Bring Your Own Charger® (BYOC) Final Report

PON-ENE- 2017-001

December 15, 2019

Project Overview

Introduction

This document summarizes the results and impacts of Sagewell's *Bring Your Own Charger®* (BYOC) electric vehicle peak load shifting pilot program that was conducted in Massachusetts from March 2018 through September 2019. The purpose of the program was to test an innovative electric vehicle (EV) peak load shifting program that does not use any load control hardware to achieve the peak reduction results. The program goal was to enroll at least 250 EVs into the study and demonstrate that the approach would be able to achieve higher enrollment, higher peak load reduction and lower cost than hardware-based load control technologies. The program outcomes exceeded the goals by a significant margin by demonstrating 95% off-peak charging compliance, an average 50% EV enrollment rate, and by demonstrating that the program could operate at approximately half the cost of hardware-based load control alternatives. This report shows that Sagewell's Bring Your Own Charger® (BYOC) program has demonstrated that it is a cost-effective and highly scalable method to reduce electric vehicle peak load in the Commonwealth and nationwide.

For this study, Sagewell partnered with four municipal electric utilities to enroll EV drivers in their territories into the Bring Your Own Charger® program. These utility partners are located in Metropolitan Boston area, but the lessons learned are applicable to municipal and investor owned utilities alike. In the ISO-NE region, the combined annual transmission and capacity costs were approximately $200/kW-year during the study. This means that during the study period, an EV charging on-peak at 10 kW would have cost the utility $2,000 annually in combined monthly transmission and annual system capacity costs. These costs, if not mitigated through load shifting, are passed on to all utility customers.

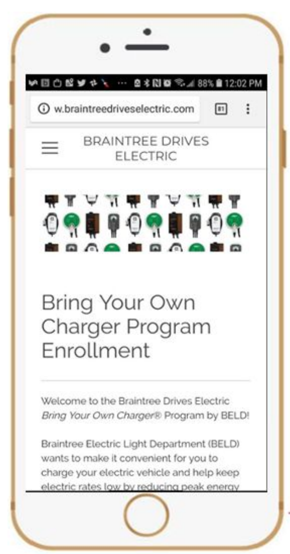
With a goal of 300,000 EVs on the road in Massachusetts in just five years (by 2025), reducing transmission and capacity costs is important for utilities and their customers. However, with fewer than 20,000 EVs in the state today, increasing EV adoption is just as crucial. The BYOC program demonstrated that it was an effective and viral electric vehicle marketing tool for the utilities. The program's $8/mo participant incentive was marketed as a benefit that provided "up to 2,000 'free' miles of driving a year" for a typical program participant (who paid approximately 15 cents per kWh for their electricity). The popularity of the marketing message was highlighted in one of the pilot towns (Wellesley) where approximately 25% of the known EVs signed up for the BYOC program in the first month. In addition, over 80% of known EV owners enrolled into the BYOC program in one community (Braintree), and across all our programs, the participation rate was approximately 50%. These are industry-leading engagement rates for an EV load management program. BYOC was able to overcome the most difficult challenge in EV load reduction, which is to ensure that large enough share of EV owners enroll into a load management program.

Theory of Impact

The two primary barriers to successful EV peak load reduction have been the high cost of hardware-based load control programs (which typically exceed the savings generated from peak reduction) and the difficulty of installing enough load-control hardware. This has effectively capped the maximum EV peak load reduction at 20% of the total EV load.However, most EV load management programs have only reaching single digit percentages of EVs in their utility territories. Sagewell sought to demonstrate in this study that the BYOC program can address both the cost and scale concerns because BYOC does not require any load control hardware and can, at a low cost, enroll large portion of electric vehicles into the program very quickly. In addition, the BYOC pilot sought to demonstrate that BYOC could also be highly effective even in areas that do not yet have AMI meters.

Lowering Barriers

Bring Your Own Charger is designed to minimize the effort and expense associated with enrolling electric vehicles into the load management program. In traditional EV load management programs, drivers must purchase and install a particular type of utility pre-approved smart charger, get it installed, request a rebate, and complete a load management agreement that gives their utility or other organization the ability to control their charger. They then receive alerts about when peak events are likely or their charger has been controlled. Typically the enrollment process is done via an app, email, or requires printing and signing of forms, which can mean the process takes days from start to finish. In addition, EV drivers who charge using 120V outlets, those who had previously installed a non-program eligible charger, or those who charge by plugging directly into a 240V outlet (e.g. many Tesla and Nissan Leaf owners) either cannot participate in these utility programs, or must install a new smart device. This effectively means that the vast majority of current EV drivers cannot participate in these utility hardware load control-based EV peak reduction programs.



In the BYOC approach, an EV driver schedules their EV to charge during off-peak periods using their vehicle's on-board charging timer, completes a 7-minute enrollment web form, uploads a picture of their charging schedule, and signs the program participation agreement on their mobile device. In return,they are paid a monthly incentive for charging off-peak. BYOC works with any charger (smart, non-smart, level 1, level 2), and any vehicle make and model. The program also provides a how-to guide for scheduling the most popular makes and models of EVs. These factors together make the enrollment process very straightforward and easy to understand. Participants are often able to enroll the very same day they bring their vehicle home.

BYOC leverages existing whole-home AMI meter infrastructure, where available, to minimize the costs of data collection. Without the need for sub-meters, smart chargers, or other hardware devices, total program costs are significantly reduced. This can result in lower costs for the consumer, program savings for the utility, or a combination of both.

Business Model

The participating utilities partially paid for the program setup, program administration, and vehicle monitoring fees. The utilities can recoup the program costs through transmission and capacity peak reduction savings as well as additional contribution margin earned from off-peak kWh sales.

Objectives and Design Goals

The goal of this project was threefold:

1. Demonstrate a cost-effective strategy for reducing EV peak load.
    a. Result: BYOC effectively shifted EV load at a lower cost than hardware based alternatives
2. Demonstrate that BYOC can achieve very high market penetration and customer satisfaction rates
    a. Result: BYOC achieved an industry-leading penetration rate of 80% at one of the participating utilities, and over 50% overall. A comparison of EV load management programs and their results are highlighted in a 2019 report by Smart Electric Power Alliance (SEPA).[1] The BYOC program also achieved an exceptionally high customer satisfaction as demonstrated by a Net Promoter Score of 78, where a score in excess of 50 is considered excellent and anything over 70 is considered exceptional.
3. Demonstrate that even without active follow-up compliance rates are very high, which means that even without AMI data, load shifting takes place at a high rate.
    a. Result: BYOC compliance rates were high (over 90%) even when participants were not actively notified about their charging behavior.

