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BMW i ChargeForward: PG&E's Electric Vehicle Smart Charging Pilot



A cooperation between



*Pacific Gas and
Electric Company*

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Executive Summary

The BMW i ChargeForward Project successfully tested the feasibility of using managed electric vehicle (EV) charging as a flexible grid resource. The Project has shown the ability for electric vehicles to provide viable grid services using the vehicle telematics system as a basis for communicating grid messages to vehicles. The grid services demonstrated in this pilot included Day Ahead and Real Time Energy, which were modeled after existing proxy demand resources

from the California Independent System Operator. These grid services have the potential to result in cost savings associated with operating and maintaining the grid as well as owning an electric vehicle. For each Demand Response event, BMW provided PG&E with 100kW of grid resources by delaying charging for approximately 100 BMW i3 vehicles in the San Francisco Bay Area and drawing from a BMW Group 2nd life stationary battery system built from reused EV batteries, for a duration of one hour.



Over the course of 18 months, from July 2015 to December 2016, the BMW i Charge Forward Project dispatched 209 Demand Response events, totaling 19,500 kWh. On average 20% of the total contribution was attributed to the vehicle pool and 80% from the 2nd life stationary battery system. The amount from the vehicle share is dependent on what time of day an event is called. If an event is called from 11 PM to 2 AM, the vehicle pool contributes more significantly by increasing the share from 20% to 50% of the 100 kW required. This increase in vehicle pool contribution is the result of PG&E's residential EV and time-of-use rate plans which provide lower cost electricity prices during this time period, thus creating an incentive for people to charge during these hours.

The BMW i ChargeForward Pilot is deemed a success both from an energy reduction and customer satisfaction standpoint. Participants were very satisfied with the program and were active participants in the research component as well. Based off customer research, 98% of participants indicated that they were satisfied with the program and 93% stated that they are likely to participate in a similar program in the future if offered. Since this program was designed to run primarily in the background of customers' lives they were able to participate at high rates and felt little

to no customer fatigue. Results indicate that the electric vehicle (EV) owners have a strong interest in supporting renewable energy through managed charging programs. They are willing to participate in managed charging or charge during the day as long as they are not inconvenienced or limited in their ability to use their car. The largest barrier to day time charging and managed charging is the lack of workplace charging. Based on the success of the BMW i ChargeForward pilot, BMW received a grant from the California Energy Commission (CEC) to continue with a second phase of the pilot. Program participants express an interest in having the automakers participate and expand their role in providing grid services; this is seen as an added benefit to drivers who want to optimize the positive impacts of driving their electric vehicle. The second phase looks further into the grid benefits attained from greater flexible charging and more advanced charging management while continuing to utilize vehicle telematics to facilitate grid messages to the vehicle and driver. Overall, the size and magnitude of this resource, and the associated cost savings, will ultimately be dependent on EV adoption and the types of grid services that can be cost effectively offered.

1

Project Overview

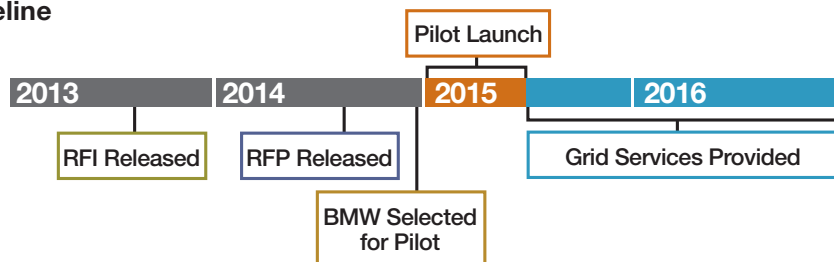
The BMW i ChargeForward Project (known as the Plug-in Electric Vehicle Demand Response Pilot Project as described in D.12-04-045 and Advice Letter 4077-E) aimed to demonstrate the technical feasibility and grid value of managed charging of electric vehicles, as a flexible and controllable grid resource. The main goal of this project was to understand the potential of using Electric Vehicles (EV) for grid services, which can result in cost savings associated with operating

and maintaining the grid as well as owning and operating a vehicle. Added grid services can potentially reduce the need to increase California's electricity generation capacity and is aligned with the State's loading order for resources, effectively reducing energy procurement costs. The magnitude of these services and their associated cost savings will ultimately be dependent on EV adoption and the types of grid services that can be cost effectively offered.



FIGURE 1 Project Timeline

The RFI was released in the third quarter of 2013 and the RFP released one year later in the third quarter of 2014. BMW was selected at the end of 2014 and BMW i ChargeForward officially launched and began enrolling customers during the first half of 2015. BMW provided grid services from July 2015 to December 2016.



The higher cost of an EV compared to traditional internal combustion engine (ICE) vehicle is widely considered the major obstacle toward mass market EV adoption. The strategy of this pilot was to develop a mechanism that partially or fully levels the higher costs of EVs compared to internal combustion vehicles. The project aims to accomplish this goal by bundling the grid value of an EV's demand response (DR) capability over the vehicle's useful life and beyond (as a battery 2nd life stationary grid storage asset). This value is paid to the EV manufacturer, who then passes on this value to the driver.

The figure below illustrates the project timeline for the BMW i ChargeForward Pilot Project. It is important to note that considerable work went into this pilot prior to the launch of the program with BMW. In 2013 PG&E released a request for information (RFI) to automakers to better understand their interest in participating in a grid services pilot with EVs and 2nd life batteries. PG&E received significant interest in the RFI which prompted the release of a request for proposal (RFP) in 2014. BMW was selected as the vendor for this project as a result of providing the most competitive and comprehensive proposal.

In addition to BMW, Olivine acted as the project administrator, utilizing the Olivine DER, a complete distributed energy resource management platform to manage the demand response program aspects of the pilot. Olivine—an approved Scheduling Coordinator (SC) with the California Independent System Operator (CAISO)—acted as the interface between PG&E and BMW. This included managing resource enrollment, nominations, awards, and dispatch notifications to BMW based on an event schedule provided by PG&E. It is important to note that this project did not directly bid into the CAISO market; however grid services were modeled after existing CAISO proxy demand resource products.

Olivine was also responsible for interfacing with Whisker Labs (Whisker) to retrieve customer-level raw meter data from their peel-and-stick electricity metering platform, to perform validation, estimation and editing, and to calculate settlement quality meter data for use in event baseline, performance, and settlement calculations, and ultimately for payment of incentives directly to BMW.

FIGURE 2 Overview of Project Partners and Roles

The graphic provides an overview of the partners supporting the overall project structure.



2

System Architecture & Project Development



This section includes an overview of the system architecture, summary of the technology developed by BMW to deliver the required demand response commitment of 100 kW, and the customer enrollment process. This section also includes a description of challenges faced in project development and solutions developed to overcome these project barriers.

Overview of the System Architecture

The pilot requires BMW to provide 100 kilowatts (kW) of capacity at any given time, regardless of how many BMW i3 EVs are charging. BMW is required to provide this capacity in the form of either Day Ahead or Real Time Energy, which were modeled after existing proxy demand resources from the CAISO. An overview of this system is described in the figure below.

To meet the EV managed charging component of the pilot, BMW has enrolled 96 BMW i3 drivers located within the South Bay Area to participate in this pilot.¹ All vehicles are owned and operated

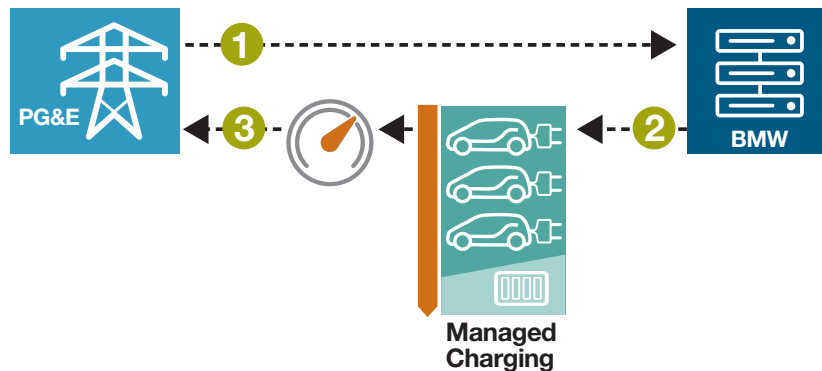
by pilot participants who are PG&E residential customers. Once an event is called, BMW utilizes proprietary aggregation software to delay charging of participating customers (via telematics embedded in the vehicle) in order to reduce load on the grid. The algorithm prioritizes the reduction of electricity consumption from charging without interfering with customers' mobility needs; however drivers can opt out of event participation at any time. To address uncontrollable fluctuations regarding managed charging capacity, BMW developed a stationary battery system made up of eight used BMW Group batteries (100 kW/225 kWh) as backup storage to fill the gap between available load drop from managed charging and the required 100 kW of DR capacity.

PG&E leverages the Whisker metering system and Olivine's online monitoring system to produce real time baseline calculations in event dispatches, ensuring that the BMW systems can accurately meet the dispatch requirement.

See Figures 25-27 in the Appendix for a description and example of the systems used to track the performance of each event.

FIGURE 3 BMW i ChargeForward System Architecture

PG&E initiates a DR event to BMW (via Olivine) by sending a signal via a standard communication protocol (OpenADR 2.0b) similar to how PG&E communicates with other DR providers. Once the event has been triggered, BMW's aggregation software determines how much of the 100 kW load drop will be met by managed charging and how much by the stationary storage resources made of used EV batteries, or a combination of both.



¹BMW enrolled 96 customers at the outset of the project. At the end of the pilot 92 customers remained.

Demand Response Technology Development

BMW was able to successfully fulfill their demand response commitment of 100 kW with the combination of BMW i3 vehicles and a stationary battery system housed at their Mountain View, CA campus. The stationary storage asset was built to leverage used BMW Group 2nd life EV batteries from the MINI E Cooper trial which ran from 2009–2012. In order to control the charging of the pool of BMW i3 vehicles and the stationary battery storage, BMW developed a backend system which was successful in optimizing the contribution of the vehicle pool and the BMW Group 2nd life battery storage system to provide the required 100 kW. The section below provides more detail regarding the development of the stationary battery storage system and the back-end system used to manage the vehicle pool and the battery system as well as the on-site energy management system at the Mountain View Campus.

BMW Group 2nd Life Stationery Battery Storage System

In January 2015, PG&E issued an interconnection agreement granting permission for BMW to operate its BMW Group 2nd life battery system. The 2nd life battery system was an essential component to the overall system architecture of this pilot. This battery provided BMW with the ability to support the full required capacity at any given DR event, regardless of the vehicle pool contribution. A description of the battery system is provided on next page:

Overview of 2nd Life Battery System

Name Plate:

225 kWh, 100 kW AC (charging and discharging)

Components:

- 8x EV Grid MINI E battery packs (used in parallel)
- 8x EV Grid MINI E BMS (battery management system)
- 1x EV Grid Super-BMS
- 1x Princeton Powers Systems GTIB 100 inverter
- 1x Princeton Powers Systems site controller
- 1x Princeton Powers Systems isolation transformer
- 10ft container, fire suppression system, battery rack, e-stop, breaker panel, thermal management (cooling) system, etc.

