environmental outcome (17%). While renewable energy can be used to motivate customers, on its own it was less effective than cash incentives.

The Driver Cohort Plugin Study

For the Driver Cohort Plugin study, participants were asked to plug in more and each participant received an individualized "plug-time" goal. They were entered into a drawing for a chance to drive a BMW i8 over a weekend if both the group and the individual driver met their goal. This was another opportunity for participants to get more renewable energy into their vehicle by plugging in for more hours to increase the flexibility in their charging. The results were mixed, and the cohort did not unlock the grand prize, meaning on average, the individuals did not meet their increase plug-time goals. When asked whether participants would have preferred a cash prize instead, 75% responded that they would have preferred cash.

63% INCREASE IN DAYTIME CHARGING DURING EARTH WEEK



The Advanced Distribution Study

The Advanced Distribution study ran three tests to see whether people would respond to increasingly stringent requirements if they were offered higher financial rewards. More than 80% of participants met the criteria and received their cash bonuses. Unlike past bonuses, this study only paid out bonuses if 100% of the criteria were met on a daily basis for the entire duration of the test (the longest test ran four weeks).

While it is important to incorporate education and messaging to induce behavioral change in smart charging programs, incentives will remain the primary motivator for participation.

PARTICIPANT FOLLOW-UP SURVEY RESULTS

90% are aware of special events and extra incentives

84% make an extra effort to participate in special charging events with extra incentives

78% state that the incentive criteria are easy to follow

PARTICIPANT FEEDBACK ON PROGRAM INCENTIVES

"Great program for financial incentives to encourage new charging behaviors and great educational tool for how charging times can be impactful."

"Getting incentives for helping the electric grid is a great opportunity."

"A small incentive can change my charging habits."

"Money and participation in a group that is trying to electrify transportation. I deeply appreciate anything that increases awareness of CO2 levels and energy conservation."

"Incentives can guide behavior."

"It struck a good balance between active events and set-and-forget. People want opportunities to earn but also not have to 'live in the app' to be rewarded."

DISTRIBUTION SAVINGS THROUGH SMART CHARGING

ChargeForward explored how smart charging can positively impact our grid infrastructure. Grid congestion stresses distribution infrastructure, shortening its useful life. With almost 70% of current distribution infrastructure nearing the end of its useful life, avoiding congestion helps utilities defer some major cost investments and create long-term savings (otherwise averaging around $51 billion annually[9]).

ChargeForward explored reducing grid congestion in two ways – by modeling potential value at real-world charging sites, and by developing an innovative demonstration of how smart charging can avoid peak hours at a local level.

[9] https://www.utilitydive.com/news/aging-grids-drive-51b-in-annual-utility-distribution-spending/528531/