Process and Strategy

The BYOC program has two processes that run in parallel: utility recruitment and participant enrollment and monitoring. For this study, Sagewell focused on municipally owned electric utilities for several reasons:

1. Municipal utilities have more regulatory leeway to experiment with programs without needing approval from regulators
2. Investor-owned utilities in Massachusetts essentially no AMI meters installed on residential accounts

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1 https://sepapower.org/resource/residential-electric-vehicle-time-varying-rates-that-work-attributes-that-increase-enrollment/

3. Sagewell has a long history of working with municipal utilities on energy efficiency, analytics and other programs

These factors led us to focus on municipal utilities for this study, but the BYOC approach is applicable at any utility, including investor owned and cooperative utilities. Sagewell focused on municipal utilities with: high EV penetration, residential AMI meters, or both.

For participant enrollment, our goal was to be representative of the general EV population, but at the same time, we understood the importance of enrolling a sufficient number of Teslas and other high charging rate BEVs given their disproportionately large impact on utility peak load. In addition to coordinating with the utilities, Sagewell worked closely with in-town groups and organizations whenever possible, like Wellesley's Sustainable Energy Committee (SEC),Concord's Comprehensive Sustainability and Energy Committee (CSEC), Sustainable Braintree. These groups are able to tap into and activate motivated individuals who drive EVs themselves and/or want to spread the word about the BYOC program.

Sagewell had already partnered with Braintree Electric Light Department (BELD) and Belmont Light to run EV marketing and load management programs before the launch of the DOER study. Because of this experience, we had already worked out many of think kinks and challenges in the EV owner enrollment process. For example, we transitioned from pdf forms to the web-based enrollment. Prior to using an enrollment website, many participants were spending a lot of time printing, completing by hand, and scanning their forms to submit and we were spending a significant amount of time processing enrollment forms. The web application used by the BYOC program now requires just 7 minutes on average to complete on a smartphone.

Challenges and Opportunities

Sagewell was one of the first organizations to run smart charger based EV load management programs using commercially available smart chargers on behalf of utilities starting in 2016. The following describes some of the challenges we encountered by initially using smart chargers as the load management technology and what led to the development of the Bring Your Own Charger® program - and to the subsequent discontinuation of the smart charger programs. It is worth noting that none of the challenges below relate to the actual smart chargers themselves which worked as promised. Instead, the challenges were external to the chargers.

The biggest obstacle to hardware based EV load management is cost. In most cases, the costs of running a hardware load management program are higher than the value of the reduced capacity costs. This was the case even in the high cost greater-Boston (NEMA-BOS) capacity region where the total annual capacity costs exceeded over $200/ kW-yr during the study period The program costs include:

- Charger purchase and or installation rebates paid by the utility,
- Unsubsidized portion of Charger purchase and installation costs for EV drivers,

- Network fees (which enable load control functions) paid to charger manufacturers by utilities,
- The personnel cost to monitor grid conditions and to decide when to call load control events,
- Managing load management events (e.g. monitoring that chargers did successfully reduce peak load and that EVs returned back to charging after load control event), and
- The cost of continuously contacting participants to get their chargers to be re-connected to their Wi-Fi Network

The second challenge is market share. We acquired 50 JuiceBox chargers and we offered these to EV drivers at no cost (a $599 value), but even after a year we had not given all the units away. Despite the availability of free chargers, fewer than 20% of EV drivers installed them in the partner utility territory. EV load shifting depends on getting high participation rates, and without large-scale adoption charger-based programs struggle to reach high levels of participation. In particular, Tesla and newer model Nissan Leaf drivers are less likely to buy a smart charger, as Teslas and Leafs come with a charging cable that can plug directly into a 240 volt outlet. In addition, the Tesla branded home charger is not WiFi connected and not load controllable remotely. Sagewell's research shows that Teslas are over 50% of Massachusetts EV peak load and are a key market to capture with load management that smart chargers effectively do not address. Teslas are often over 50% of EV peak load elsewhere in the U.S. as well.

We also encountered challenges with smart charger device connectivity and load management protocols. In our experience, 10-20% of smart chargers are not connected to the internet at any given time and could not be load controlled. This was despite our efforts to assist participants in getting their chargers back online. This consequently reduced the maximum smart charger peak load reduction potential by 10-20%. The primary reasons for the high disconnect rate included a changed Wi-Fi password or poor Wi-Fi connectivity where the charger was installed. Additionally, we observed that Tesla vehicles appear to not be fully compliant with the J1772 charging standard that smart chargers use, which resulted in Teslas not returning to charging after a load control event. Consequently, we had to disconnect the few Teslas with smart chargers from the smart charger load control program. This was one of the key reasons that led us to develop the BYOC program as an alternative peak load reduction program for Teslas and then later expanding it to all electric vehicles.

The BYOC program was enabled by our AMI smart meter data analytics software SageSight℠ and its load disaggregation capabilities. The BYOC program quickly surpassed the hardware load control program results and prompted us to to transition all electric vehicles into the BYOC program and end our hardware-based load control offering.

Technologies Used

Bring Your Own Charger requires no hardware to be installed by the participant. The program leverages existing EV charging timer features, utilizes advanced metering infrastructure (AMI) installed by utilities and uses Sagewell's SageSight^{SM} AMI meter data analytics software. BYOC uses whole-home AMI data to measure results and doesn't require additional sub-meters or time of use rates. The hourly (or 15-minute) interval meter data from smart meters is analyzed daily by SageSight^{SM} which looks for EV charging signatures SageSight was customized for this project to maximize the speed and accuracy of EV monitoring processes. Extensive testing and refinement of the EV analytics was required to handle the difficulties in detecting EV charging signatures apart from the rest of the residential energy use. Additionally, an EVFinder algorithm in SageSight^{SM} runs each day on the meter data and flags potential unenrolled vehicles.

Sagewell also makes use of its participant enrollment web application. This application was designed to lower the barriers to entry by allowing participants to use their smartphones without needing to download forms or email documents to complete their enrollment. Most participants are able to enroll within about 7 minutes.

Energy and Performance Data

Participation Data

The BYOC program study began in March 2018 at Braintree Municipal Light Plant (BELD). By November 2018, there were 63 known EVs in Braintree and we were able to monitor 40 of them via AMI meter data or through smart charger data.The rest either charged at a very low rate (around 1 kW at Level 1) or were unable to charge their EV using their own personal condo or apartment meter and instead used a shared electric meter, e.g. a parking garage meter. BELD had decided to allow these customers to enter the BYOC program even though their EV charging could not be monitored with certainty from the AMI meter data. We apply the same deemed savings metrics to these participants as those who live in utility territories without any AMI.