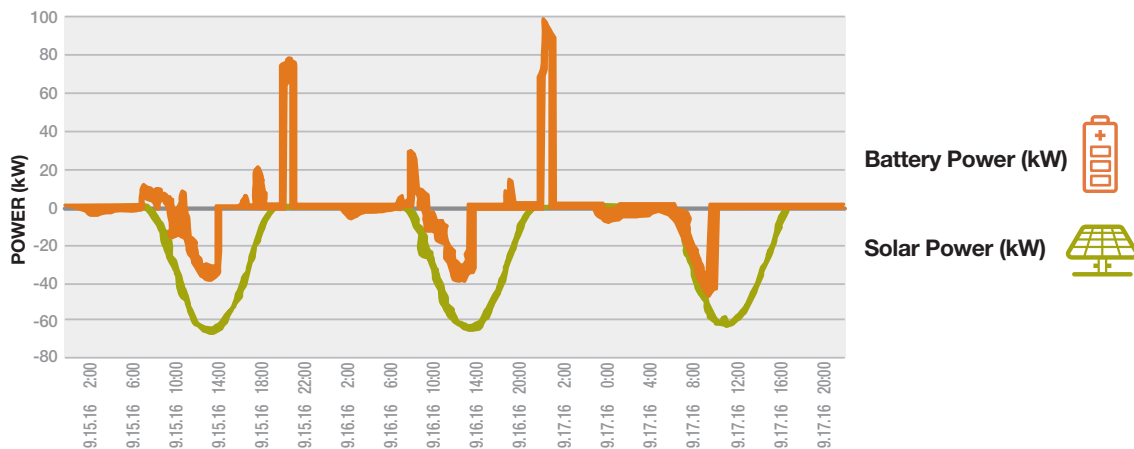
During commissioning, several issues of the system were discovered and a task force led by BMW was put in place to resolve these issues. Once resolved, the BMW Group 2nd life stationary battery storage system ran reliably throughout the pilot with minor issues (additional details regarding issues and resolutions are described in Section 4).

A micro grid system was developed at BMW Group Technology Office USA to coordinate the 2nd life battery charging with on-site renewable energy and grid energy, supporting the main office building functions while ensuring sufficient state of charge to cover BMW's commitment to provide 100 kW of demand response.

The remaining flexibility when recharging the battery was leveraged to optimize the usage of locally produced solar energy. The scheduling of the recharging process also incorporated next-day weather forecasts to better predict the future solar energy produced and thereby stored in the stationary battery system.

FIGURE 4 Solar Production and Battery Recharge

This graph illustrates the local solar production during three consecutive days. Energy production from the solar panels as well as battery recharging is displayed as negative values. The energy exported from the battery to the building or grid is positive. The two distinct orange spikes indicate the DR events called in the evenings where the battery dispatched power.



Solar and Battery Profile of the BMW Group Technology Office USA

EV Pool Control: Back-end Automated Aggregation

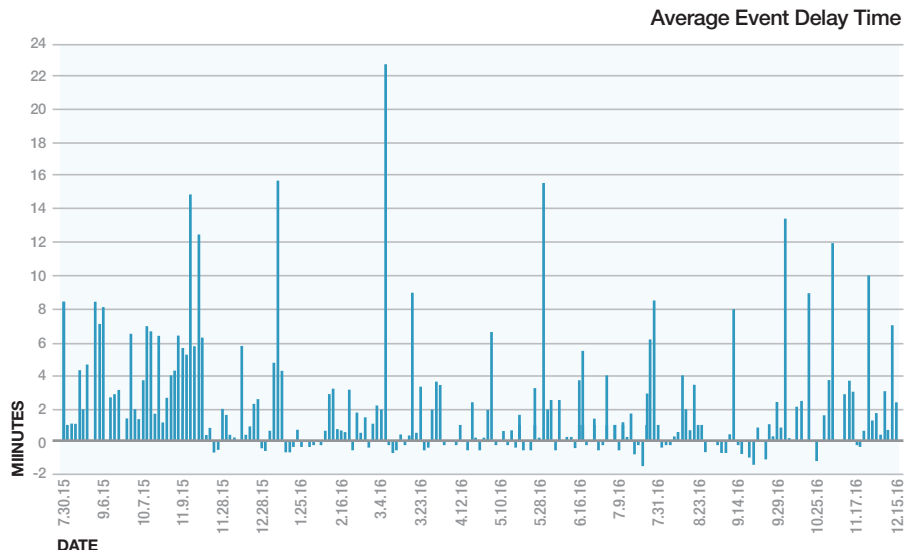
The EV Pool Control system aggregates the vehicles in the BMW i3 vehicle pool (vehicles are owned by pilot participants) and the stationary battery system (owned by BMW), to provide the requested DR capacity. The back-end automated aggregation system was effective in prioritizing the participants driving needs while ensuring that BMW was able to meet their 100 kW load requirement between the vehicles and the battery system. For each DR event requested there was an associated latency, or delay, between when the signal is sent and when the load drop is recorded. The latency levels observed throughout the pilot were in line with the acceptable levels needed to meet the majority of grid services in California.

Figure 5 outlines the average time it took from sending the load drop signal to the vehicle until the load drop is visible in the meter data. For vehicles that are plugged in at the start of a DR event, this delay can be negative, as the signal is sent 2 minutes prior to the event.

Delay issues of several minutes (up to 10 minutes) were observed during the first month of DR events. The root cause for these issues was identified by an analysis of the system log files. The issue was resolved by deploying a more advanced algorithm. However, the team experienced additional delays as a result of the cellular carrier. Issues with the communication between the vehicle back-end and the BMW i3 vehicle fleet during early afternoon hours Pacific Time were observed around the time of project launch. Communication issues caused signals sent between the back-end and vehicles to be occasionally delayed or lost, resulting in vehicles not participating in DR events when they system requested they reduce their charging load. This issue was not caused by the BMW i ChargeForward program, but is a more fundamental problem of the GSM-based Telemetry Services. A BMW task force successfully identified issues with servers of the cell phone carrier as the root cause, resolving the issue by September 2015.

FIGURE 5 Average Delay of Vehicle Pool by Event

For each DR event there was latency between the time when the load drop signal was sent and when the vehicles picked up the signal and responded, thus registering the load drop in the data read out. This figure shows the average time it took the vehicles in the vehicle pool to respond to each event from BMW's signal.



There were additional delays throughout the pilot that were not primarily attributed to the vehicle telematics or the vehicle pool control algorithm. These delays were a result of various different causes, which included longer and unexpected processing times on backend servers due to load sharing and communication delays—the communication mechanisms between the different subsystems were not primarily optimized for low latency operation. However, in over 200 events called throughout the pilot, the vehicle pool had only seven events where the average delay was greater than 10 minutes. Rather, the average latency per event was only 2.3 minutes, far below the required response time of 4 minutes for modeled Real Time and 24 hours for modeled Day Ahead events. Individual vehicles had an average reaction time of 3 minutes from the signal, slightly more than the event average but still within the 4 minute target. While a faster response was not required for this pilot, there is potential for the vehicle pool, by leveraging on-board telematics, to have a shorter latency period.

EV Pool Control: Managed Charging of a Fleet of BMW i3 EVs

BMW is able to manage the charging process of the BMW i3 vehicle pool vehicle pool by leveraging cellular (GSM-based) telemetry services. The details of this technology are proprietary BMW intellectual property. The communication link from the BMW back-end system to the vehicles has shown to have a typical latency of 10-30 seconds, a latency level appropriate to meet the majority of grid service in California. This latency reflects the capabilities of the communication architecture used specifically in this pilot. Other telematic approaches may result in a lower latency. It is important to note, that this covers only the latency of the telematics system. The complete technical chain of command consists of a number of steps between calling a DR event and when the effect can be measured which has provided an average of 2.3 minute latency and was noted in Figure 5.

The back-end control software developed by BMW for this project was operational from project go-live on July 30, 2015 to the completion of the project at the end of December 2016. Several system upgrades were released throughout this time to improve the resource's performance regarding delayed activation of the resources, refining the vehicle pool controls, and optimizing the push notification methodology from the smart phone app notifying customers of the event.

BMW i ChargeForward Smart Phone App

The BMW i ChargeForward smart phone app was specifically developed for this program to gather information from participants to ensure that their mobility needs were always met. This gave the participant full control over the charging process of their vehicle. Once enrolled in the BMW i ChargeForward program, participants were defaulted to be selected to participate in an event if their vehicle was available but were always given the option to opt out.

Customers had options to make sure that their car was fully charged whenever they needed it:

- Customer could opt out pro-actively for a single day from the BMW i ChargeForward program. If an event was called that day they were not selected.
- Customers received push notifications if their car was selected for an event. If the time did not fit with their needs they could opt out of that event and their car would resume charging.

Aside from just managing the charging times, the BMW i ChargeForward app provided the user with an overview of their incentive balance (further discussed in Section 5) and a FAQ section that was updated periodically throughout the program.

While not a component of the BMW i ChargeForward App, participants had the ability to set a departure time with the BMW i Remote App, the BMW Connected App and the in-vehicle display. This ensured that their vehicle had enough time to fully charge and be ready for their selected departure time.

Customer Enrollment

BMW's customer enrollment strategy for the BMW i ChargeForward pilot included reaching out to BMW i3 owners in the San Francisco Bay Area directly as well as through social media outlets.

The BMW i ChargeForward landing page (BMWChargeForward.com) was developed in Q4 2014 and was intended to answer frequently asked questions about the pilot as well as provide an online application. The pilot was included in the BMW Press Conference at the 2015 International Consumer Electronics Show (CES) in Las Vegas, Nevada. On the same day as the press conference, BMW and PG&E both issued press releases. The program was well covered by influential news and social media sites, including: the San Francisco Chronicle, Inside EVs, Automotive World, CleanTechnica, Green Car Congress, GreenTech Media, Utility Dive and Auto Evolution.

FIGURE 6 BMW i ChargeForward Smart Phone App

Interface of the BMW i ChargeForward smartphone app



The press coverage combined with targeted emails to all BMW i3 owners living in the South Bay Area in January 2015 were successful tactics in driving traffic to the online application. In March the BMW Group Technology Office USA hosted a meetup of local BMW i3 drivers to improve the connection to the local owner network and provided additional information regarding the pilot. A second round of targeted BMW i3 owner emails was sent in April 2015 to include all customers who had bought vehicles and live in the project area. Over the course of the participant enrollment process, BMW received significant interest in the pilot, with over 500 applications for only 100 available spots.

In parallel the BMW team worked with BMW of North America's Legal team, PG&E and its partners to define all participant requirements and draft a contract to be signed by each customer and by BMW of North America. This contract defines participant responsibilities, BMW responsibilities, and outlines criteria for contract termination.

The online application was designed to quickly identify interested participants and pre-screen them based on the five most important criteria for the pilot, before directing them to the full application. These criteria were:

- Owning a BMW i3 by July 2015
- PG&E customer
- Willing to charge BMW i3 primarily at home during pilot
- Level 2 EVSE installed by July 2015
- Live in PGP2 Sub-LAP (determined by ZIP code)

Approximately 500 people signed up as interested in the program, of those that indicated they were interested only 275 passed the primary five criteria. Of those that passed the pre-screening almost 200 submitted the full application.

BMW Group Technology Office USA team conducted interviews with the participants who submitted the full application with the following goals:

- Verify all information submitted online
- Review project overview and goals
- Test vehicle connectivity in charging location
- Go over contract and sign if possible

During the enrollment process the BMW team conducted 107 in-person interviews, of which 96 customers were subsequently enrolled in the pilot. By the end of the pilot, 92 customers remained. Since the project started, four customers left the project due to a variety of reasons: two customers were unenrolled due to cellular connectivity issues at their residence, one customer was in a car accident resulting in the loss of the vehicle and the last customer moved outside the project area.

On July 22, 2015, the BMW Group Technology Office USA hosted a Kickoff Event for program participants. The goal of the event was to introduce the program participants to each other, as well as the BMW and PG&E team. Over 50 customers attended. Following the Kickoff Event, the BMW team distributed a customer handbook to all participants that provided extensive program details, best practices, and a contact list in case of questions/concerns.

Coinciding with the program launch, BMW i ChargeForward received a second round of news media coverage due in part to two well-timed interviews by the BMW and PG&E teams with the Atlantic's CityLab website and Bloomberg Business. Media coverage included: CityLab, Bloomberg, Engadget, Chicago Tribune, Fortune, CNET, Business Insider, Forbes, SlashGear, The Verge, Transport Evolved, Green Car Congress, and Ecomento.