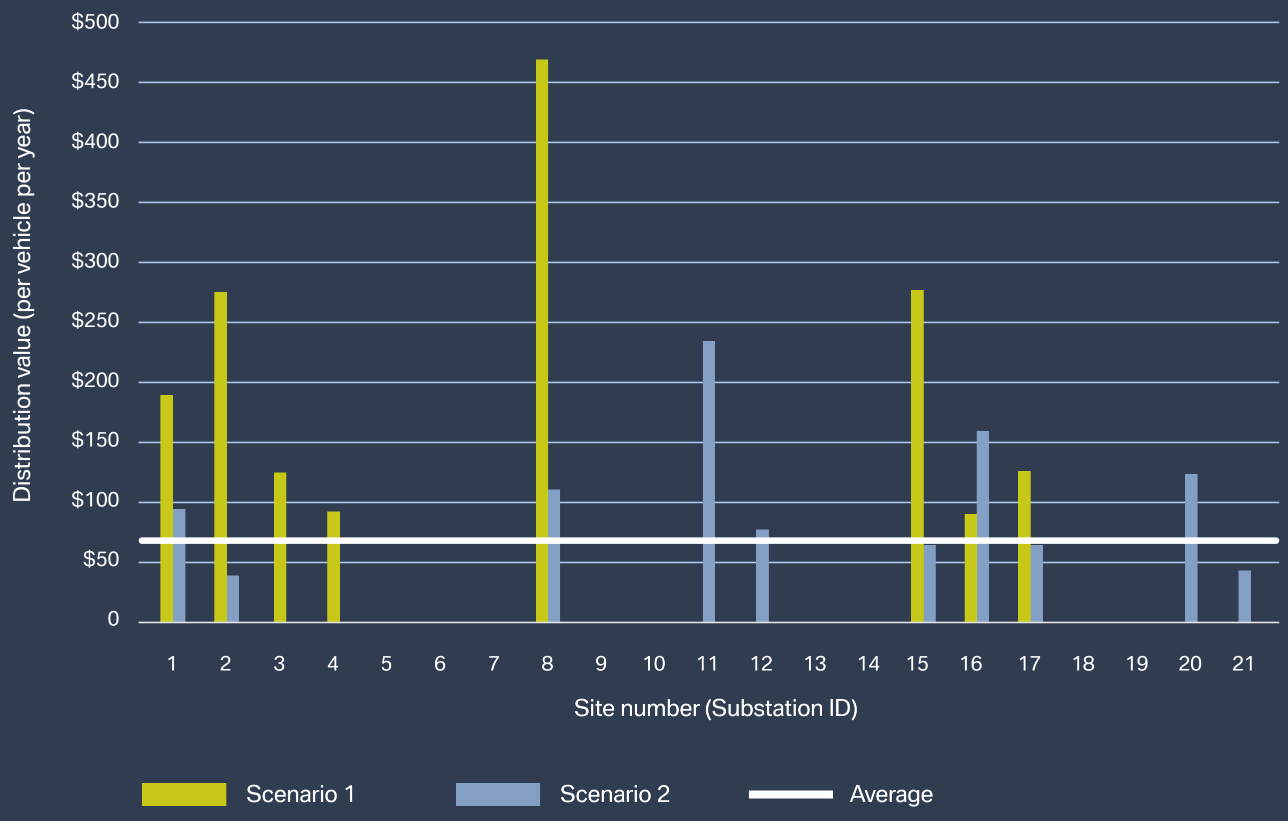
Distribution Deferral Value

The value from avoiding congestion is known as distribution deferral value (DDV). DDV is typically calculated from a utility's avoided capital costs related to distribution infrastructure and operations. In other words, utilities can extend the life of distribution capacity infrastructure (the grid's poles, wires, and substations) by avoiding electric load at peak times unique to each electric substation or its associated neighborhood feeder lines.

BMW worked with Kevala Analytics to calculate the DDV at 21 charging sites used by BMW ChargeForward participants. The current infrastructure and load profiles at each site were evaluated to determine what an upgrade would cost and which hours experienced congestion.

Once the costs were assessed and a congestion analysis determined which hours were most impacted by congestion stresses, a DDV was assigned for each of the congested hours. Next, actual charging behavior from ChargeForward vehicles was examined to determine if smart charging could be used to shift charging out of congestion hours. This analysis discovered that, on average, electric vehicles charging during the day (9AM - 5PM) can create around $67.54 of annual distribution deferral value (per year per site) through smart charging, with an upper range of $461.33 among the 21 sites. A given vehicle could accrue DDV at multiple sites throughout the year, resulting in a per-vehicle value that may exceed the per-site value.