On November 1st, 2018, BYOC launched in Concord Municipal Light Plant (CMLP) territory. Within the first month, 33 Concord residents enrolled, or 15% of the total EVs in town. Because CMLP has installed AMI meters only in limited number of homes (solar, whole-home TOU, water heater, etc.), only a portion of their customers' energy use data is monitorable hourly. Of the 33 initial enrollees, 14 (about 40%) had AMI data that we could access and analyze.

By the end of April 2019, there were 143 enrolled EVs - 77 in Braintree and 143 in Concord (a 430% increase in five months). Of these 143 vehicles, 83 had AMI or smart charger data that we could use to monitor program compliance. At this point, the 83 meters exceeded the minimum sample size of 75 that was established as a program goal to measure off-peak charging compliance. In May 2019 the program was opened to customers of Norwood Light Department and Wellesley Municipal Light Plant.

We also opened enrollment to a limited number of EV owners outside of the four participating utilities, and 20 EV owners from across Massachusetts were quick to join. These participants were offered a one-time incentive for their participation, and were recruited from sustainability list-servs across the state.

In Wellesley, an impressive 66 EVs were enrolled in the first month (26% of total EVs in town). This is particularly notable because approximately 70% of Wellesley EVs are Teslas and this was a key demographic the program was interested in targeting due to their disproportionate contribution to peak load. By June, the overall BYOC program enrollment had grown to 224 EVs. Unlike the other participating utilities, Wellesley does not have AMI meters. Furthermore, only one participant in the town indicated that they had a Wi-Fi connected smart charger. This mirrored our experience with other utilities where Tesla owners have generally not purchased smart chargers. We were able to receive permission to get data access to the one smart charger for monitoring. However, among the participating utilities, Wellesley had the largest capacity cost risk due to the high Tesla penetration rate which warranted the program even if they could not monitor the individual vehicles. In addition, Wellesley has a high EV peak load concentration risk in their distribution network because EVs can cluster in certain neighborhoods and can overloaded distribution network components.

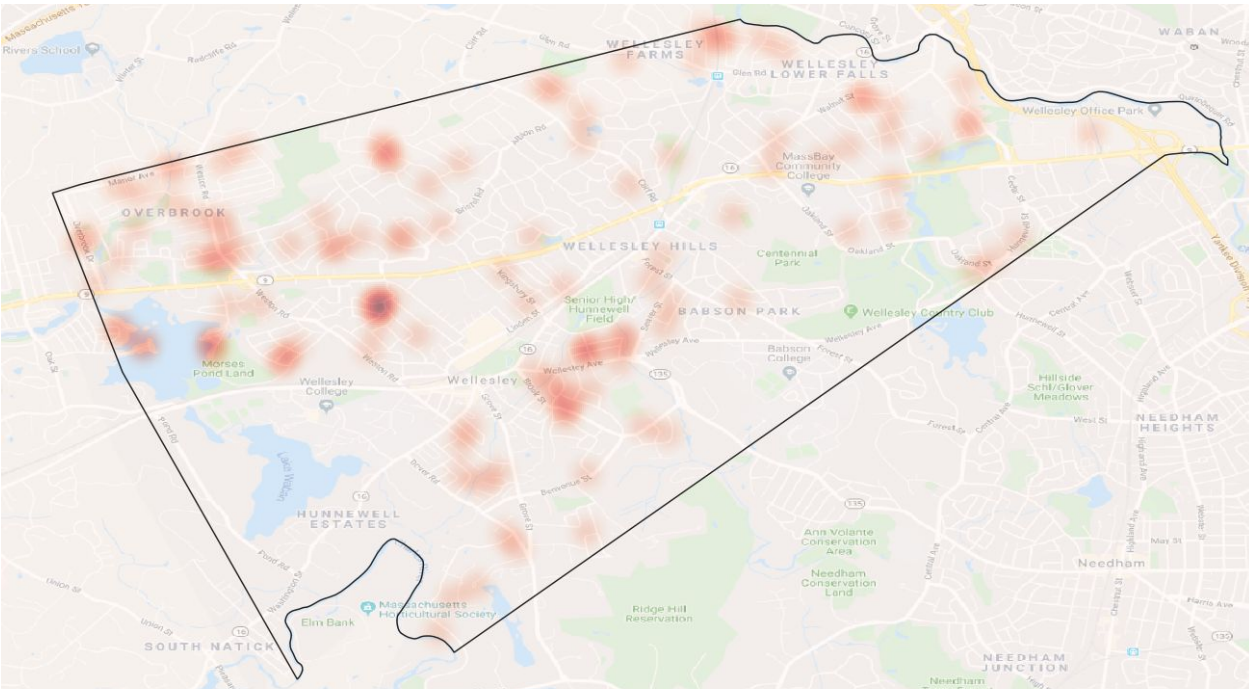

Figure 1, heat map of BYOC enrollees in Wellesley, MA

The rest of the summer saw more program growth, and by the end of September there were 330 enrolled EVs which exceeded the program goal of 250 EVs. 107 of those 250 EVs had monitorable data.