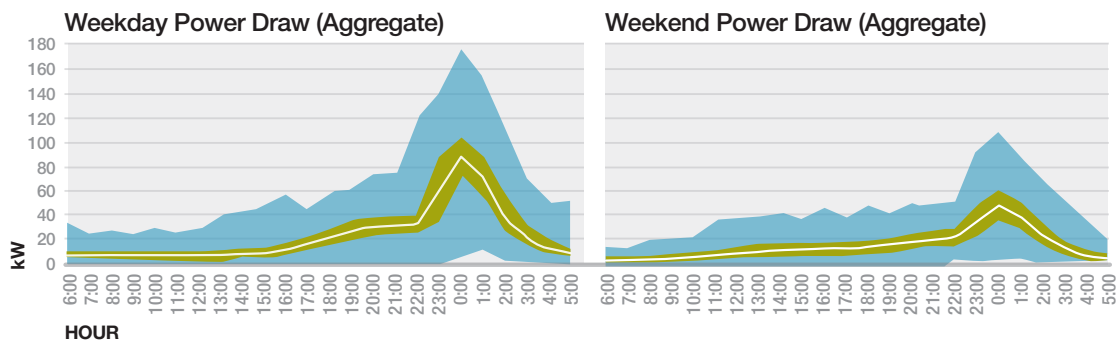
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Analysis of Charging Behavior and Driver Archetypes



FIGURE 7 Weekday and Weekend Charging Demand from the BMW i3 Fleet

The figure below displays the weekend and weekday charging of the BMW i3 vehicle pool from 8/2015–12/2016. The demand curve has a similar shape for both weekday and weekend but the weekday curve is characterized by a steeper and larger peak demand around midnight.



This section examines the charging behavior of the BMW i ChargeForward participants from a variety of angles to identify trends in charging and help influence future managed charging programs.

First, the demand load curves for weekend and weekday charging are described. Second, the section explores three possible charging archetypes of the participants studied and variations in the charging behavior of the battery electric (BEV) and range extender (REX) versions of the BMW i3. Lastly, the section examines other locations, aside from home, that the pilot participants charged.

The demand response capacity from the vehicle pool varies significantly over the course of a day and by day of the week. Figure 7 (on page 16) displays the aggregate weekday and weekend charging demand from the BMW i3 Fleet between 8/2015–12/2016.

This is baseline charging data, excluding demand response event days. For these figures, a day is defined as starting at 6:00 AM and ending at 5:59 AM the next day. The center white line in each figure represents the median power draw for the EV pool, with the green

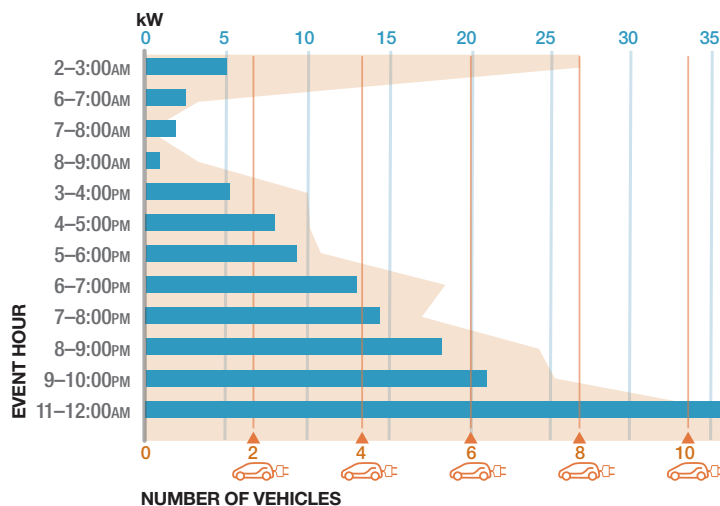
band showing the inter-quartile range (25th–75th percentile). The light blue section represents the minimum and maximum demand measured.

The weekday charging profile for the BMW i Charge Forward fleet is relatively low from 6:00 AM to 4:00 PM, and increases beginning at 4:00 PM creating a small peak or increase at 8:00 PM and a large peak at 12:00 AM. The weekend demand profile has lower maximum demand and less variability.

The vehicle share had a wide range of load contribution based on when the event is called due to the charging patterns of the participants. On average, 20% of the total resource was attributed to the vehicle pool and 80% was provided by the battery. However, the highest vehicle contribution was during events that were called within PG&E’s “off-peak” time-of-use periods, specifically 11:00 PM–2:00 AM. The higher share at these times is the result of about 60% of the BMW i ChargeForward participants that are on a time-of-use rate plan, either the whole house electric vehicle rate plan (EV-A) or the tiered, time of use plan (E-6). These rate options incentivize “off-peak” charging by offering a lower price per kWh between the hours 11:00 PM–7:00 AM on weekdays and 7:00 PM–2:00 PM on Weekends and Holidays.

FIGURE 8 Average kW Contribution and Vehicle Participation per Event Hour

The time of hour the day an event is called was strongly correlated to the number of vehicles participating. This was largely due to the high number of participants on a time-of-use electric rate plan that incentivize charging after 11 PM.



Driver Archetypes

In analyzing the charging behavior of participants, three clear groups were identified. The first group, Frequent Drivers (42), is characterized by having a consistent charging pattern and a commute of greater than 30 miles a day. The second group, Infrequent Drivers (45), had no regular charging schedule and drive less than 30 miles a day. The third and smallest group, Household Drivers (9), had no regular schedule but drive more than 30 miles a day.

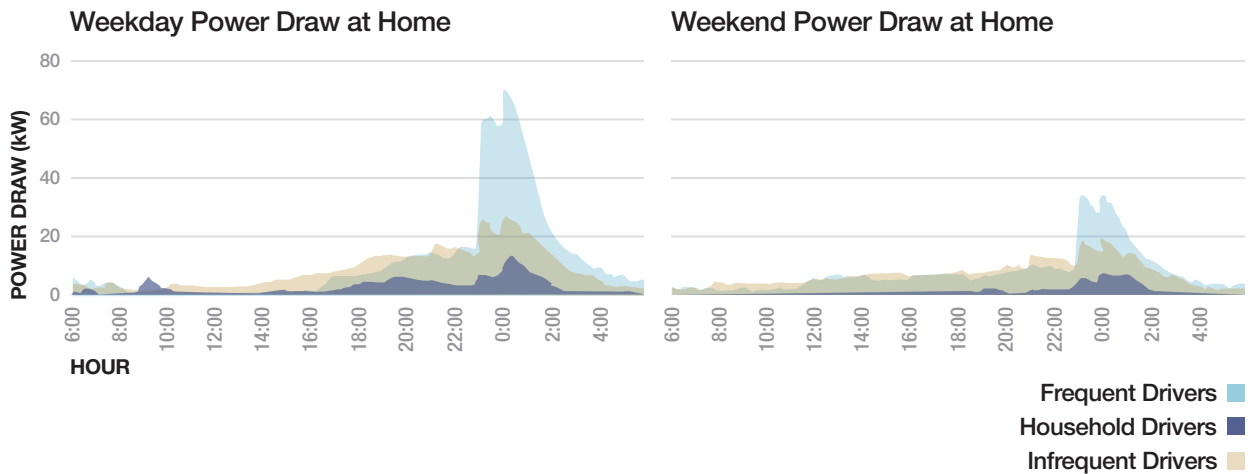
As expected, frequent drivers charged more often than household drivers or infrequent drivers due to typically longer commute and drive times. Frequent drivers had the tightest distribution curve with the most pronounced

spike in the evening regardless of weekday or weekend. A majority of frequent drivers are on one of PG&E's time-of-use (TOU) rates which would explain the significant spike around 11:00 PM on weekdays. Household drivers have the lowest spike and greatest variability in charging times both on the weekdays and weekends.

Weekends have a wider distribution but overall a similar load shape. Frequent drivers have about half the power draw on weekends, 35 kW, compared to weekdays, 75 kW. Infrequent and household driver's power draw is slightly lower on weekends by about 3 kW which suggests there is no significant change in driving distance or time.

FIGURE 9 Aggregated Power Draw by Driver Archetypes

Frequent drivers have the largest power draw of the three driver archetypes. Household driver's power draw curve is slightly skewed due to the small sample size of customer that fit this driver archetype.

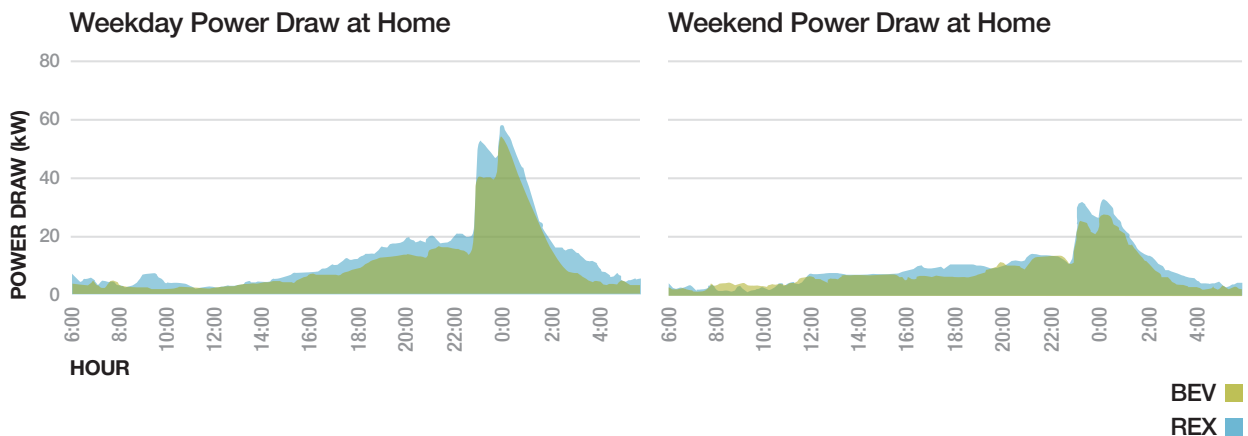


Comparison of Battery Electric and Range Extender Participants

The BMW i3 is offered in two different versions, a battery electric vehicle (BEV) or range extender (REX). For the 2014 BMW i3, the BEV version is fully electric with an EPA estimated 80 miles per full charge. The REX version of the i3 has an EPA estimated range of 150 miles due to the addition of a small gas engine that charges the battery while driving and is designed to enable the driver to reach the next charging station and reduce range anxiety.² Within the BMW i ChargeForward vehicle pool 44 participants have a BEV and 48 have a REX BMW i3.

FIGURE 10 Battery and Range Extender Aggregate Power Draw Comparison

REX drivers have an earlier peak and a slightly larger power draw throughout the day for both weekday and weekend. The power draw difference between REX and BEV pool at the peaks is about 10 kW with the exception of the second weekday peak at midnight when the power draw is the same. This slight difference in power draw may suggest that REX drivers drive slightly further between charging event. However, overall the charging behavior is very similar between the REX and BEV.



²Since i ChargeForward launched, BMW has increased the range for both the BEV and REX. Participants for this pilot had the 2014 version of the BMW i3.

Non-Home Charging

The BMW i3 offers a competitive range on a single charge but occasionally drivers will need an additional charge before they return home. Although charging stations are not yet ubiquitous, participants have been able to charge around the Bay Area. Participants charge in two key areas aside from their home, at work and at public charging stations.

While participants have been able to charge around the Bay Area, their main source of charging is at their home. Although 81% of BMW i ChargeForward participants work full time but only 37% charge at both home and work. Those who do not drive their BMW i3s to work rarely, if ever, charge their vehicles away from home. The largest barrier to charging away from home, reported from participants, is the availability of chargers, costs, and the risk that charging stations at a specific location will be full.