SITE-SPECIFIC DISTRIBUTION CAPACITY VALUES FOR CHARGING BETWEEN 9AM-5PM



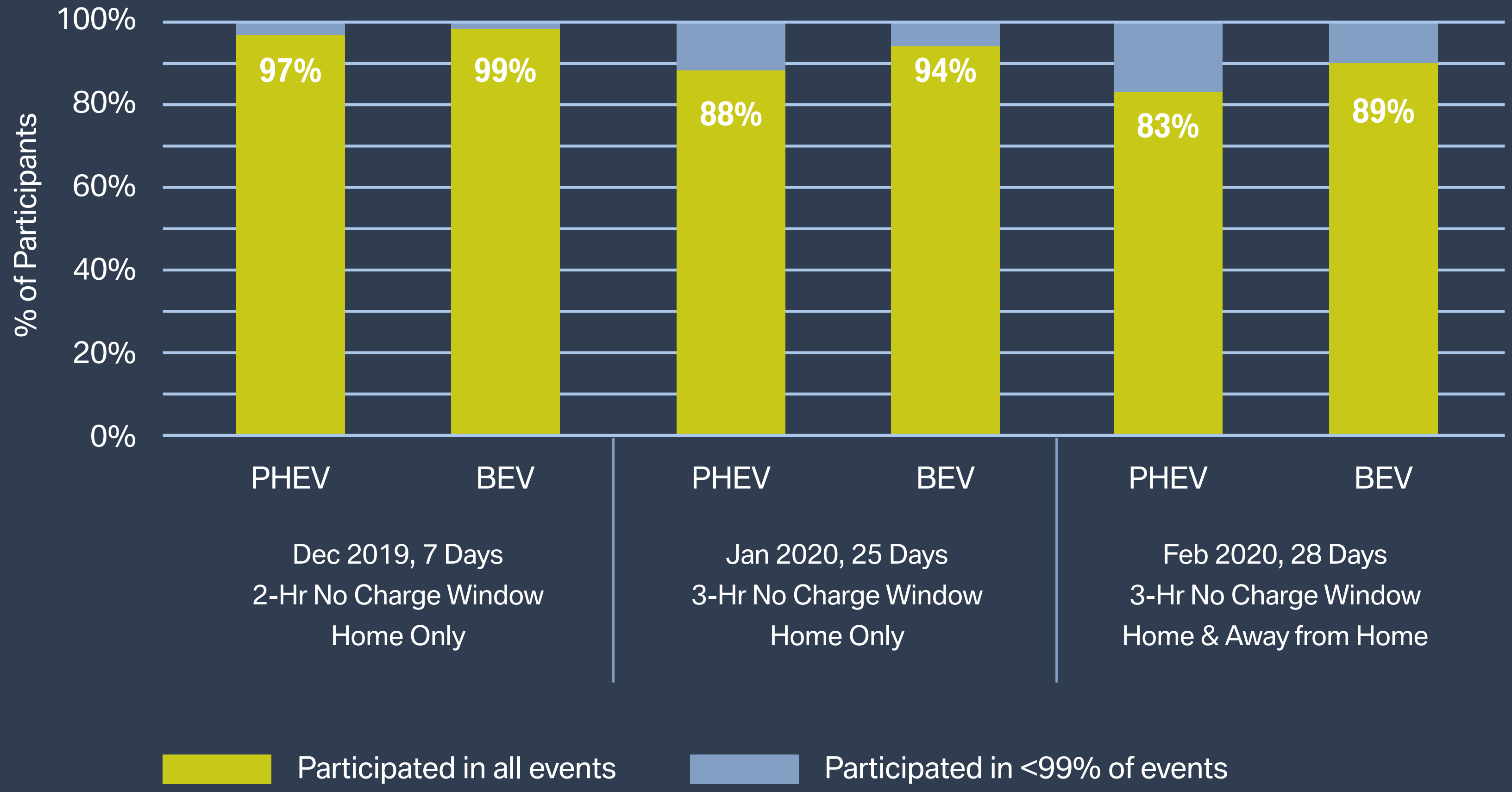
Advanced Distribution Deferral Study

BMW partnered with PG&E to conduct an advanced DDV performance study. The approach was to assume that all charging locations could have infrastructure nearing the end of its useful life. The study examined if EVs could respond during likely congested hours on a consistent basis. The results showed that it is possible to reliably call upon vehicles to act as a distribution deferral resource.

Participants were notified in advance about the daily 'no-charge hours.' BMW signaled all vehicles to stop charging during these hours each day regardless of charge state or other participant conditions. Participants could opt out or override the BMW command. However, if a customer successfully avoided charging for all (100%) of the test days, they received a bonus incentive. BMW worked with PG&E to determine the incentive levels, which were set based on potential distribution deferral value to the utility.

Three tests were completed from December 2019 through February 2020. The testing periods became longer and the requirements became more stringent with each subsequent test. Over 80% of participants had perfect participation during all three. The December study, a week-long period of two-hour 'no-charge' windows, saw the highest perfect participation rates, with 99% of BEV drivers not charging during the designated window for the week. As the criteria became more stringent, the levels of complete participation dropped, but still remained over 80%.

