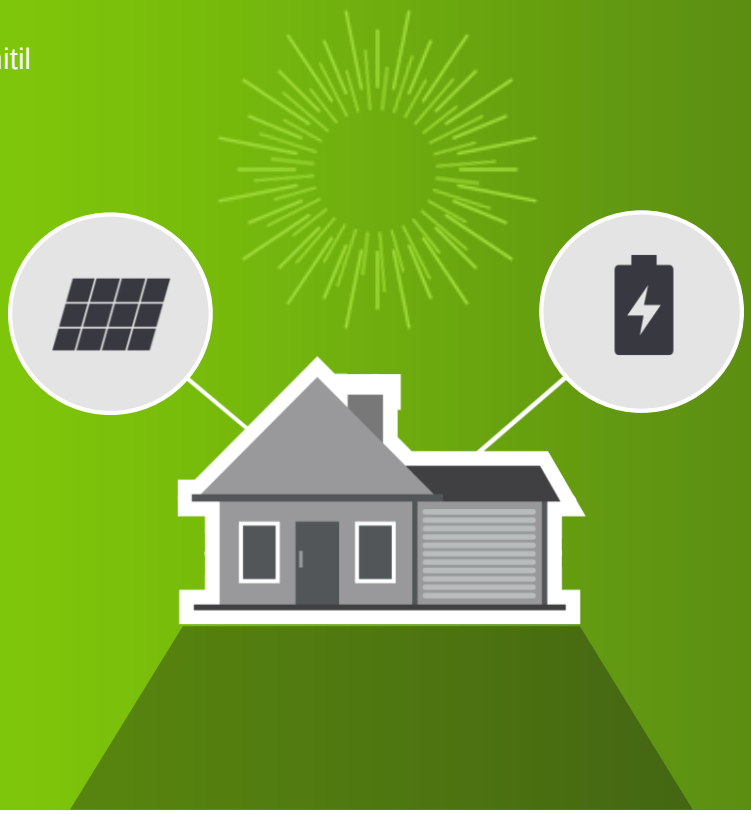
2019 RESIDENTIAL ENERGY STORAGE DEMAND RESPONSE DEMONSTRATION EVALUATION

Summer Season

Prepared for:
National Grid and Unitil



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Reference No.: 148414
February 10, 2020

STUDY OVERVIEW

Demonstration Summary

The two residential storage demonstrations evaluated in this study are part of the Program Administrators' broader active demand response initiatives.

National Grid's demonstration targets residential customers that already installed or are considering installing a battery storage system as part of a "Bring Your Own Battery" or "BYOB" demonstration. Through the months of June and August, 63 devices were added to National Grid's demonstration in Massachusetts.

Of these, data indicated that 50 participated in at least one event called during the summer season. National Grid called 27 events between July 3, 2019 and August 22, 2019. The first of these lasted 3 hours, while the remaining lasted 2 hours, and all of them occurred at some point between 3 p.m. and 7 p.m.

Unitil's demonstration paid for and installed a battery storage system for each of four participants. There is no additional participant incentive. Until called events every day from August 1 through October 31 from 1 p.m. to 5 p.m. or 3 p.m. to 7 p.m.

Evaluation Objectives

The goal of this evaluation was to assess the technical feasibility, customer acceptance, and scalability of battery storage as a resource for lowering the system peak demand (National Grid) and flattening the solar PV output curve (Unitil) for residential customers. The evaluation consisted of process and impact components.

The process component assessed participant motivation and acceptance of the piloted battery storage technology (a key to scalability) through surveys and phone interviews. The impact component assessed whether the battery storage system lowered demand during the Summer Peak Periods and measured demand and energy impacts.

Evaluation Approach

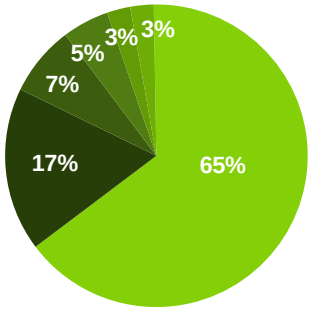
This evaluation focused on assessing customer acceptance of the piloted battery storage technology (a key to scalability), as well as whether and how much the battery storage system lowered demand during the Summer Peak Periods. The evaluation approach is summarized below:

Task / Activity	Description
Online Surveys (National Grid)	• Navigant developed, fielded, and analyzed online surveys of National Grid's participants to solicit feedback about their experience and thoughts on their participation. • Navigant obtained 41 completes out of a population of 65* for a response rate of 63%.
Phone Interviews (Unitil)	• Navigant administered phone interviews with the four Unitil participants to solicit feedback about their experience and thoughts on their participation. Navigant also interviewed Unitil's battery storage system installer.
Data Management	• Navigant and the PAs performed a data transfer test of the whole home, solar PV, and battery storage telemetry data. Navigant conducted a QA/QC review to ensure data was being collected from the limited number of participants and could be readily analyzed. • After the summer demonstration season the data was transferred to Navigant for impact analysis and QA/QC.
Telemetry Data Analysis	• The evaluation measured demand and energy impacts of the energy storage, assuming the whole-home and solar PV data as the baseline. Navigant used the whole-home, PV and battery storage telemetry data to perform this analysis.

* The survey population was the subset of devices confirmed as installed in either Massachusetts or Rhode Island that were accepted into the program prior to August 6, 2019 to ensure participants had sufficient experience with the program.

ANALYSIS FINDINGS
NATIONAL GRID

Participant Research



MOTIVATIONS FOR BATTERY STORAGE PURCHASE

- Access to battery backup
- Save money on my energy bills
- Reduce need for additional power plants
- Other
- Ability to test new technologies
- Support community/state's energy initiatives

OTHER HIGHLIGHTS

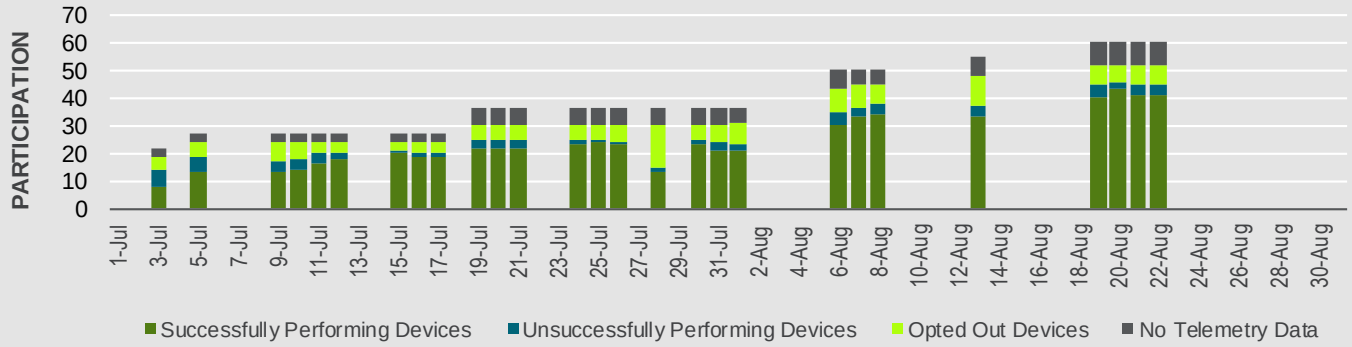
94% never **opted out** of an event

97% would **recommend** the program to other customers

97% are likely or very **likely to continue** with the program

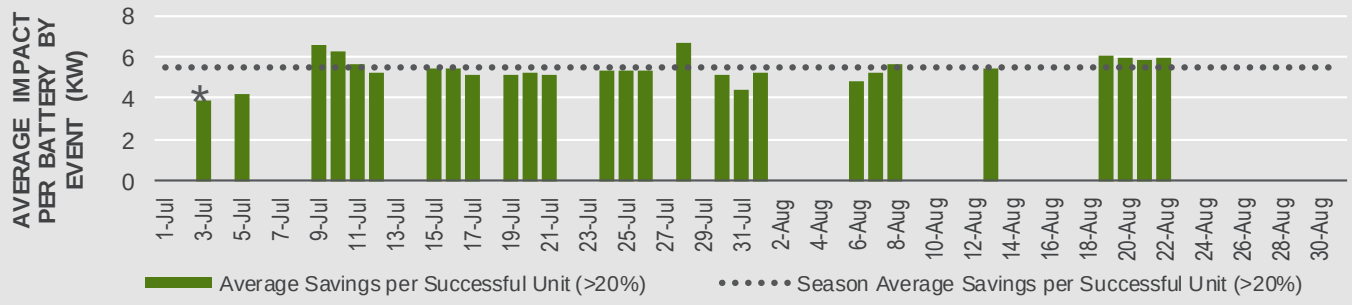
Event Participation

On average, **63%** of devices enrolled on a given event day successfully performed in the event. Of the 50 devices that participated in at least one event, **64%** successfully performed every time they participated.