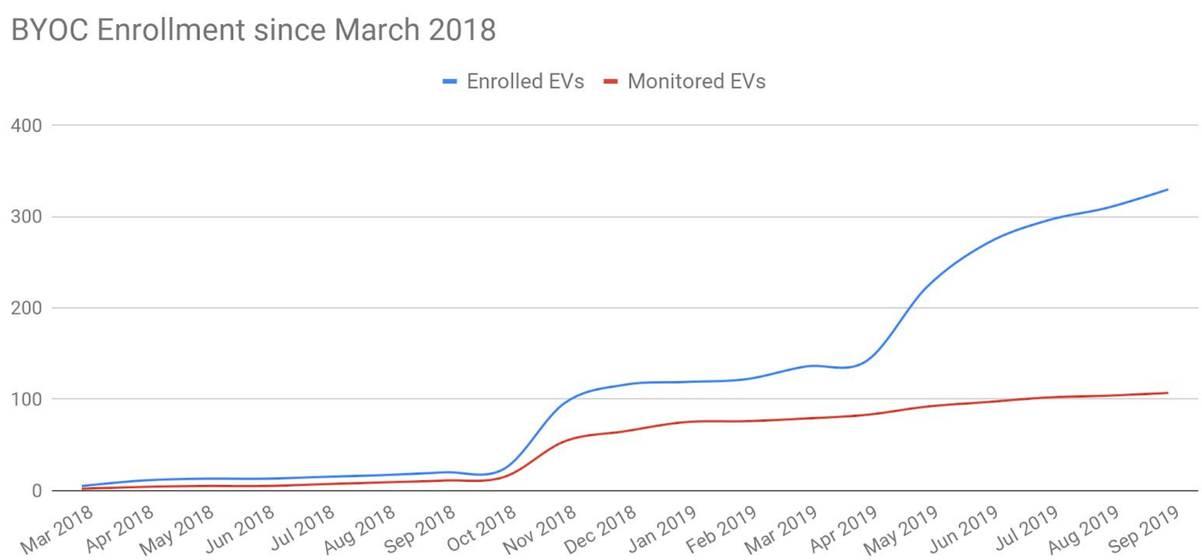

Figure 2, enrollment history

Utility	Off-Peak Charging Period	Incentive amount
BELD	9pm to 12pm, M-F	$8 per month
Concord Light	10pm to 12pm M-F	$5 per month for PHEV $10 per month for BEV
Wellesley Municipal Light	10pm to 12pm, M-F	$8 per month
Norwood Light	10pm to 12pm, M-F	$8 per month
Non-utility participants	10pm to 12pm, M-F	One-time incentive of $25, $25 bonus incentive for participants who share smart charger data

Table 1, program design, by territory

Vehicle and Charging Mix

Overall, the enrolled EVs skew towards Battery Electric Vehicles (BEVs) (73.6%) instead of Plug-in Hybrid Electric Vehicles (PHEVs) (26.4%). Through the end of 2018, the MOR-EV rebate program had issued 43% of rebates to PHEVs, meaning that BYOC has a higher adoption rate among BEVs, which are able to charge at higher rates and are more valuable for load management programs. Due to the launch of the Tesla Model 3, the BEV ratio of MOR-EV rebates had jumped to 70% for December 2018; however, the average for the year was still nearly 40% PHEVs. Statewide through 2018, 36% of vehicles that received the MOR-EV rebate were Teslas. Overall, 39% of BYOC participants had Teslas, but 68% of Wellesley BYOC participants had Teslas. BYOC is particularly valuable in utilities with higher percentages of BEVs and Teslas in particular.

Partway through the program Sagewell added a question to the enrollment form to determine charger type and level. Participants could select, “I use a level-1 (120 Volt) charger,” “I have a Wi-Fi connected charger,” or “I use another type of level-2 (240 Volt) charger.” By combining this with other participant data, we have charger type and level data for 235 participants. 17.8% of all BYOC participants charge at level-1, while 82.1% have a level-2 charger. 28.1% of all BYOC participants use a smart charger of some kind[2], though 41 of those (62% of enrolled smart chargers) are in BELD territory where Sagewell actively promoted smart chargers before the start of the BYOC program. The smart charger market share for program participants outside of BELD was 10%.

Of 158 enrolled Teslas, we have amperage settings for 135 (85% of total), and a simple calculation gives us their kW charging rate. The chart below shows the distribution of Tesla charging rates. The average is 8.1 kW, the most common charging rate is 7.7kW. For those

[2] Only 10 non-BELD smart charger owners provided valid serial numbers, the remainder were not used for compliance monitoring

Teslas that charge at level 2, the average is 9.5kW, however, over 27% of those vehicles charge at 11kW or higher.

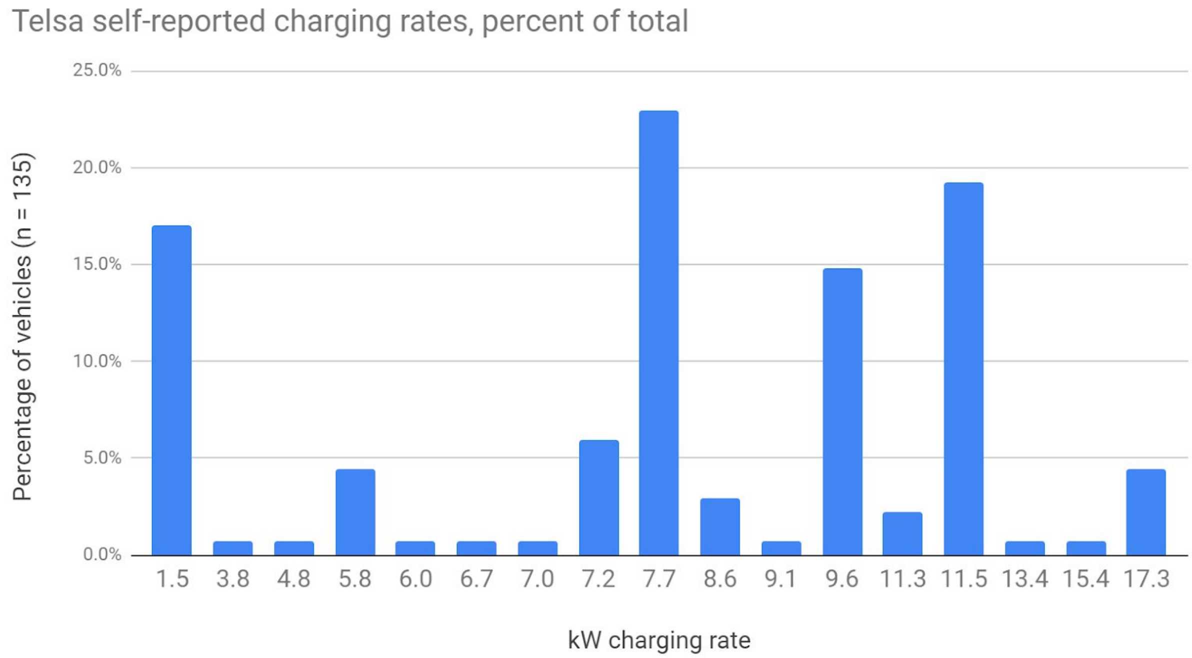

Figure 3, distribution of Tesla charging rates

The following table provides a summary of the enrolled vehicles and the maximum charging capacity that they represented, which equated to 3.2 Megawatts in October 2019. It is worth noting that Teslas represented 68% of the total potential peak load in the cohort, even though they were only 27% of the vehicles. However, going forward, 9.6 kW and greater charging capacity is becoming increasingly common which will increase the contribution of EVs to the system peak