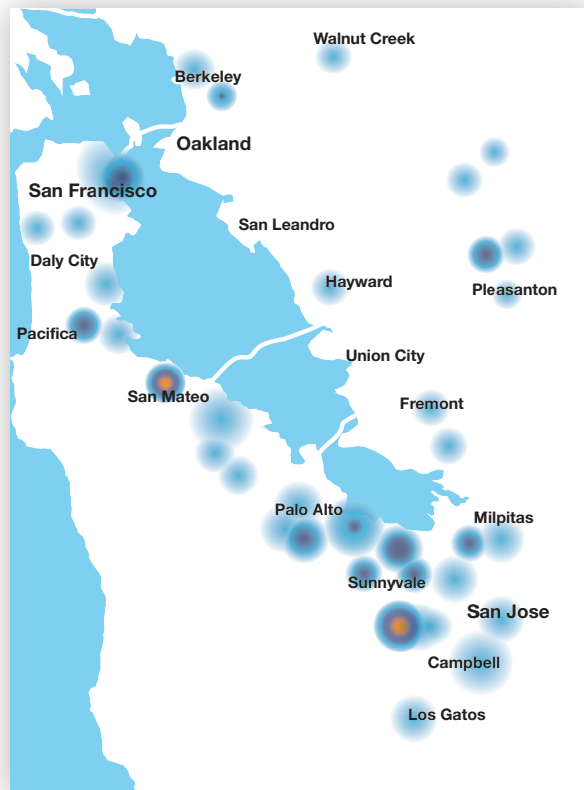
FIGURE 11 Alternative Charging Locations (Non-Home)

The figure below indicates where participants have charged outside their homes. Areas of purple and orange have a higher frequency of charging events.

All customers, workplace charging



All customers, not at work or home





4

Participation in Demand Response (DR) Events



³Prior to October 2015, BMW was required to provide 80 kW.

⁴These percentages are derived from the total delivered amount, 19,500 kW.

⁵Graph does not total 100% since BMW did not meet the full 100 kW in every event.

Between the start of the project in July 2015 and end of December 2016, the BMW resource was called 209 times. In order to test the flexibility of the vehicles and battery as a grid resource, events were tested in both Day Ahead (notifications sent 24+ hours before the event) and modeled Real Time (notifications sent 4 minutes prior to the event). These events were modeled after existing proxy demand resource products developed by the California Independent System Operator.

This section describes BMW's performance in responding to the DR events called. Specifically the section addresses the overall system performance, an evaluation of Day Ahead and Real Time events, and vehicle participation. In addition, this section provides additional detail regarding the issues that impacted system performance and the resolutions to these issues.

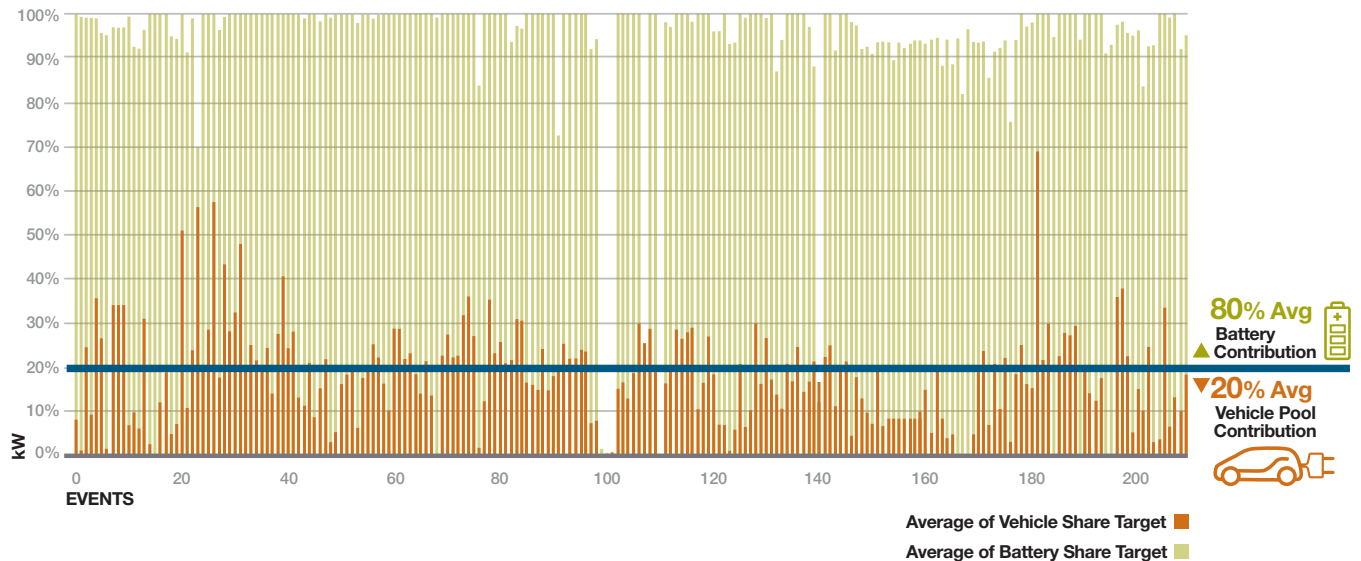
System Performance

In total, BMW has participated in 209 Demand Response (DR) events. As stated in Section 1, BMW was required to provide capacity of 100 kW over an hour-long period.³ BMW met the performance requirements for 90% (189) of the events with an average delivered contribution of 20% for the vehicle pool and 80% from the 2nd life battery system.⁴ A successful event is defined as BMW reaching 90% (90 kW) of the target (100 kW) load reduction.

The graph below describes at what percentage of the target (100 kW per event) was attributed to the vehicle and battery share.⁵

FIGURE 12 Vehicle Performance from Target (100 kW)

The vehicle pool contributed an average of 20% of the target kW reduction.



Real Time and Day Ahead Events

Between July 2015 and the end of December 2016, the BMW resource reliably provided grid services for both Day Ahead and Real Time events. The results indicated that there was no significant difference in the vehicle and battery contribution percentage between Real Time and Day Ahead.

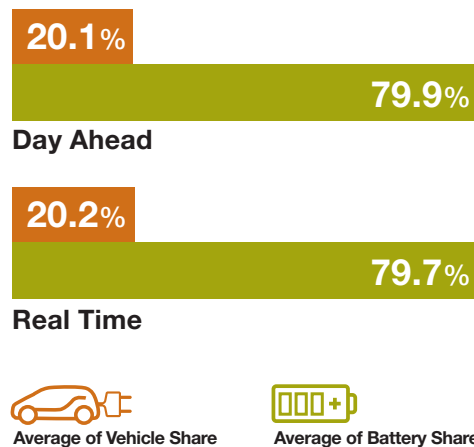
Across all DR events (Both Real Time and Day Ahead), the vehicle pool of customer owned BMW i3 vehicles has contributed, on average, approximately 18% while the BMW Group 2nd life battery system has contributed 77% of the targeted DR resource.⁶ While the vehicle share has varied throughout the pilot, the majority of events have been between 15 and 35% of the total DR resource. Each vehicle has a maximum capacity of 6.6 kW per charge⁷; results from the pilot indicate a lower average vehicle capacity

per event. On average, the per vehicle capacity during an event was 4.43 kW.⁸ The lower capacity observed (compared to the maximum capacity) is a result of a portion of vehicles that either end or start a charging event during an hour-long DR event.

During the summer when demand response programs are utilized frequently, customers often feel the burden of repeated events in a row. This can place a burden on customers to perform and often result in less successful events (lower curtailment), poor customer satisfaction, and increase dropout rates. Unlike typical demand response programs, the BMW i ChargeForward Pilot had significantly more events at a much higher frequency. For context, PG&E's SmartRate residential demand response program caps the number of events at 15 per year whereas the BMW i ChargeForward pilot had over 200 events across an 18 month period.

FIGURE 13 Day Ahead and Real Time Delivered Contribution Comparison

The vehicle pool contributed to an average of 20% of the total resource for both Day Ahead and Real Time events respectively



⁶Percentages come from the targeted amount (100 kW per event) and is slightly less than the percent from the total delivered kW.
⁷Based on the maximum capacity of the BMW i3 on-board charger.
⁸Average vehicle capacity was calculated by averaging the kW reduction attributed to each vehicle that participated throughout the program's duration.

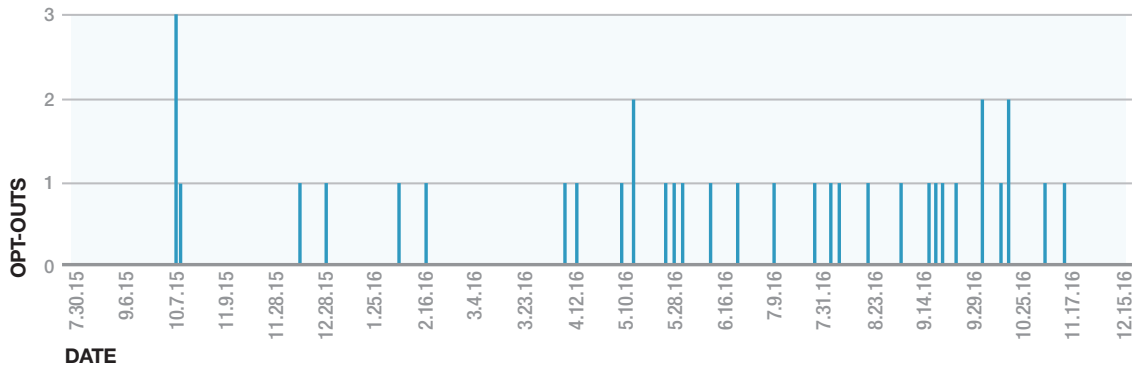
Throughout the pilot, PG&E called an average of three to four events per week. BMW was able to reliably and successfully respond to these events over 90% of the time. This indicated that both the vehicles and the battery had a consistent response time and were able to meet the contribution multiple days in a row. Since this program was designed to run primarily in the background of participants' lives they were able to participate at higher rates and felt little to no customer fatigue.

This is further evidenced by reviewing the customer opt-out rate. Each customer had the ability to opt out of each event at any time. However, the overall rate was low throughout the pilot. The most opt outs for one event was on the October 14, 2015 11 PM event with three customers opting out. The majority of events had no opt-outs.

The low opt out rate suggests that customers were not negatively impacted by the program and didn't feel customer fatigue from consecutive events. Further, only two participants opted out for more than two events over the 18 months. Based on surveys of BMW i ChargeForward participants, most participants never felt the need to opt out. Of the participants surveyed, 95% noted that they never, or very seldom, had to change their driving or charging behavior as a result of participating in the BMW i ChargeForward program.

FIGURE 14 Number of Opt Outs per Event

Opt out rates were very low for BMW i ChargeForward in comparison to the number of participants per event, only 6% of participants opted-out of an event.



Vehicle Participation

As noted in *Section 3: Charging Behavior Analysis*, the number of vehicles participating in an event is correlated to the participant’s residential rate. In the BMW i ChargeForward group about 60% of the participants are on a Time-of-Use (TOU) rate that provides an economic incentive to charge off-peak between the hours of 11:00 PM and 7:00 AM.

The top 10% of vehicles with the highest number of event participation share similar driver characteristics. They are characterized as frequent drivers, who have regular charging patterns and are not on a TOU rate. These drivers habitually plug in and begin charging around 8 PM in the evening and typically charge for about 3 hours. Since a majority of the events were called from 8–9 PM, these vehicles were frequently called upon and able to participate.

The highest number of BMW i3s participating at one time was 29. On average, 7 vehicles participated in a given event with the majority of events having between 5 and 11 of all pilot vehicles participating. The number of vehicles per event was strongly correlated to the charging behavior and residential rate structure of the customer as mentioned in Figure 8.

FIGURE 15 Vehicles Participating per Demand Response Event

Demand Response Events per Vehicle. The figure below displays the distribution of vehicles participating in events throughout the pilot. The bars represent the number of vehicles participating in events. For example, in 27 events five vehicles participated. The average number of vehicles participating in an event was seven. However, five events had over 20 vehicles participating.