Event Impacts

The program saved **139 kW** per event on average, including **126 kW** during the 2019 ISO-NE Peak Hour. Batteries that successfully participated in 2-hour events saved an average of **5.5 kW/unit**.



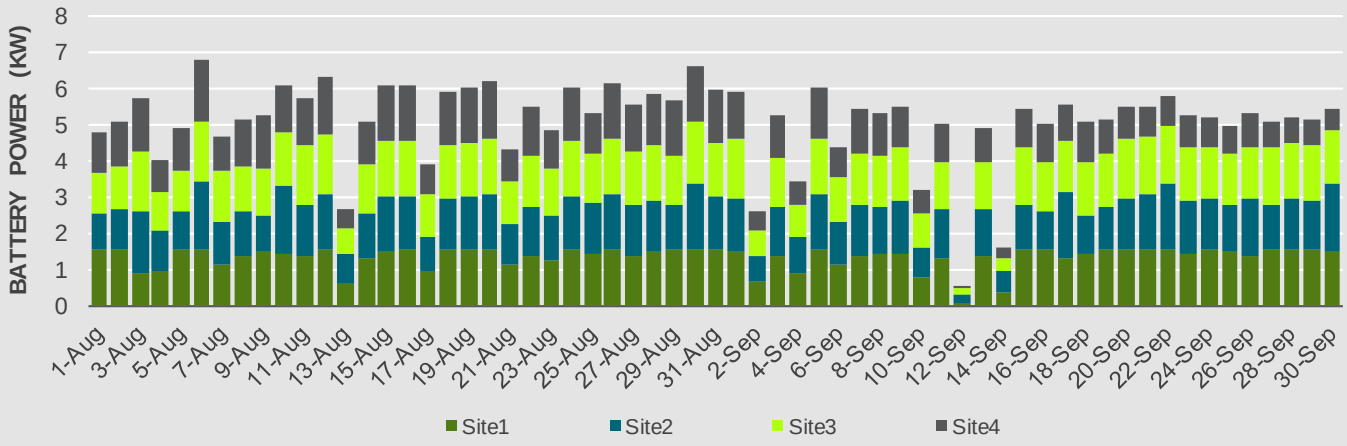
* The first event of the season on July 3rd was the only 3-hour event of the season.

IMPACT ANALYSIS FINDINGS
UNITIL

Event Performance Summary

Average Event Impacts

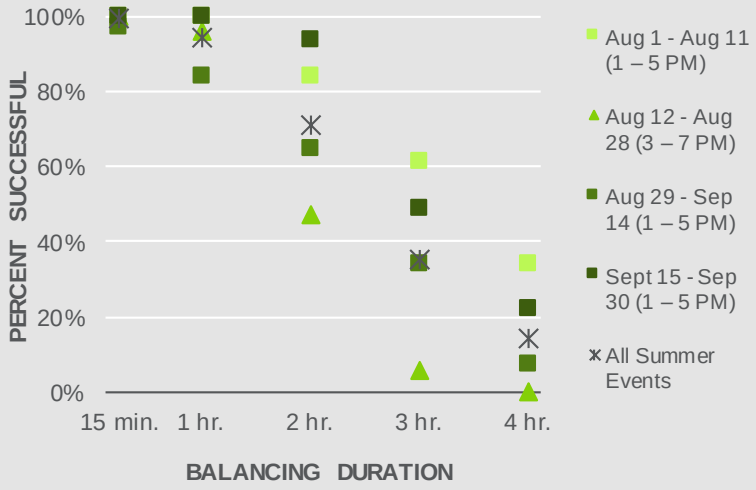
All four enrolled Unitil batteries participated in all event days. The total discharge for the four batteries averaged **5.1 kW** per event, ranging from 0.5 kW to 6.8 kW.



Impacts per Battery

The batteries averaged **1.3 kW** discharge over the four-hour event periods and there was **minimal difference** when averaging over 4 hours between the 1 p.m. to 5 p.m. events and the 3 p.m. to 7 p.m. events.

Site	1 p.m. to 5 p.m. Events	3 p.m. to 7 p.m. Events	All Events
Site 1	1.34	1.36	1.35
Site 2	1.30	1.35	1.32
Site 3	1.34	1.40	1.36
Site 4	1.02	1.29	1.10
Avg. per Battery	**1.25**	**1.35**	**1.28**
Total per Event	**5.01**	**5.41**	**5.12**



Solar PV + Battery Balancing

The success rate of Solar PV + Battery balancing was highest during 15 minute durations of an event (**99%** success). As the balancing window increased, the average success rate declined. Batteries were able to successfully balance the Solar PV + Battery output for 1-hour during **94%** of event days, while only **14%** of event days were successfully balanced for the full 4-hour event duration.