EV	EV Type	Max kW	Concord	Wellesley	Braintree	Norwood	Non-Muni	Total EVs	Total Max kW
Audi e-tron	PHEV	9.6	0	3	0	0	0	3	28.8
BMW 530e	PHEV	3.6	0	1	0	0	0	1	3.6
BMW i3	BEV	7.4	2	3	6	1	0	12	88.8
BMW X5	PHEV	3.6	1	3	1	0	0	5	18
Chevrolet Bolt	BEV	7.2	14	7	9	0	7	37	266.4
Chevrolet Volt	PHEV	7.2	9	4	11	1	2	27	194.4
Chrysler Pacifica	PHEV	6.6	0	3	2	0	0	5	33
Fiat 500e	PHEV	6.6	1	0	0	0	0	1	6.6

Ford C-Max	PHEV	3.3	2	0	3	0	0	5	16.5
Ford Fusion	PHEV	3.3	0	1	1	1	0	3	9.9
Honda Clarity	PHEV	6.6	1	2	4	0	0	7	46.2
Honda Fit EV	BEV	6.7	1	0	0	0	0	1	6.7
Hyundai Ioniq PHEV	PHEV	3.3	0	0	0	0	0	0	0
Hyundai Sonata PHEV	PHEV	3.3	0	0	0	0	0	0	0
Hyundai Kona EV	BEV	7.2	4	2	0	0	0	6	43.2
Kia Niro EV	BEV	7.2	2	0	0	0	0	2	14.4
Kia Niro Plug-in	PHEV	3.3	1	1	0	1	0	3	9.9
Kia Soul EV	BEV	7.2	0	0	0	0	0	0	0
Mini Countryman PHEV	PHEV	3.3	0	1	0	0	0	1	3.3
Mitsubishi Outlander	PHEV	3.3	1	1	2	0	1	5	16.5
Nissan Leaf	BEV	6.6	5	3	9	0	4	21	138.6
Tesla Model 3	BEV	11.5	25	47	12	2	4	90	1035
Tesla Model S	BEV	17.2	10	28	4	3	0	45	774
Tesla Model X	BEV	17.2	2	16	4	0	1	23	395.6
Toyota Prius Plug-In	PHEV	3.3	2	0	2	0	0	4	13.2
Toyota Prius Prime	PHEV	3.3	3	6	6	0	0	15	49.5
Volkswagen e-Golf	BEV	3.6	3	0	2	0	1	6	21.6
Volvo XC60	PHEV	3.3	0	1	1	0	0	2	6.6
Total			89	133	79	9	20	330	**3240**

Table 2, vehicle breakdown

Customer Experience

Our data indicates that the average customer completes the enrollment web form in 7 minutes, and 68% finish in under 10 minutes. We recently completed a customer satisfaction survey, with a 44% response rate.

One particular customer satisfaction metric stands out from those surveys - the Net Promoter Score (NPS). NPS is used by many industries to calculate customer satisfaction. The responses are calculated on a scale of -100 to +100, the higher the scores the better. Most large utilities have scores ranging from approximately -10 to 20. A score above 60 is considered “industry leading and anything 70 is considered to be “world class.” BYOC participants in the participating municipal utility territories gave BYOC an exceptionally high net promoter score of 78. The 20 EV drivers that live outside of participating municipalities were also highly satisfied with the program but gave the program a slightly lower NPS of 54.Their satisfaction was lower primarily because they received their incentive payment at the end of their program instead in monthly bill credits. We surveyed these customers before they had received their incentive payment and would likely have had a higher NPS score if they had been surveyed after they received the payment. The customer feedback has helped us re-design the incentive payment system for those customers who cannot receive a bill credit.

Customers rated the ease of enrolling in BYOC a 4.5 out of 5. When asked why they enrolled in the program, 79% of responses mentioned the bill credit/discount, 8% mentioned being “green”or the environment, and 4% mentioned helping the grid. 96.5% of respondents indicated that their EV experience is the same or better after joining BYOC. 89% of respondents indicated that they never or very rarely override their vehicle’s charging schedule. Only one customer has chosen to leave the program, due to their desire to charge during the day.

Overall, the very high customer satisfaction results likely contribute to the “viral” sign-up rates where as many as 26% of EV owners signed up for the program in the first month that it was available.

Compliance Data

Between March 1, 2019 and September 30, 2019, the program reviewed 18,716 days of AMI data of enrolled vehicles in the program with an overall off-peak compliance rate of 95.42%. In other words, only 4.38% (857 out of 18,716) of the vehicle enrollment days saw any charging between 12pm and before the start of the off-peak period.[3] This analysis only considers weekday charging, as weekends have not had a peak day based on ISO-NE history and are therefore unlikely to be transmission or capacity peak days.

The histogram below shows the distribution of compliance rates in 103 enrolled homes[4], and gives additional insights into the behavior of participants. The program average compliance rate in Summer 2019 was 96.2%, as discussed in more detail below. However, as the chart shows, only 6.8% of participants had overall compliance rates under 80%, 56.3% were between 94% and 99.99% and 22.4% were 100% compliant for the entire time they were enrolled. 80% of participants had off-peak compliance rates of 93% or higher. While this study did not send immediate notices to the non-compliant EV owners, Sagewell’s typical BYOC program does send notices to customers if they charge during off-peak periods. In those programs, the BYOC compliance rates typically exceed 98%.

[3] The off-peak period is Monday to Friday, starting at 9 PM in Braintree, and 10 PM in all other towns.
[4] For this analysis, homes with more than one EV were counted as one.

Figure 4, Histogram of participant compliance rates

By the end of September 2019, the BYOC program had enrolled 310 residential EVs across all 4 municipal utility service territories, and 20 residential EVs from areas serviced by Investor Owned Utilities across the state. This is 32% higher than the project goal.

The overall program performance was measured using a Deemed Savings methodology that is similar to those used by energy efficiency programs such as Mass Save®. The compliance rate was calculated using data from 107 monitored EVs out of the total 330 program participants. Additionally, and importantly, for the duration of the study, we did not send on-peak charging alerts to participants that we were monitoring with the AMI data because we wanted to infer the compliance rate of those EVs that could not be monitored. During the 2019 summer[5], the off-peak charging compliance was 96.2% across the 7,921 charging weekdays monitored. Given the sample size, the methodology has 6% margin of error with 90% confidence..