MORE THAN 83% OF PARTICIPANTS AVOIDED CHARGING DURING EACH OF THE SCENARIOS IN THE ADVANCED DISTRIBUTION DEFERRAL STUDY



07

CHARGEFORWARD AT SCALE

ChargeForward also examined the impact that smart charging might have ten years from now. In 2030, there are projected to be 5 million EVs (based on the California Zero-Emission Vehicle 2030 target), and EV charging could represent a flexible resource of over 160 GWh[10] per day. If 40% of that load could be flexibly managed through smart charging, or about 2 million EVs, then up to 48 GWh of solar energy could potentially be absorbed each day[11], shallowing the duck curve's valley and smoothing the ramps dramatically. In fact, the charging of 2 million EVs is more than enough to soak up all of the solar generation on a current peak solar day[12] and it could reduce or eliminate the need for curtailment. Additionally, 2 million managed EVs could reduce GHG emissions by over 600,000 metric tons, or 0.6 MMT CO2e[13] and could support the absorption of over 2,400 GWh of renewable energy.[14] That equates to 13% of California's 2018 utility-scale solar PV farm capacity[15], or from a residential perspective, about 5 million[16] rooftop solar panels.

SCALED BENEFITS FOR CALIFORNIA IN 2030

What if 40% of California's electric vehicles had managed charging by 2030?

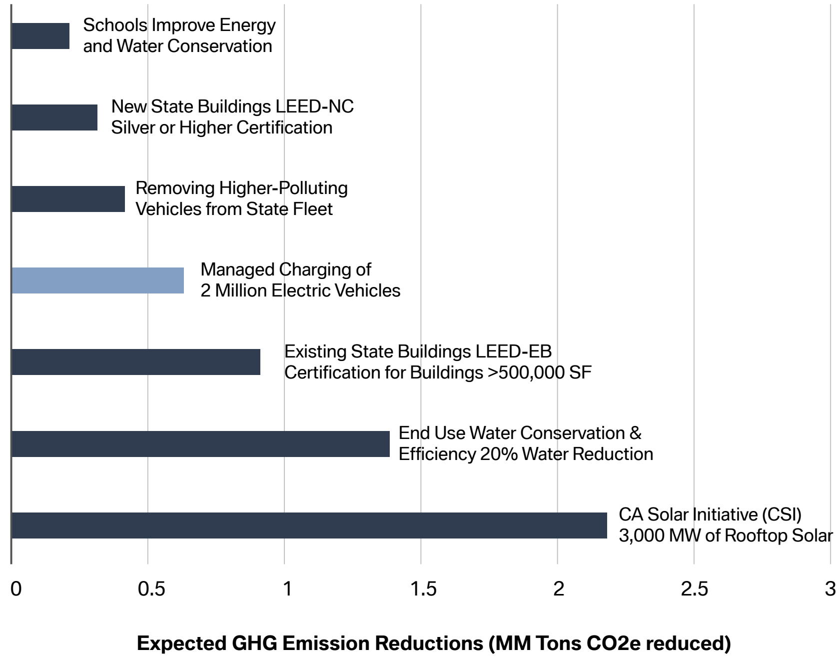
These **2,000,000** electric vehicles would introduce **64,000 kWh** of flexible load that can…

…absorb over **2,400,000 MWh** of additional renewable energy (that's a **13% increase** in total capacity of 2018 California utility-scale solar farms)

…and reduce GHG emissions by over **600,000** metric tons (equal to planting over **780,000 acres of forest** in one year, almost the size of Yosemite.)

The emissions reductions would be equivalent to the savings from adding about 190,000 unmanaged EVs to the California energy mix.[14] Comparing this value to some of the current GHG emission reduction measures in California,[15] the projected 2030 emissions reductions from managed charging would equate to about a quarter of the 2020 expected emissions reductions from the California Solar Initiative, and about three times the 2020 expected emissions reductions from the California's Schools initiative.