RECOMMENDATIONS AND CONSIDERATIONS

NATIONAL GRID

Research Category	Recommendations and Considerations
Participant Motivations and Lessons Learned	**Recommendation 1:** Ensure customers are aware National Grid knows backup is important to them. Two manufacturers include the existence of a battery reserve in their marketing materials, and one offers the option, but National Grid does not make this clear in the marketing materials. Create a consistent battery reserve level and publicize both the battery reserve and the restriction of events prior to storms. This will help alleviate customer concern about batteries being depleted when they are being relied upon to provide power in an emergency.
Energy Storage System Performance	**Recommendation 2:** National Grid to encourage EnergyHub to work with manufacturers and/or integrators to align all details of the telemetry data so the data fields are consistent.
	Consideration 1: Further explore the factors behind why the per event average fleet performance was 64% of the maximum expected impact, which includes underperformance of devices (especially DC coupled batteries) and opt outs. A subsequent analysis would confirm the appropriate maximum expected discharge to use for different battery makes and models after accounting for battery settings and inverter configurations, and investigate why some batteries failed to participate in some events despite being operational.
	Consideration 2: Explicitly monitor enrollment date versus operational date for devices to ensure devices that can perform in events are performing.
	Consideration 3: Monitor batteries and potentially troubleshoot batteries that are consistently not performing or routinely opting-out of events.

UNITIL

Research Category	Recommendations and Considerations
Participant Motivations and Lessons Learned	**Consideration 1:** Ensure customers are aware Unitil knows backup is important to them. A 20% battery reserve was seen in the data and observed by participants. This will help alleviate customer concern about batteries being depleted when they are being relied upon to provide power in an emergency.
	Consideration 2: Educate participants more fully about the program design upon enrollment to ensure participants understand their commitment.
	Consideration 3: Ensure internal processes and data protocols are well established and defined. This will help limit delays in enrollment and installation and help keep customer satisfaction high.
Energy Storage System Performance	**Consideration 4:** Consider different approaches to increase event success, for example, reduce the duration of events from 4 hours to 2 hours or reduce the targeted output of the combined Solar PV + Battery during events.
	Recommendation 1: Discuss with the battery manufacturer why the battery charging stopped at 1 p.m. for events that occurred from 3 p.m. to 7 p.m.
	Consideration 5: Continue the evaluation into summer 2020 to include June, July and August when solar insolation is typically stronger and any control algorithm updates have been implemented.

NAVIGANT
A Guidehouse Company

2019 Residential Energy Storage Demand Response Demonstration Evaluation – Summer Season

MA19DR02-E-Storage

Prepared for:

National Grid and Unitil

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DISCLAIMER

This report was prepared by Navigant Consulting, Inc., n/k/a Guidehouse Inc. (Navigant),[1] for National Grid and Unitil. The work presented in this report represents Navigant's professional judgment based on the information available at the time this report was prepared. Navigant is not responsible for the reader's use of, or reliance upon, the report, nor any decisions based on the report. NAVIGANT MAKES NO REPRESENTATIONS OR WARRANTIES, EXPRESSED OR IMPLIED. Readers of the report are advised that they assume all liabilities incurred by them, or third parties, as a result of their reliance on the report, or the data, information, findings and opinions contained in the report.

[1] On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently ren amed Navigant Consulting Inc. as Guidehouse Inc.

LIST OF ACRONYMS

AC	Alternating Current
BYOB	Bring Your Own Battery
DC	Direct Current
ESS	Energy Storage System
EV	Electric Vehicle
ISO-NE	Independent System Operator New England
kW	Kilowatt
kWh	Kilowatt-hour
PA	Program Administrator
PCS	Power Conversion System
PV	Photovoltaic
QA	Quality Assurance
QC	Quality Control
SOC	State of Charge
TOU	Time of Use
W	Watts
Wh	Watt-hour

1. INTRODUCTION

This evaluation report describes Navigant's assessment of the technical feasibility of using residential energy storage systems ("ESS" or "battery storage") to reduce peak demand for National Grid and to flatten the solar output curve for Unitil as part of their broader active demand response initiatives. Navigant's methodology and key findings are presented as well.