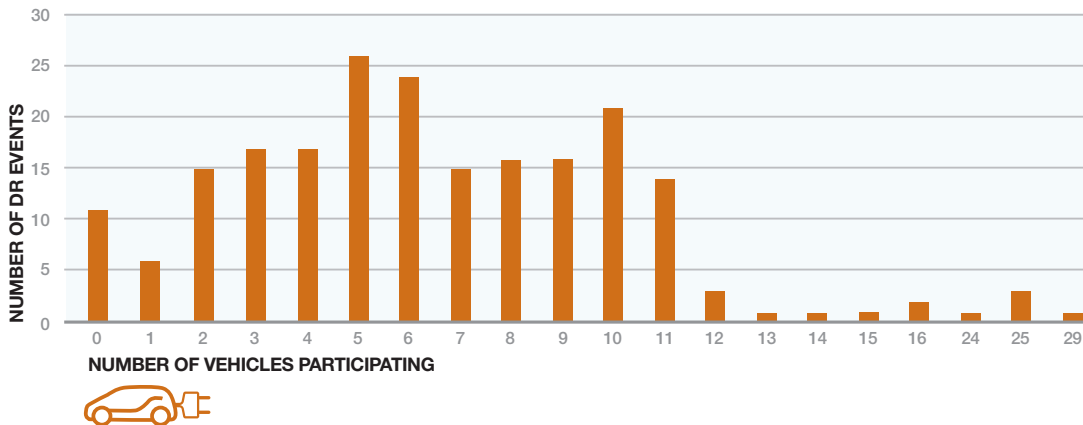
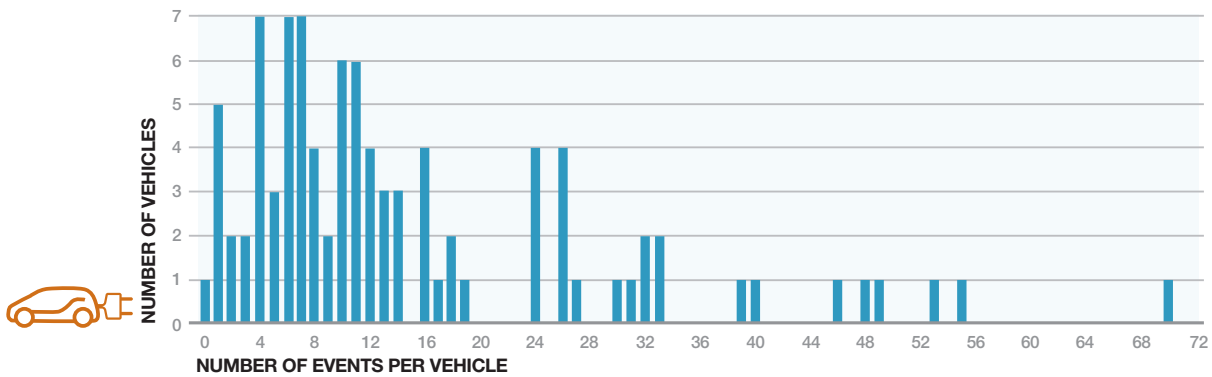




FIGURE 16 Demand Response Events per Vehicle

The figure below displays the distribution of event participation per vehicle. The bars represent the number of events in which each vehicle participated. For example, four vehicles participated in 24 events. On average vehicles participated in eight events across the pilot. However, three vehicles participated in over 50 events.





Program Issues and Solutions

Backend software updates were deployed during the first 30 events to improve the system response. However, there have been events where the vehicle pool combined with the 2nd life battery or the overall system failed to meet the required load curtailment. Problems occurred in various areas in the technical chain of command in the system, which was spread among different servers at different providers (Olivine, BMW Munich, BMW of N.A., and BMW Technology Office in Mountain View, CA). For each problem, the root cause was identified by the affected project partners, and a systematic solution was targeted to prevent the specific error from occurring again. This strategy improved the overall system stability.

⁹The server that transmits OpenADR signals to end devices or other intermediate servers, in this case the intermediate server is BMW's backend automated aggregation server.

¹⁰The server that accepts the OpenADR signal, in this case the server is BMW's backend automated aggregation server.

¹¹The communication between the OpenADR Server and OpenADR Client noting that the OpenADR client has received the OpenADR signal.

¹²Database and system that verifies the amount of load reduction from BMW, confirms that event requirements have been met and calculates payments for modeled grid services.

An overview of different problems which occurred is given in the following table.

DR performance Issue	Resolution
OpenADR server ⁹ taken down during a maintenance cycle—a DR event was not communicated to the OpenADR client. ¹⁰	Once back online, the OpenADR server again was able to communicate DR events.
OpenADR client did not pick up the DR event creating a timeout issue in the OpenADR handshake. ¹¹ The server took longer to respond to a request than the OpenADR client was waiting.	Increased the timeout values at the OpenADR client to allow the OpenADR server to provide longer processing times.
EV Pool Control failed as a result of a server maintenance cycle.	The server was restarted and automated restart-mechanism was implemented.
Stationary 2nd Life Battery Storage System was not operational during a DR event—control program was not working correctly. Battery did not power to the grid during an event.	Restarted the battery control program and implemented automated restart mechanism.
Whisker Labs power measurement of single participant's charging stations did not work properly. The power value was stuck at a static value, which did not reflect the true charging power. This inflated the amount of capacity available from the vehicle pool, resulting in a lower overall system contribution.	Temporarily excluded malfunctioning meter from the system. Meter was repaired and re-connected to the system.
Communication errors in sending power measurement data from the battery control system (of the stationary battery) to the Olivine settlement database. ¹² This caused the DR event to be flagged as failed even though the battery did dispatch the correct amount.	Manually reformatted and fed-in reliable historical raw power data into the Olivine systems.
Battery cell replacement took longer than expected. Battery did not power to the grid during an event. While attempting to loop-in a repaired battery pack in the second live battery the battery control loop was non-functional.	The issue was resolved by revising, repairing and adapting the configuration in the battery system components (site controller).

The overall technical architecture has proven to be viable with minimal issues. With each new issue, the project team was able to identify and correct the problem so it did not become a reoccurring issue. All challenges encountered have been of local nature or have been related to a specific communication link. It is important to emphasize that no overarching problem occurred that would fundamentally question the integrity and design of the overall program architecture.

5

Overview of Customer Behavior Research



PG&E and BMW executed a series of surveys and focus groups from February 2016 to December 2016 in order to gain a deeper understanding of pilot participant charging behavior and charging flexibilities. This research specifically sought to better understand participants motivation for participating in the pilot, perceptions and experiences with the program, understanding participant profiles, preferences for future managed charging programs (both reducing and increasing charging), and the general comfort and trust associated with allowing their charging to be managed by a third party. This section describes the research methods, objectives and results.

Objectives and Methodologies

The BMW i ChargeForward team partnered with Ipsos RDA to conduct an approximately year-long research study looking into the needs and motivators of EV drivers. The research component was broken into two phases, BMW i ChargeForward program research and managed charging program research.

The objective of the first phase was to explore the primary motivators for participating in the BMW i ChargeForward Program, and participants' perceptions and experience with the program and the launch process. A total of four focus groups (two in-person and two-online utilizing webcams) were conducted among BMW i ChargeForward participants.¹³ In addition, an online survey distributed to the BMW i ChargeForward participants.¹⁴

The objective of the second phase was to understand an EV driver's general comfort and trust in a managed charging program concept, that includes a third party controlling charging by either reducing or increasing charging based on grid conditions. In addition, this research also explored what tactics would drive confidence and potential engagement in this program, the thresholds for allowing a third party to manage customers' battery charge, and how other factors impact customer confidence. Two online focus groups were conducted among BMW i ChargeForward participants.¹⁵ In addition an online survey was sent to BMW i ChargeForward pilot participants as well as EV owners from PG&E's Customer Voice Panel Members.¹⁶

¹³The two Customer Research In-person focus groups had 7 participants and 8 participants. The two Customer Research online focus groups had 4 participants and 5 participants.

¹⁴The survey was completed by 63 participants. At the time of the survey, 94 participants were enrolled resulting in a 67% response rate.

¹⁵The first Managed Charging focus group had 7 participants, all of whom used their BMW i3 to commute to work. The second Managed Charging focus group had 6 participants, 4 of whom were retired and 2 commuted to work by other means of transportation.

¹⁶PG&E's Customer Voice Panel is comprised of PG&E customers that have agreed to participate in online surveys. No incentive was offered to these customers for taking the survey described in this report. Of the 1,054 plug-in EV Owners in the panel, a total of 332 surveys were completed—resulting in a 32% response rate. Of the 94 BMW i ChargeForward participants, a total of 67 surveys were completed—resulting in a 71% response rate.

BMW i ChargeForward Program Research

In the first portion of the customer research, PG&E and BMW explored the primary motivators for participating in the BMW i ChargeForward program and the participants' perceptions and experience in the program. This research took place in February and April of 2016, about half way through the 18 month program.

Motivation to Enroll and Participate

As previously stated, PG&E and BMW conducted four focus groups with participants to obtain qualitative customer feedback. During the focus groups, most pilot participants identified the incentive as a key motivation for participating (primary or secondary motivator). Most participants also wanted to assist BMW and PG&E in researching sustainability and transportation, promoting grid stabilization, reuse of EV batteries, and input for the next generation electric vehicles.

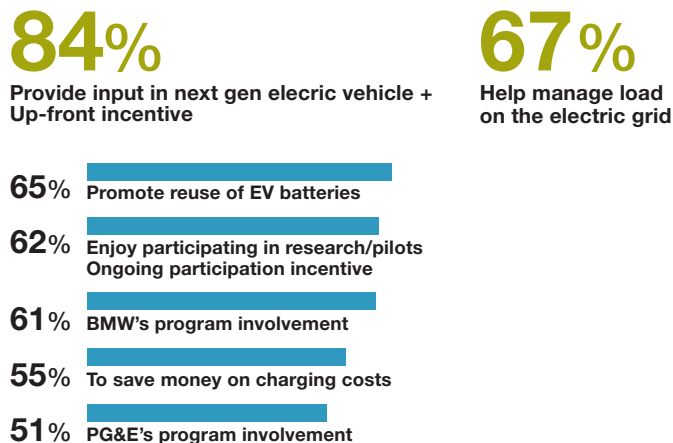
Results from the quantitative survey support the findings in the focus groups but also suggest that the incentive ranks as one of the most important factors for enrolling in the program. The most frequently reported reasons for deciding to participate in the program are to provide input in the next generation electric vehicle and the up-front incentive (84% of participants stated that these two reasons were somewhat/extremely important for both). See Figure 17 for the complete responses to the motivating factors to participate in the pilot.

Importance of Incentives

As part of this pilot, customers receive an upfront incentive of \$1,000 and an ongoing incentive for each day they do not opt-out (whether an event was called or not), up to \$540 that is distributed after the pilot has ended. It is clear from the survey results that the incentive was a significant factor in participation in the pilot. The majority of participants (84%) identified the up-front

FIGURE 17 Motivation to Enroll and Participate in the BMW i ChargeForward

Reasons for Participating in the BMW i ChargeForward Pilot: % of participants who rated "somewhat (4)" or "extremely (5)" important to the following questions, "Using a five-point scale, please indicate how important each of the following items were in regards to your decision to participate in the BMW i ChargeForward program." (n = 69)



incentive was more important compared to the ongoing incentive (62%). It is interesting to note that participants indicated that helping to manage load on the electrical grid and promoting the reuse of BMW Group 2nd life batteries as more important than the ongoing incentive.

Participants were also surveyed to understand the effectiveness of future incentives in motivating participants to join a program like the BMW i ChargeForward pilot. Up-front incentives and reduction in energy bills were the most preferred methods, with 89% of participants rating these methods as extremely effective and somewhat effective. Ongoing incentives were also a popular choice with 84% of respondents stating this was an effective method. Not having an incentive or offering a donation to charity would have negatively impacted participation in the program, with only 19% and 23% of customers indicating these were effective strategies for participation, respectively.

Perception of Participation and Communication

Overall satisfaction was high among participants surveyed. Nearly all, 92% participants describe their participation in the program as 'passive', in which the program runs in the background of their daily routine and does not affect them in any significant way.