ANNUAL GHG EMISSIONS REDUCTION PROJECTIONS FOR VARIOUS CALIFORNIA MEASURES



[10] Based on an average 32 kWh battery size

[11] With 75% of charging being shifted to daytime

[12] 2019 California solar peak was 11,473 MW on July 2 (http://www.caiso.com/Documents/2019Statistics.pdf); 4 hours of full generation equates to 46 GWh of solar generation that day, compared to 48 GWh of potential daytime demand from two million EVs

[13] Based on UC Berkeley's calculation that each managed electric vehicle can reduce GHG emissions by about 300 kg per vehicle per year

[14] Based on UC Berkeley's calculation that each managed EV can absorb an additional 1,200 kWh of renewable energy per year.

[15] CA 2018 utility-scale solar PV capacity of 10,652 MW (https://ww2.energy.ca.gov/almanac/renewables_data/solar/index_cms.php)

[16] 250W output per residential panel

[17] 3.16 tons CO2e reduction per vehicle; https://ww2.energy.ca.gov/2017publications/CEC-999-2017-008/CEC-999-2017-008.pdf (Table E-1)

[18] 2018 State Agency Greenhouse Gas Reduction Report Card (https://www.energy.ca.gov/sites/default/files/2019-12/2018_CalEPA_Report_Card.pdf)

08

NEXT STEPS AND RECOMMENDATIONS

Vehicle grid integration will require changes to the current rules and customer programs used by utilities and grid operators. Because smart charging often falls into the Demand Response category of utility programs, utilities and stakeholders must reimagine demand response programs to capture the potential of smart charging.

Below are some primary changes state regulators, utilities, and grid operators should consider:

1. Use tools that directly reach vehicles and drivers.

Behavior incentives and messaging must reach the actual driver of the vehicle. Traditionally, utilities contact electricity account holders and rely on utility meters to determine performance. This is insufficient as the account holder is not always the EV driver, especially in cases of apartments and workplace charging.

2. Use vehicle telematics as a data source.

Vehicle telematics can serve as an effective source of performance data and it is the only measurement device that follows the vehicle and the driver throughout their daily charging events. Thus, it is well-positioned to capture maximum value from flexibility in a driver's driving and charging behavior.

3. Incentivize daytime charging.

Effective smart charging and VGI requires that charging be shifted from nighttime to daytime hours when possible. This behavior change requires a close relationship with drivers to ensure their driving needs can be met by their battery. When asked what would encourage daytime charging, the most common responses were:

- Lower utility rates at home during the day (55%)
- Higher incentives to offset more expensive daytime rates (47%)
- Better access to workplace charging (43%)

4. Simplify enrollment requirements.

When enrollment for ChargeForward began in 2016, the utility registration process was time-consuming and confusing for customers, requiring hard-to-find account information. Instead, a streamlined smart-charging enrollment process should include the following:

- Straightforward and automated utility account information
- Immediate confirmation of eligibility
- Participation in multiple device-level programs (such as A/C programs or smart rates) that do not directly overlap with smart charging

5. Share Renewable Energy and GHG data with partners.

A critical element of this program was access to renewable energy data. PG&E's willingness to share their daily renewable energy projection allowed the following:

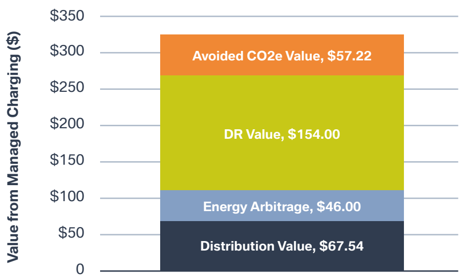
- BMW to optimize charging against renewable generation
- EV drivers to understand how charging behavior impacted the emissions associated with electric fuel through tracking and measuring their performance
- The ChargeForward team to evaluate how different incentive structures engaged customers in smart charging

6. Unlock the full value of smart charging.

Multiple value streams from utility and wholesale markets could be condensed into a customer — transparent value to motivate higher levels of participation in the future. Based on the multiple value streams explored in this program, we estimate EV drivers could earn around $325 annually if they could access the following value streams:

- Demand response market or utility value for load shifting
- Energy price arbitrage through charging optimization
- Distribution deferral value
- Carbon emission reductions from renewable energy alignment[19]

Value from managed charging (per vehicle/year)