[5] Defined as May 1, 2019 to August 30, 2019

	Peak Day	Peak Hour Ending	Peak Day Compliance Rate	Peak Hour Compliance Rate
May 2019	20	19	93.67%	98.75%
Jun 2019	28	18	97.80%	98.90%
Jul 2019	30	18	93.75%	**98.97%**
Aug 2019	19	16	94.90%	98.98%

Table 3, summer 2019 transmission and capacity peaks. Note: July 30 is preliminary capacity peak

Off-peak charging compliance was monitored for the entire program and it was designed to monitor if the customer charged during the peak period. We tracked detailed charging session data beyond basic compliance data from 52 vehicles for Summer 2019, including charging start time, end time, duration, estimated kWh and kW charging rate. In particular, this data collection focused on customers with AMI data who typically charge at 6kW and above.[6] Monitoring higher charging vehicles was of primary interest due to their higher contribution to peaks. Across the 123 days of data from this summer, an average of 31.1% of vehicles charged on any given day this summer (31.7% during the week, and 29.4% on weekends). However, any individual day saw between 14% and 50% of vehicles do some charging.[7] When looking specifically at on-peak hour charging, the overall compliance rate was 97.7% . This detailed data also shows that the average charging session is 3 hours in length with very little variation between weekday and weekend sessions.

Smart charger data provided additional context and largely agrees with our analysis of AMI data. Due to limitations in charger data access, only vehicles with one manufacturer's smart chargers in Braintree are included in this dataset (total of 35 devices). In total, the dataset includes 53,543 hours of charging data between March 1, 2018 and September 25, 2019, including when chargers were actively charging vehicles, as well as in a standby state. This data indicates that fully 75% of the time when a charger is connected to a vehicle, it is in a standby mode, with only 24% of the time is charging occuring.[8] Across 12,911 hours of charging, only 1% occurred during the peak period.

[6] Because this data is a subset of the overall program data, the numbers do not align fully.
[7] 80% of days saw between 23% and 41% of participants charge their vehicles
[8] The data in this analysis does not include data from when the charger was not plugged into a vehicle, was disconnected from the internet, or had some other error. The data does show that 10-20% of devices are disconnected from the internet at any given time, which makes active load management less effective.

Based on actual maximum charging rate, we divided vehicles into “over 6kW” and “under 6kW” ‘categories to compare their charging behavior. The Summer 2019 data indicates that the under 6kW group charged during off-peak hours 98.9% of the time, while 99.1% of the over 6kW charging sessions were during off-peak hours. There effectively was no difference in the off-peak charging compliance between the two groups

Load Shifting Performance

The tables below estimate the median case of kWh and kW load shifted, per vehicle for different charging rates. Because BYOC is “always on” the kW load shifted applies to any weekday. This table only includes 6.6 kW and above charging rates because the future EV models charge at 6.6 kW or higher rate.

Charging Rate	**6.6kW**	**7.7kW**	**9.6kW**	**11kW**
Chance of charging per day (average)	**32%**			
• 10th and 90th percentile	23%, 41%			
Chance of charging during peak hrs (avg)	**35.5%**			
• Values from two different estimation methods. 35.5% Avg. used above.	30%, 41%			
Probability charging on peak	**11.4%**			
Average kW impact (Probability charging on peak* Charging rate)	**0.75 kW**	**0.87 kW**	**1.09 kW**	**1.25 kW**
Upper bound kW impact	1.1 kW	1.3 kW	1.6 kW	1.8 kW
Lower bound kW impact	0.5 kW	0.5 kW	0.7 kW	0.8 kW

Table 4, load shifting calculations

Using this data, we can calculate the total load shifting for the 330 participating vehicles, in Table 5 (following page).

Charging Rate	Level 1	Level 2, < 6 kW	Level 2, > 6 kW	Total
Percent of total	18%	27%	55%	100%
Number of vehicles	59	90	181	330
Charging rate	1.2 kW	3.4 kW	8.7 kW	
Probability charging on peak		11.4%		
Expected contribution to peak without load management	8 kW	35 kW	180 kW	223 kW
Peak load reduction estimate, BYOC reduces peak by 95%	7.6 kW	33.25 kW	171 kW	212 kW

Table 5, BYOC pilot load shifting calculations

Finally, if we extrapolate the load shifting to a future statewide BYOC program, the impacts become clear. This calculation assumes by 2025 80% of vehicles charge at an average 10.5kW and the remaining 20% charge at an average of 3 kW (to include level 1 and remaining low charging rate vehicles). The blended average charging level would be 9 kW, and at 11.4% probability of coincident peak, the expected coincident peak contribution of the vehicles is 1 kW.

Total Enrollments	100,000	200,000	300,000
Weighted average peak contribution		1 kW	
Collective Impact	100 MW	200 MW	300 MW
BYOC peak reduction 95%	95 MW	190 MW	285 MW

Table 6, potential future impacts

Sagewell used two methods to calculate load shifting performance. The first method used utility smart meter data to analyze the charging behavior of vehicles that are known to have EVs but are not enrolled in any EV load management programs. The second method used data from smart chargers of BYOC program participants in Braintree because it allowed us to “time shift” the delayed charging to the time when they plugged in their vehicles each day. The analysis of future EV peak impacts should focus on vehicles that charge at a rate of 6 kW and above because nearly all new vehicles on the market today charge at that rate. The older plug-in hybrid models that charged at lower 3.6 kW Level 2 are being phased out of the market and therefore do not represent the majority of EV load today and the expected charging levels going forward. The charging levels are in fact going up with 9.6 kW to 11.5 kW increasingly being available and therefore the analysis in this section may in fact offer a conservative picture of the future EV load growth without load management.

In the first case (labeled as utility A in Figure 5 below), we estimated that 40.7% of non-load managed EV charging was occurring during peak hours. We used AMI meter data from a municipal utility in metro-Boston that was not a part of the DOER study that also has a list of known EV drivers. Using our EVFinder algorithms on utility smart meter data, we flagged charging sessions of 6kW and above between May 1, 2019 and August 30, 2019. These customers had no incentive to shift their load to off peak hours. This analysis found 19 homes[9] and 648 high-probability EV charging sessions. To match the second analysis method discussed below to make them comparable with each other, Sagewell calculated the percentage of charging sessions that matched Braintree's on-peak period (12 noon to 9pm). The non-load managed EV smart meter data indicates that 40.7% of weekday EV charging occurred on-peak. As an additional validation point, we typically see 30% to 50% of charging sessions take place during peak hours at other utilities.

The second method (labeled Utility B in Figure 5 below) estimated that 30% of EV charging takes place during peak hours. We used smart charger data from BYOC participants in Braintree to estimate the amount of peak load shifted by BYOC. Because the charger data includes the timestamp of when a customer plugs in their vehicle, we know when charging would have started without load management. To calculate this difference we timeshifted the charging load to the plug-in time to estimate what the charging sessions would have been like without BYOC. This data shows that on average, the start of the charging sessions were delayed by 3.8 hours with BYOC.