Results from the focus groups and online survey suggest customer communication may be improved. Although about two-thirds (68%) of participants are satisfied (Somewhat/Extremely) with the communication they are receiving, based on verbatim comments, it appears that most participants would desire more frequent communication about the programs impacts.¹⁷ The survey indicates that the majority of customers want to hear more about the energy saved and how the program is performing relative to its goals and prefer to receive this information in a monthly email.

¹⁷As part of the pilot, participants received a quarterly newsletter detailing program performance and activity.

Customer Satisfaction

Overall satisfaction with the program was very high, at the end of the program 98% indicated they were satisfied with the BMW i ChargeForward program (a 4 or 5 rating on a 5 point scale); this is up from 92% at the first survey in February 2016. Participants were also very likely to participate in another delayed charging program in the future, with 93% indicating this interest. In terms of advocacy for the program, 98% would likely recommend the program to family/friends compared to 86% during the February 2016 survey.

Among all the items related to participating in the program, nearly all respondents (94%) were satisfied (Somewhat/Extremely) with the up-front incentive and the process of how they were invited to participate. While satisfaction is lowest for workshops introducing the details of the program, very few (7%) were dissatisfied (Somewhat Dissatisfied/Not at All Satisfied) with the

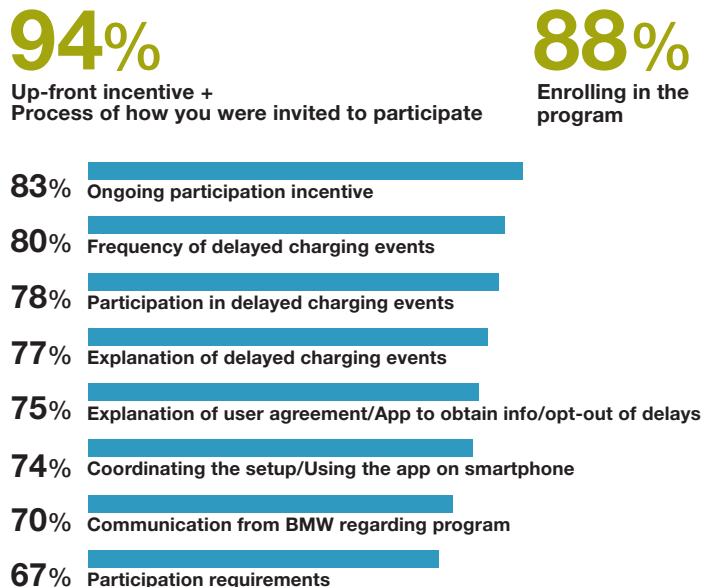
workshops. Participants like the nonintrusive nature of the program and that their driving needs were always met. Overall, participants would like more communication from BMW and PG&E regarding the program's objectives and if their participation is helping BMW and PG&E meet those objectives.

Managed Charging Program Research

The main objective for this phase of the research was to understand the different driving and charging habits of the BMW i ChargeForward participants and what requirements or preferences they have for a future managed charging program, including both reducing and increasing charging. Research was conducted by doing two online focus groups with the BMW i ChargeForward participants and two surveys, one to BMW i ChargeForward Participants and the other to a customer voice panel of EV owners in PG&E's service territory.

FIGURE 18 Levels of Satisfaction with Elements of the BMW i ChargeForward Program

Level of satisfaction with elements of the BMW i ChargeForward program: Percent of pilot participants who rated "somewhat (4)" or "extremely (5)" satisfied to the following question "Using a five point scale, please indicate your level of satisfaction with each of the following items related to the BMW i ChargeForward program." (n=69)



Charging Behavior

Two qualitative online focus groups were conducted among the BMW i ChargeForward participants. The first focus group consisted of all commuters who used the BMW i3 as their primary vehicle to and from work. The second focus group consisted of retirees and household drivers or those who commute to work by other means of transportation. Participants who use their BMW i3s to commute to work have vastly different opinions regarding their charging behavior than those who do not.

The utilization of the BMW i3 varied from weekday to weekend. During the week, most participants with full-time jobs primarily use their BMW i3 vehicles to commute to work, and some of these participants also run various errands throughout the week after work. Unless workplace charging is reliable and available this makes daytime charging hard to accomplish. There are BMW i3 owners who are retired or use another form of transportation for their work commute and use their BMW i3s sparingly during the week—primarily for errands close to their homes. They have a greater ability and willingness to charge during the day as they

have more flexibility in their schedule or their vehicle is at home during the day. On weekends, the BMW i3 is typically used to run errands, go on trips into the city, or explore other areas around the greater Bay Area.

Range-anxiety, or the feeling of not having enough range to be able to meet your destination, generally exists among those who do not have a range-extender—especially among those who drive their BMW i3s to work. Range-anxiety is one of the primary reasons participants want to ensure they receive a full charge at night. This lowers the stress around not being able to make their commute or run errands when they have a full battery. While those with range extenders may have less range anxiety, they generally plan their trips and charging schedule to avoid using the gas option of the extender.

Almost all BMW i3 owners charge their vehicle every night at their home. Charging away from the home varies widely. Some participants charge daily at work, others charge periodically when running around town, and some never charge anywhere but at their home. Participants like to leave the house in the morning with the freedom and comfort that comes with a full charge.

Charging Away from Home and Barriers to Daytime Charging

While workplace charging stations may be provided, participants indicated that charging at work is increasingly becoming more difficult. The most frequent barrier to daytime charging, and charging away from home, is the availability of charging stations, cost of charging stations, and vehicles parked at a charging station but no longer charging. As mentioned above in *Section 3: Analysis of Charging Behavior and Driver Archetypes*, 81% of BMW i ChargeForward participants work full time but only 37% charge at both home and work. On average 85% of charging is done at home with occasional charging away from home when it is convenient or necessary.

Those who regularly drive the BMW i3 to work feel charging during the day is quite tedious—mostly due to the lack of charging stations and charging ethics, such as moving your car once it has finished charging. Participants prefer to charge at night, regardless of the amount of charge left in their battery. Participants indicated that charging at home during the night is more convenient and their preferred option.

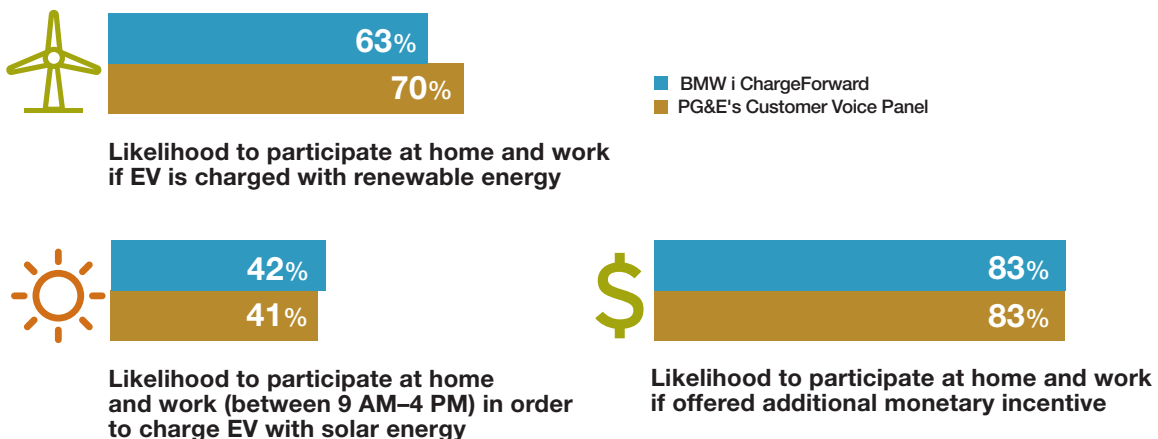
The participants would be more likely to charge during the day if charging stations were reliable and readily available, but also feel there will be less of a need to charge during the day as the range of EV batteries increases.

Comfort and Trust in Managed Charging

Participants are very interested in managed charging and have a high degree of confidence in both PG&E and BMW to effectively manage the charging of their electric vehicles. Despite high interest in the program and confidence in PG&E and BMW, participants still want to retain some control of their EV charging. Specifically, participants want to have the ability to opt-out of events and knowledge of the exact times and length for events. Overall, participants rated the ability to set an exact time their EV needs to be at a desired charge level as one of the most important program feature.

FIGURE 19 Influence of Renewable Energy on Managed Charging Participation

The figure displays how renewable energy impacts participation in a potential managed charging program. Participants indicate a strong interest in charging with renewable energy, but require an incentive to charge during the middle of the day.



Thresholds and Flexibility for Managed Charging

Among four potential program features tested, participants rank the ability to set a time their car would need to be at the desired charge level as most important, as participants want assurance their EVs will be sufficiently charged for their commute. An additional important feature is the ability to set a minimum level of battery charge before managed charging would begin, as participants want assurance they will not be stranded away from their homes. Participants are more likely to participate in a program if they know the exact times and length of the upcoming delayed charging events.

Participants want to retain flexibility and control through the ability to opt-out of managed charging events as they see fit. For PG&E's Customer Voice panelists, they felt that approximately 40 opt-outs are reasonable before having an incentive negatively impacted.¹⁸ This relatively high number could be attributed to a lack of familiarity and confidence in the program since they have not participated in a similar program before. BMW i ChargeForward participants are much more lenient with the

number of opt-outs. They feel about 20 opt-outs are reasonable. These participants are familiar and confident with the program design due to their participation in the BMW i ChargeForward program. If the number of opt-outs is limited to 5 times in a 12-month period at home and work, about half (52%) of the PG&E Customer Voice panelists would be less likely to participate while far fewer (17%) BMW i ChargeForward participants would be deterred by this number of acceptable opt-outs.

When presented with the option of charging EVs with renewable energy (solar or wind), roughly two-thirds (68%) are more likely to participate in a managed charging program. This number drops significantly to less than half (41%) when participants are told they will need to adjust their charging to the core daytime hours (9:00 AM to 4:00 PM) to take advantage of solar energy. However, the presence of an additional monetary incentive significantly increases the likelihood of participating from 41% to 83%. Thus, there is clearly a high interest in charging with renewable energy provided the participants receive an additional monetary incentive for changing their charging behavior.

¹⁸Important to note that PG&E's Customer Voice panelists were not participants of the BMW i ChargeForward pilot thus do not have previous experience with a managed charging program.

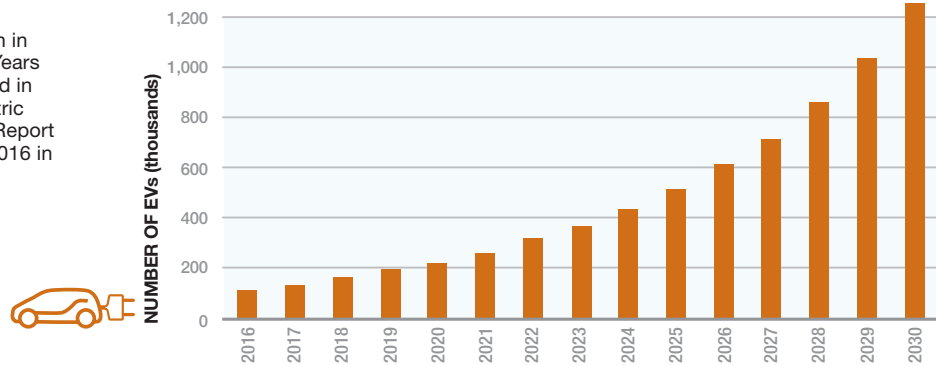
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EV Adoption and its Potential for Further Grid Support



FIGURE 20 Forecasted EV Adoptions in PG&E's Service Territory

PG&E's 2016 Expected Forecast for EV adoption in PG&E service territory. Years 2017-2023 were included in the 2016 Joint IOU Electric Vehicle Load Research Report filed on December 30, 2016 in CPUC R. 13-11-007.