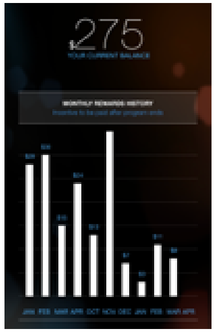


7. Avoid reliance on aggregated load baselines when determining performance.

Traditionally, demand response requires electricity consumers to reduce load for a given time period and requires the program to measure performance against a baseline. However, utility meters only capture the aggregated load of a household or business. This type of data is problematic for determining EV performance. For households with solar generation (the majority of ChargeForward customers), fluctuations in solar generation (i.e. cloud cover) can entirely mask any demand response. Further, optimized vehicles are unlikely to be charging during demand response hours, leading to reduced baselines from daily shifts to the lowest cost hours. Instead, we recommend moving away from the baseline approach for Demand Response, and focusing on the overall value of the resource.

8. When it comes to incentives, cash is king.

Survey and study results repeatedly demonstrated that cash incentives were the most successful motivator for customers. Most notably, the Earth Week study showed a 225% participation increase in daytime charging on the double incentive day. A recent survey also revealed that 67% of participants stated that they will make a reasonable effort to participate in special charging events with extra incentives.



Screenshot of the ChargeForward phone app

9. Avoid setting vehicle incentives based purely on battery size.

When paired with smart charging incentives and abundant workplace charging opportunities, PHEVs can generate environmental and grid benefits significantly higher than their battery size suggests. However, many state governments use battery size as a proxy for the environmental benefits of PHEVs. ChargeForward demonstrated that PHEVs provide an outsized benefit relative to BEVs when measured based on battery size. Governments should instead take into account the full GHG benefits possible when PHEVs are paired with robust infrastructure investments and smart charging programs.

"Incentives are the **best motivator**."

"This whole program is a great idea. I checked off that **the incentive money** was the primary reason I participated, which is true because it's what gave me the final push, **but being more green and also supporting this experiment** are also very important to me."

[19] The value presented here is just a snapshot based on seasonality, select locations in Northern California, and unique charging profiles. The Demand Response Value ($154) is from E3's presentation to the CEC Vehicle Integration Roadmap working group: E3 Presentation - Quantifying Value of VGI

CONCLUSION

Smart charging presents an exciting opportunity to integrate two primary technology solutions for climate change and decarbonization – electric vehicles and renewable energy. Our drivers that choose smart charging are not only cutting their carbon emissions by switching from gasoline to electricity, but they are also helping to accelerate the adoption of renewable energy.

ChargeForward demonstrated that managing EV charging is a potential tool for utilities and grid operators to maintain grid balance while achieving high renewable energy adoption targets. Based on analysis by UC Berkeley, smart charging can deliver over 32% more GHG savings from BEVs and PHEVs than conventionally-charged vehicles. Under optimal infrastructure assumptions, smart charging EVs can help the grid absorb over 1,200 additional kWh of renewable energy per vehicle per year, an equivalent of four months of charging for a typical BEV driver.

Automakers are well-suited to support the realization of these benefits. Vehicle telematics can transform EV charging into a sophisticated grid resource whenever and wherever a vehicle charges. Automakers also have a direct relationship with their customers, which is essential to facilitating smart charging. In the future, engaging the vehicle and the driver in smart charging will be critical to using vehicles to support renewable energy integration. Incentives and messaging in smart charging programs can create new habits in drivers that encourage more frequent plug-ins to support the variable needs of the grid.

The lessons learned from the BMW ChargeForward program represent the foundational step toward integrating bi-directional (V2G) vehicles as a grid resource. Though the program's scale was small, smart charging has the potential for massive environmental and electrical benefits when scaled to larger settings. The successful realization of these benefits will require an alliance of utilities, automakers, and drivers that extends from the home, to the workplace, and into daily life.

ACKNOWLEDGMENTS

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BMW of North America, LLC would like to thank the ChargeForward drivers for their trust and willingness to participate in this program, as well as acknowledge its project partners for all their support:

PG&E

UNIVERSITY OF CALIFORNIA Berkeley
Transportation Sustainability
RESEARCH CENTER

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