Among the 28 Braintree BYOC participants who had smart charger data, 99% of the charging occurred during the off-peak period from 9pm to 12 noon, but when the charging start times are shifted based on when customers actually plugged in, 30% of charging would have occurred during peak hours without the BYOC program. When expressed in kWh consumed, the BYOC customers used 565 kWh on-peak between March 1, 2018 and August 30, 2019. On the other hand, these same BYOC customers would have used 18,590 kWh, or 32 times as many on-peak kWh if they had not enrolled in BYOC. If we look only at the four months of the Summer of 2019 (May 1 to August 30), the BYOC customers with smart meter data charged 14,543 kWh during the off-peak period, and only 99 kWh during the peak period. The modeled non-BYOC participants would have charged 10,465 kWh during the off peak period, and 4506 kWh during the peak period.[10] This is a total on-peak reduction of 4407 kWh over the course of 4 months.

[9] There could be more than one vehicle at each home.
[10] The total kWh charged for these two groups vary slightly due to shifts in weekend versus weekday charging due to the calculations

Figure 5 shows the distribution of charging hours for the two control datasets and BYOC participants. The figure does not show charging likelihood by hour, but instead shows the share of total charging that occured at that hour. However, the graph shows how effective BYOC has been in moving charging to off-peak hours.

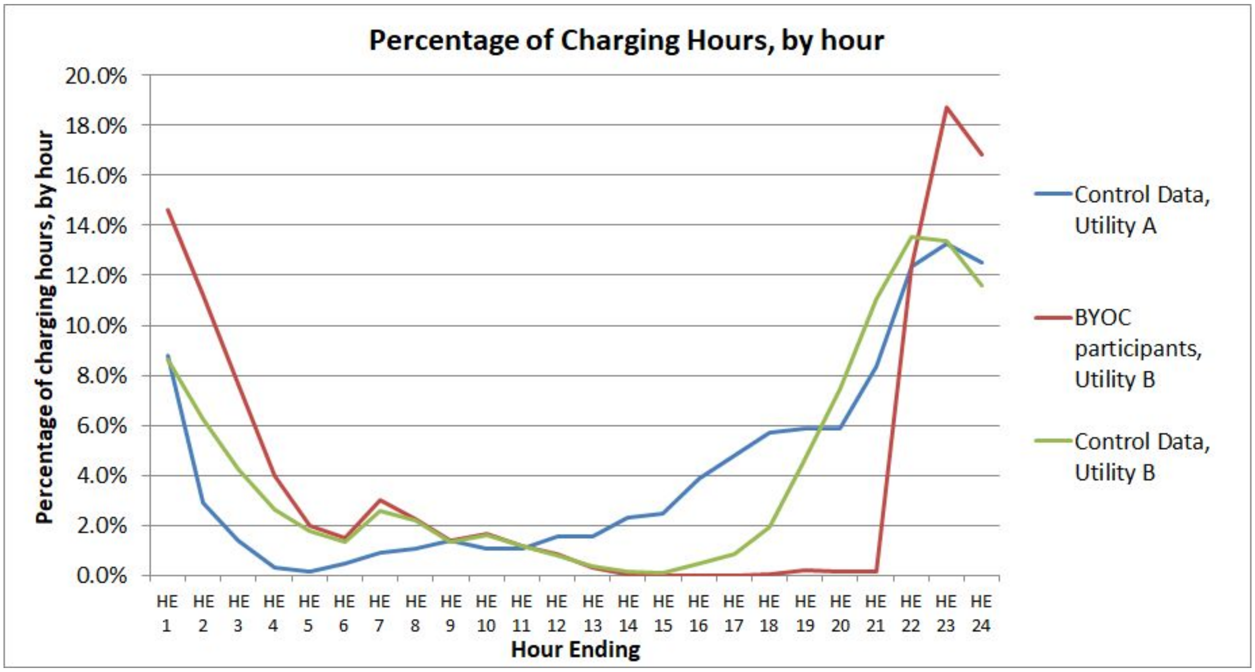

Figure 5, distribution of charging hours, BYOC participants and control groups

Non-Energy Impacts

Distribution system reliability problems and proactive mitigation
Electric vehicles may already be negatively impacting parts of the distribution network. Based on Sagewell's AMI meter data analysis, the typical summer coincident peak contribution of a home is under 2 kW. A single 11.5 kW Tesla charging during the summer coincident peak can overload a distribution transformer because the typical distribution transformer serves fewer than 10 homes, and often even fewer than that. Having two or more high-capacity EVs charging simultaneously can overheat a transformer and shorten its life, or even overwhelm it and result in a shut down, an explosion or a fire. While smart meter data analysis software such as Sagewell's SageSight^{SM} can detect these conditions and help predict transformer failures in advance, the investor owned utilities in Massachusetts do not have smart meters. Therefore, the data is not available on whether concentration of electric vehicles in the investor owned utility territory is already causing distribution network reliability problems. It is worth noting that Sagewell has observed up to 50% coincident EV charging at times. However, these events are relatively rare and because the EV penetration rates are still low, they have not yet manifested as major problems. This may be changing and Sagewell is pursuing analysis on this topic with

its utility partners to measure the grid impacts of EVs and how significant they may be in the future.

Emissions reduction

Decreasing peak charging has many benefits including decreasing air emissions from energy generation as off-peak energy production is New England tends to be associated with lower air emissions.