Over the next 15 years electric vehicle adoption is projected to rise dramatically as vehicle price drops, range increases, and a wider range of models becomes available. By 2020 almost every major vehicle manufacturer is expected to have a long-range electric vehicle on the market. However, consumers do not have to wait until 2020 as manufacturers are beginning to release these vehicles now. At the end of 2016 the first long-range battery electric vehicle with a competitive, mass market price point and 238 mile range was released.

As EV adoption grows, the potential for EVs as a grid resource becomes more significant. Throughout the course of this pilot, an average of 7 out of 92 customers participated in each event representing approximately 8% of the total vehicle pool. On average, the vehicle contribution per event is 4.43 kW. The average contribution is attributed to vehicles that join the event after the start, unplug during the event or are near the end of their charge cycle. While this may seem like a small contribution, it is important to recognize

the potential if this pilot were to scale to a larger vehicle population. Aggregating EVs en masse creates the potential for a large demand response resource.

The BMW i ChargeForward pilot provides some insight into the magnitude of the future load reduction of this population. The table below outlines this potential by assuming and enrollment of 20% of customers with similar behavior of BMW i ChargeForward participants (8% participation rate and a contribution of 4.4 kW per vehicle). Based on these assumptions, the potential load drop of a single event in 2030 is about 77.6 MW, which is enough to power approximately 58,000 homes in California.²³ Thus, on a larger scale, a similar program has the potential to provide a significant resource.

FIGURE 21 Forecasted Electric Vehicles in PG&E's Service Territory

By 2020 EV adoption is expected to increase from about 100,000 vehicles in 2016 to over 200,000, and by 2030 PG&E is forecasting over 1.2 million electric vehicles within their service territory.

Year	Total Vehicles ¹⁹	Projected Enrollment ²⁰	Customers Participating in an Event ²¹	Load Drop (MW) ²²
2020	226,000	45,200	3,164	14.0 MW
2025	513,000	102,600	7,182	31.8 MW
2030	1,251,000	250,200	17,514	77.6 MW

¹⁹Forecasted Total number of Electric Vehicles in PG&E's service territory

²⁰Predicted Enrollment: 20% of the forecasted EV's in PG&E's service territory for the specified year. An average was taken since the actual enrollment in a program is unknown.

²¹Customers Participating: The average number of participants in a given event assuming that 8% of customers participate in each event.

²²Load Drop (kW): The approximate load drop per event based on the number of customers participating in the event and the average contributed load drop (4.43 kW) per vehicle per event.

²³Glossary of Energy Terms. California Commission—www.energy.ca.gov/glossary/ISO_GLOSSARY.PDF

Analysis of Vehicle Plug Time

In 2013, the California Independent System Operator published research on a significant change in energy balance across California. This research coined the term, the Duck Curve (Figure 22), in which the net energy load drops significantly throughout the day as a result of significant solar energy production and then ramps up sharply later in the day as solar production drops.²⁴

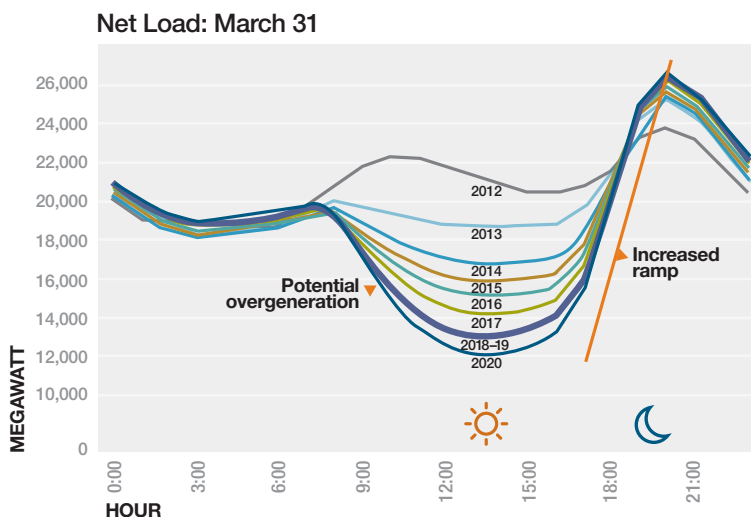
While the research predicted the “Duck Curve”, it has now become a reality. In fact in 2015 the lowest mid-day net load reached 2017 predicted values at 14,335 megawatts.²⁵ The concern with the changing grid conditions is that the sharp decrease in net energy load during the day coupled with a rapid increase in the evening will result in challenging grid reliability. As a result of the change in grid conditions, flexible resources that are able to utilize the excess generation during the day and aid in curbing the steep ramp towards the end of the day are becoming increasingly important.

As discussed above, electric vehicle adoption is projected to have substantial growth. This growth could provide a flexible resource if it can be called upon during the day to absorb the excess solar generation and reduce the ramp in the evening. While the BMW i ChargeForward pilot did not test the ability to absorb excess generation, PG&E and BMW did evaluate participants plug times analyzing when a customer is connected to a charging station. Results of this analysis suggest a high propensity to plug in at home (during evening hours), regardless of whether the vehicle began charging immediately or not. Phase 2 of BMW ChargeForward will test the ability to absorb excess solar generation as noted below in Section 7.

As displayed in Figure 23 (on page 41), it is clear that there are a low percentage of vehicles charging during the weekend, however, there are a much higher percentage of customers that are plugged in. When we compare the data on vehicles connected at home and those that are at home but not charging, we see an increased potential to leverage these vehicles charge during the day.

FIGURE 22 California ISO Duck Curve

Electric vehicles present one possible solution to help thin out California's increasing duck curve.



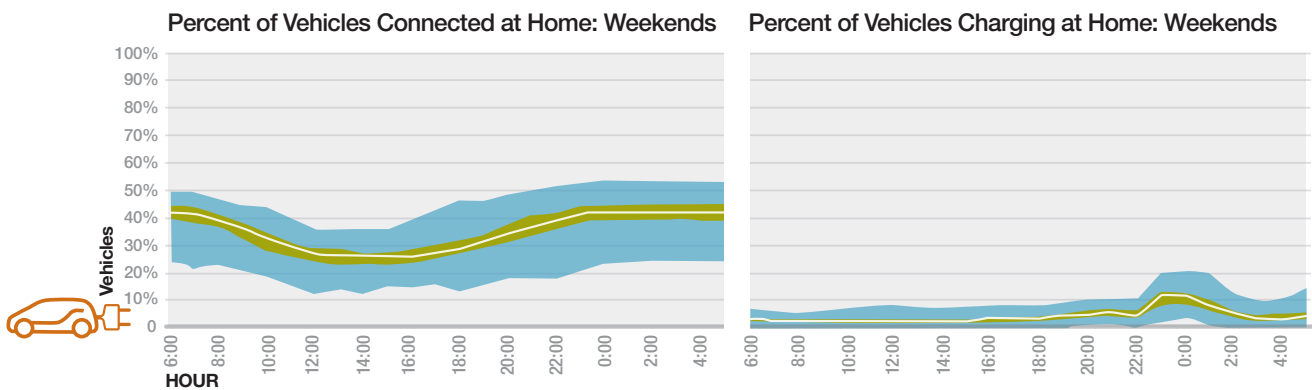
²⁴California ISO, Flexible Resource Fast Facts. www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

²⁵St. John, Jeff. (2016, November) *The California Duck Curve Is Real, and Bigger Than Expected*. GreenTechMedia

While there is limited load consumption from BMW i ChargeForward participants during the day, results from the customer research suggest that there is an opportunity to harness electric vehicle charging at the workplace. The vast majority (81%) of participants surveyed work full time and a slightly smaller number (79%) use their BMW i3 to commute. The majority (79%) of these participants also indicated that the BMW i3 was their primary vehicle with over half (62%) indicating they charge once a day. These survey results suggest there is a significant opportunity to leverage EV charging at the workplace. However, it is important that these customers have access to charging at their place of employment and that programs are available to leverage this increasingly valuable load. While the majority of participants commute to work, less than half of the respondents (41%) have access to charging at their workplace.

FIGURE 23 Weekend Percent of Vehicles Connected vs. Charging

The two graphs display the comparison between the percentage of vehicles charging and the percentage of vehicles plugged in but not charging.



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BMW ChargeForward Phase 2



BMW and PG&E will collaborate to build on the learnings described in this study through the implementation of a second phase of the BMW ChargeForward project. The second phase of the pilot will explore two primary themes—testing advanced smart charging use cases that promise additional value to the grid; and evaluating customer engagement strategies that incentivize drivers to provide additional flexibility in their charging behavior. With the support of a California Energy Commission grant, BMW will work with PG&E to explore how charging can be moved throughout the day and across the geographic areas that a vehicle travels within. In 2017 and 2018, BMW will work with a vehicle pool of over 250 vehicles, now including BMW iPerformance PHEVs as well as BMW i3 and BMW i8 vehicles, to explore the grid benefits of increasing charging flexibility as well as customer engagement in advanced charge management.


Near-term and long-term advances in electric vehicle technology necessitate taking a new, broader view when managing vehicle charging. Vehicle battery size is increasing, which will reduce the need for vehicles to charge every night for most vehicles. The average commuter, driving 30–40 miles per day, may no longer find it necessary to charge every day or even every other day. With this range, drivers may be able to charge only two or three times per week to fully meet their mobility needs. While current policies have tried to address ‘range anxiety,’ new policies will need to be in place to capture the grid opportunity of ‘range freedom.’ The higher range vehicles increase the flexibility in charging vehicles, which can be better adapted to meet the grid’s needs. The average vehicle is parked for most of the day and night, which provides numerous opportunities to move charging so to avoid charging during hours when the grid is strained or power is expensive, and increase charging when it is advantageous to do so. At the same time, this greater range could also reduce the predictability of electric vehicle load.

To explore the value of this increased flexibility, BMW and Olivine—with support from PG&E—will test new ways to shift charging across both time and locations that respond to functionalities that will be needed to address new challenges that the grid will face in the future. For example, the growth of renewable generation is expected to create more dynamic conditions on the grid, that require more options for grid operators to match load to unpredictable renewable generation. Figure 24 (on page 45) shows the hourly aggregated load curve for the entire vehicle pool and three load requirements that will be required to enable grid management under ‘duck curve’ conditions:




Nighttime charging can be more beneficial if the ‘timer peak’ is eliminated and charging is allowed to follow nighttime wind production.

10,000 vehicles all following timers at midnight would mean that 77 MW of power would be instantly added to the grid. If this load is concentrated in urban areas, it could increase the risk of grid instability. Nighttime charging has a high degree of flexibility, as the charging dramatically drops around 4 AM, hours before vehicles generally begin their morning commute.



Adding load in the afternoon can help address the growth of solar.

While the afternoon hours are currently peak hours, the steady increase in solar panels will soon require new afternoon loads to maintain grid balance. This need is likely to be localized on specific circuits. Circuits during these hours are likely to exhibit strongly different needs depending on their climate and solar adoption—those circuits with significant solar penetration will need additional load, while those circuits without solar will continue to need to reduce load.



Price signals can help to defer early-evening charging.