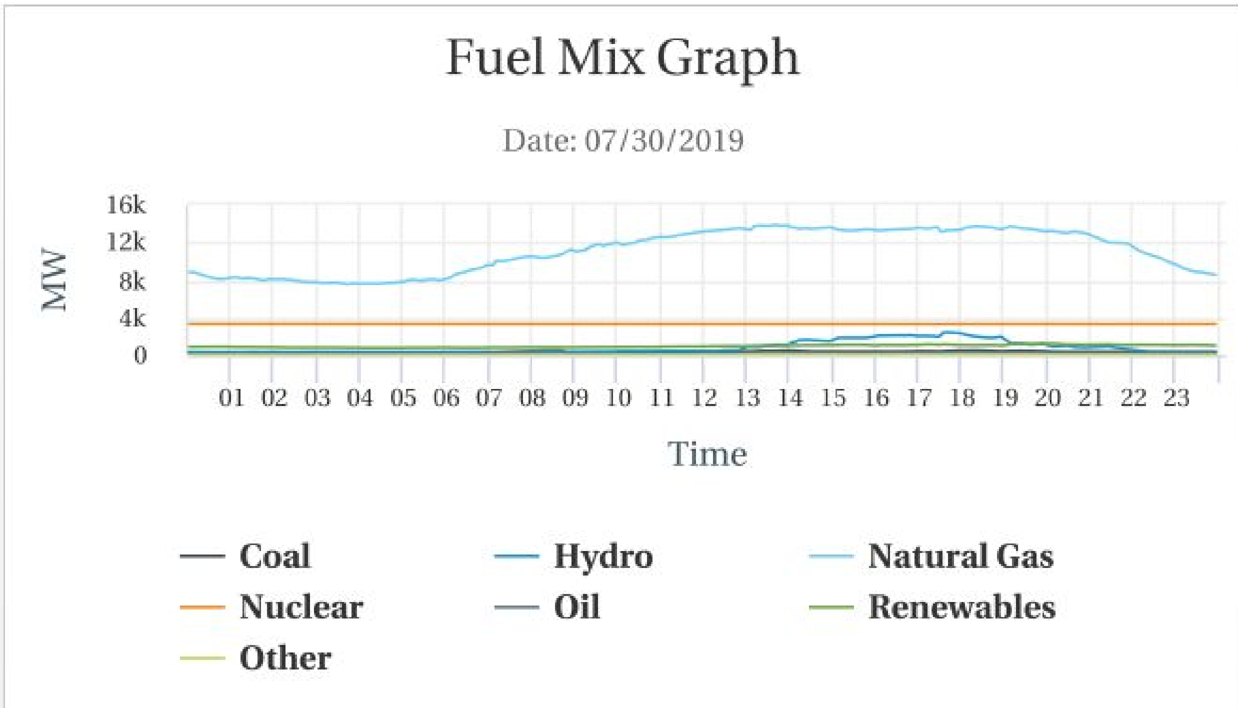

Figure 6, ISO-NE fuel mix on 2019 system peak day

Incentivizing off-peak charging may also have additional air quality impacts by increasing EV adoption which can decrease tailpipe air emissions from automotive vehicles. Power plants tend to have additional technologies to decrease air emissions than individual vehicles so increasing EV adoption can improve neighborhood air quality.

Energy procurement cost savings to utility customers

In addition to the capacity cost reductions, shifting energy use into off-peak hours reduces the energy procurement costs. The savings have been approximately 1 c/kWh, or $35 a year for an electric vehicle that consumes 3,500 hours of electricity. While this may seem small, it can be as much as 10% to 20% reduction in local marginal price (LMP) wholesale electricity costs, which is the marginal price typically paid by utilities for incremental energy use..

Budget

Sagewell and municipal partners anticipated sharing a minimum of 50.59% of the project cost and ultimately Sagewell and municipal partners shared 59.12% of the cost.

Costs	DOER	Matching Funds	Total Project Costs	Sagewell Cost Share %	Budget Period
Estimated Expenses	**$92,320**	**$93,500**	**$184,820**	**50.59%**	**3/1/18 - 10/31/19**
Actual expenses	**$91,320**	**$132,082**	**$223,402**	**59.12%**	**3/1/18 - 12/15/19**

Table 7, program budget predictions vs actual expenses

Sagewell has been able to utilize the lessons learned from the pilot and has been able to reduce its program costs further which is being reflected in its ongoing program pricing. Furthermore, Sagewell's improvements to the analytics software and operating software will now allow us to to enroll tens of thousands of EVs and do it at a significantly reduced unit cost..

Lessons Learned

Sagewell demonstrated that the BYOC approach is more effective than hardware based load control programs. Our experience with hardware programs demonstrated that 20% market penetration was a real-world limit, and 10% is likely more common. Wellesley, with its 70% Tesla market share, has a smart charger penetration rate of 0.75% among BYOC participants . Because 10-20% of hardware devices are offline at any time, and the ability to match load management events to peak events is never perfect, the peak load shifting effectiveness ranges from 80-90%. The table below multiplies the market penetration percentage by the load shifting percentages to determine the total percent of EV peak load that is shifted by BYOC and smart charger programs. It is also important to keep in mind that with multiple smart charger manufacturers on the market, a utility would need active partnerships and programs with any whose devices they'd like to control, which drives up costs and complexity of program administration.

	BYOC Program	Hardware-based programs
Market share range	50-80%	10-20%
Load shifting & effectiveness	80-95%	80-90%
Minimum effectiveness (market share * load shift %)	**40%**	**8%**
Maximum effectiveness (market share * load shift %)	**76%**	**18%**

Table 8, load shifting effectiveness

In addition, having access to smart meter data was crucial to understanding the EV charging behaviors of EV owners who did not participate in any load management programs.

Additionally, the different enrollment rates across utilities and the non-utility enrollees demonstrated that target marketing and close ties with community groups are key to high adoption rates. In Wellesley, Concord and Braintree, close ties between Sagewell, community groups, town departments and EV drivers lead to high adoption rates, while in locations with less active community members, those connections were less strong, which resulted in slower uptake.

As the data indicates, the vehicles that charge at 6kW and above are the greatest value for load management. Because nearly all future vehicles will have charging rates over 6kW, these vehicles should be seen as the base case going forward.

Project Team

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Project Schedule

Updated Milestones			
Original Date	Modified Date	Actual Date Completed	Milestone
June 8, 2018	July 31, 2018	July 13, 2018	Product offering developed and participant recruitment has begun
June 15, 2018	August 8, 2018	July 13, 2018	Evaluation Measurement & Verification plan and data plan submitted
July 6, 2018	December 31, 2018	November 5, 2018	At least 50 program participants have been signed up
August 15, 2018	June 30, 2019	May 22, 2019	At least 150 participants signed up (75% of 200 target participants). At least 40 participants can be monitored through smart meter data or through smart chargers
October 31, 2018	October 31, 2019	November 7, 2019	Evaluation, Measurement & Verification data submitted. Scalability report submitted to DOER

Table 9, project milestones

Appendices

Utility websites about the BYOC program can be found at the following links:
https://wellesleyma.gov/1339/BYOC-FAQ
https://braintree-ev.ene.org/charging-guide/rebates-and-incentives-charging/
http://www.norwoodma.gov/departments/norwood_light_and_broadband/electric_vehicle_program.php
https://concordma.gov/2274/EV-Miles-Program

The enrollment web forms can be found at:
https://www.bringyourowncharger.com/wellesley
https://www.bringyourowncharger.com/beld
https://www.bringyourowncharger.com/norwood
https://www.bringyourowncharger.com/evmiles