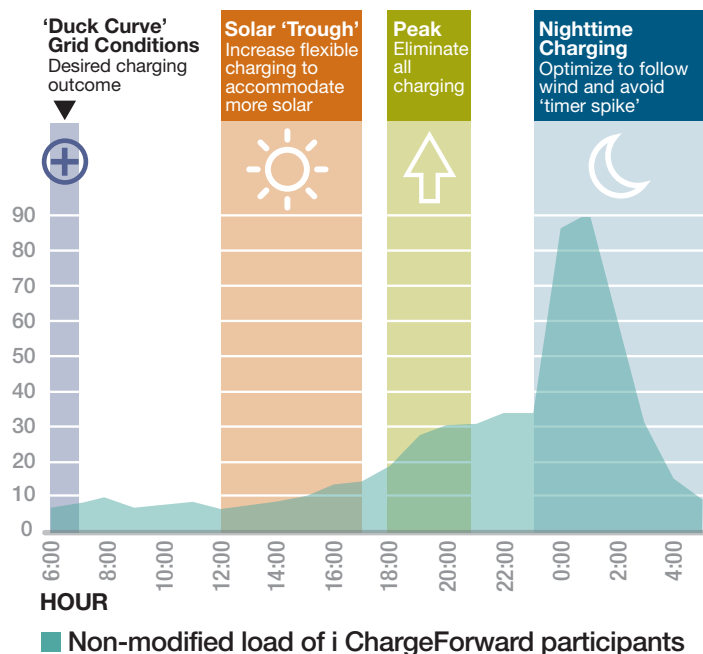
While not all EV drivers may be sensitive to TOU price signals, many are, and these signals and additional mechanisms such as “power alerts” could enhance the ability of grid operators to defer EV charging from the early evening when drivers arrive home to their homes or apartments. Charging could be deferred to late night or even to the following day(s) depending on their battery charge level and travel patterns. These programs could be localized to address distribution issues unique to specific neighborhoods and grid areas.

The second phase of BMW ChargeForward will test functionality needed to address these challenges. For example, BMW will test the ability to move load from nighttime charging to daytime charging. Doing so has the potential to address excess solar supply that may occur in the future on PG&E's grid. BMW will also test the ability of its charging control system to control charging in response to price signals that reflect dynamic generation prices or impacts on the distribution system.

In addition to testing the functional capabilities needed to provide advanced grid services, BMW will also test different ways to engage customers in ways that encourage drivers to provide more charging flexibility to the grid. BMW will explore how different types of customer engagement—including customer incentives and customer performance data—can be used to encourage customers to allow BMW greater flexibility in managing vehicle charging. BMW will also test how a renewable energy 'signal,' showing customers how much renewable energy their vehicles absorbed, can serve as an incentive to encourage smart charging.

FIGURE 24 Hourly BMW i ChargeForward Aggregated Load (total kWh) Against 2020 Estimated 'Duck Curve' Grid Needs

The hourly aggregated load curve for the entire vehicle pool and three load requirements that will be required to enable grid management under 'duck curve' conditions.



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Conclusion



The BMW i ChargeForward pilot demonstrated that vehicles can be an effective grid resource, both from a technical perspective and customer engagement perspective. BMW and PG&E have been successful in responding to over 209 demand response events over the course 18 months. Load curtailment from vehicles has been achieved with minimum disruption to customers. In our customer research, 98% of customers are satisfied in the project (a 4 or 5 rating on a 5 point scale) and 93% indicated they would participate in a similar project if available in the future.

The first Phase of the BMW i ChargeForward program halted vehicle charging when called upon for up to one hour. By creating opportunities for greater control over vehicle charging, the program would increase the benefits of smart charging. The grid can benefit from starting vehicle charging when the grid needs load, a condition the grid will experience more frequently in the future as renewables increase. This would allow vehicles to support the grid during system overgeneration events or absorb local renewable generation where local circuits might be adversely impacted.

Based on the successes in this phase of BMW i ChargeForward, BMW has been awarded a California Energy Commission grant to continue with a phase 2 of BMW i ChargeForward. As noted in Section 7, BMW will be working with PG&E to explore how charging can be moved throughout the day and leverage the work completed to date but expand the scope to identify methods to manage charging across the geographic areas that a vehicle travels within. In 2017 and 2018, BMW will work with a vehicle pool of over 250 BMW i and BMW iPerformance vehicles to explore the grid benefits of increasing charging flexibility as well as customer engagement in advanced charge management.

Appendix

FIGURE 25 Examples of Demand Response Event, Vehicle Pool

The figure displays the performance of the vehicle pool (Residential BMW i3) customers during a demand response event on 10/21/2015 from 8:00–9:00 PM. The colored bands indicate individual vehicles charging. The orange column indicates the demand response event duration when charging was delayed for each customer charging at that time.

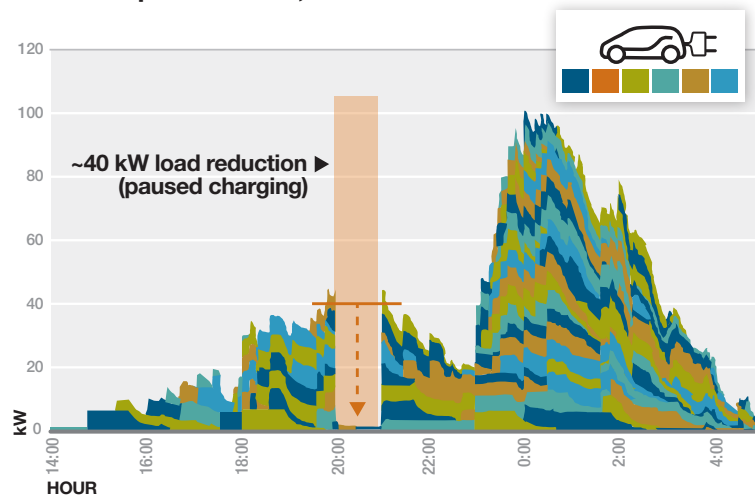


FIGURE 26 Example of Demand Response Event, BMW Group 2nd Life Battery System

The figure displays the performance of the microgrid at the BMW Group technology Office USA (including the battery 2nd life system) during a demand response event on 10/21/2015 from 8:00–9:00 PM. The orange band indicates the demand response event duration when power was exported to meet the 100 kW required obligation.

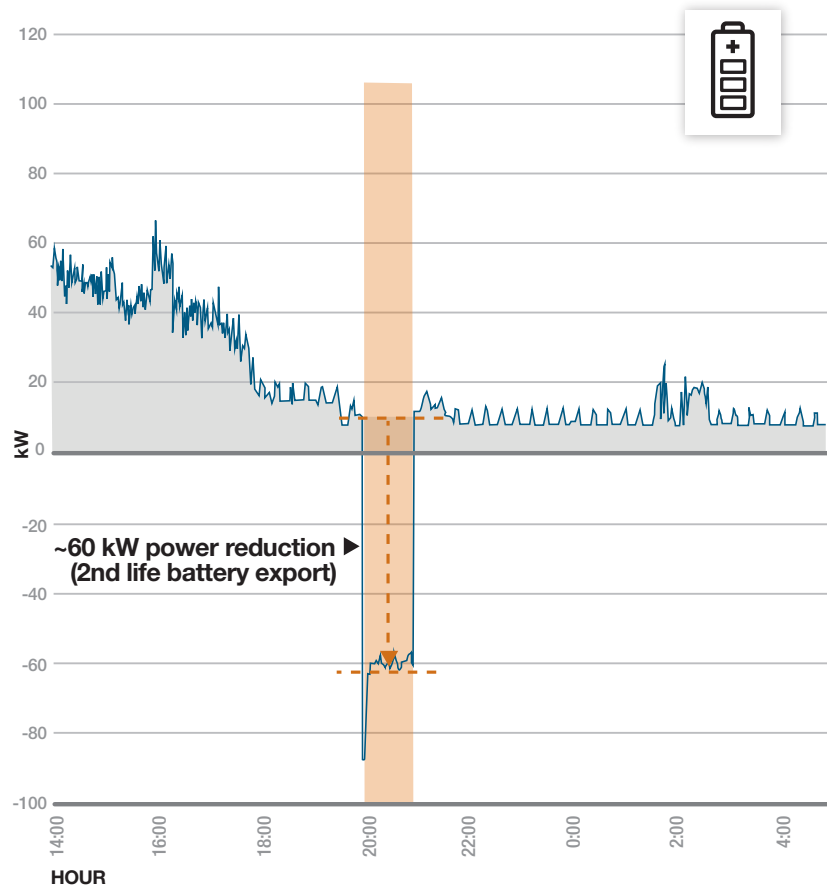
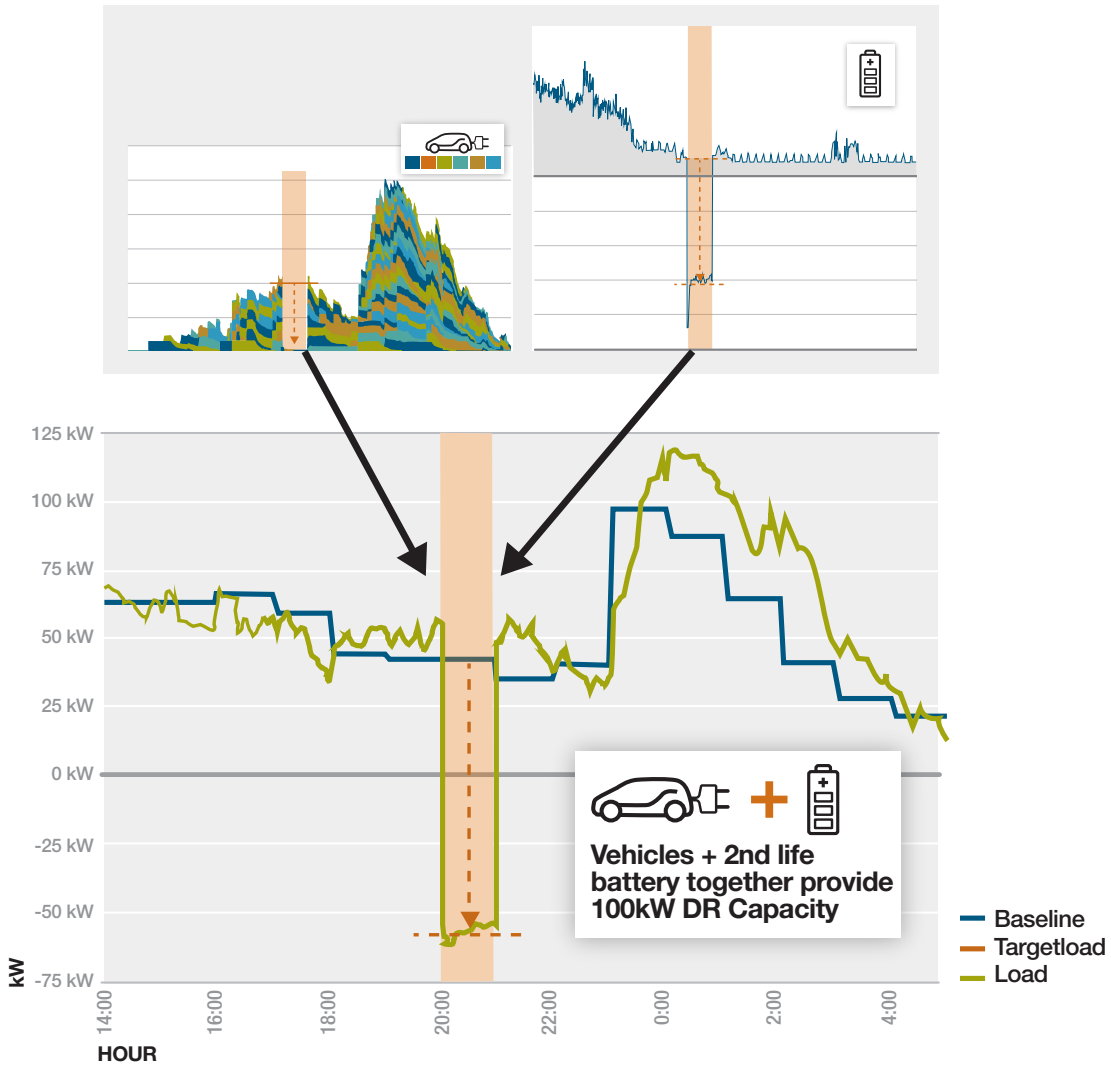


FIGURE 27 Example of Demand Response Event, Combined System

The figure below displays the performance of the combined system including the microgrid at the BMW Group Technology Office USA (top right) as well as the vehicle pool (top left) during a demand response event on 10/21/2015 from 8:00–9:00 PM. The chart at the bottom of the figure represents the aggregated resource along with the baseline (blue line) computed using the 10-in-10 baseline methodology. The orange band indicates the demand response event duration.



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