1.1 Demonstration Summary

For this demonstration, National Grid is targeting residential customers that already installed or are considering installing battery storage as part of a Bring Your Own Battery (BYOB) demonstration by providing a performance incentive. Unitil provided each participant with a battery at no cost to the participant. For a typical installed cost of around $1,600/kW, these incentives are similar assuming customers participate for the entirety of the typical 10-year life of the battery device. While not a program requirement for National Grid, most of the batteries are charged from solar PV to comply with the Federal Investment Tax Credit (ITC).[2] These devices are primarily discharged during hours specified by National Grid and Unitil. Table 1-1 summarizes key characteristics of the summer season demonstration.

Table 1-1: Residential Energy Storage DR Demonstration Summary – Summer Season[3]

Demonstration Attributes		National Grid	Unitil
Participants	**Customer Segment**	Residential	Residential
	Participating Customers, as of August 31	50[4]	4
	Battery Ownership	Participant owned (BYOB)	Participant owned (paid for and installed by Unitil)
Incentives	**Enrollment Incentive**	No enrollment incentive	Entire installed cost of energy storage system
	Participation Incentive	$225/kW in summer	No annual incentive
Summer Event Criteria	**Season**	July 1 to September 30	August 1 to October 31[5]
	Event Days	Non-holidays	Every day
	Event Window	2 p.m. to 7 p.m.	1 p.m. to 7 p.m.
	Event Dispatch Criteria	Most days	Every day
	Event Duration	Max of 3 hours	4 hours
	Battery Control Logic	Battery discharges evenly throughout event duration	Battery discharges throughout event duration based on solar output
	Battery Reserve Requirement	None or 20% (differs by manufacturer[6])	20%[7]

[2] The ITC provides a tax credit for a set percentage of the cost of installing an energy storage system if it is charged from solar PV.

[3] Demonstrations will continue through the 2019/20 winter season, which will be addressed in a subsequent evaluation report.

[4] There were 63 customers enrolled in the program in Massachusetts as of August 31, 2019.

[5] Navigant analyzed participation data through September 30, 2019.

[6] Sunrun and Tesla have a 20% reserve mentioned in program materials, sonnen offers the option to set a reserve but it is not the default, and Pika and Solar Edge do not mention a reserve in program materials.

[7] Unitil reported there was no reserve level in the program design. However, a 20% reserve is observed in the impact analysis.

1.2 Evaluation Objectives

This evaluation assessed the technical feasibility, customer acceptance, and scalability of battery storage as a resource for lowering the system peak demand and flattening the solar output curve for participating residential customers. The evaluation consisted of process and impact components. The process component assessed participant motivation and acceptance of the piloted battery storage technology (a key to scalability), while the impact component assessed whether the battery storage system lowered demand during the Summer Peak Periods. Table 1-2 lists the evaluation objectives.

Table 1-2: Evaluation Objectives

Research Category	Research Questions	Evaluation Approach
Participant Motivations and Lessons Learned	• What is the primary motivation for participants to obtain a battery and then participate in the demonstration? What value streams are most important to them (e.g., reduce need for peaking power plants, reduce environmental impact, access to battery backup, pilot new technologies, incentives, guaranteed incentives over time)? • What barriers do the participants and Unitil's battery system installer identify to the potential statewide application of energy storage to lower demand during the Summer Peak Period? • Would participants continue to allow their Program Administrator to control the battery storage system during peak periods in the future and, if so, would there be certain conditions under which they would or would not? • How does the increased operation of the battery system affect participants' bills?	Phone Interviews Online Survey Bill Impact Estimate
Energy Storage System Performance	• What percentage of days during the event did each battery storage system successfully charge and discharge? • What is the whole-home usage, solar PV output, average battery charge or discharge each hour during the Summer and Winter System Peak Period for each participant? • What is the average kilowatt output from batteries over the Summer and Winter System Peak Period for each participant? • How does solar PV output and battery system performance (e.g., percent of maximum capacity dispatched) vary by solar PV orientation—for east-facing and west-facing systems (if available)? • How does calling multiple events on consecutive days affect battery performance? Are batteries able to fully recharge between consecutive events? • How does the solar PV and energy storage inverter configuration (e.g., AC coupled vs. DC coupled) and inverter rating affect the system's performance (if available)?	Telemetry Data Analysis

Source: Navigant

2. EVALUATION METHODS

This evaluation assessed customer acceptance of the piloted battery storage technology (a key to scalability), and whether and how much the battery storage system lowered demand during the Summer Peak Period or flattened the solar PV output curve. The evaluation approach is summarized in Table 2-1.

Table 2-1: Evaluation Approach

Task/Activity	Description
Online Surveys	After the summer demonstration season, Navigant developed, fielded, and analyzed online surveys of National Grid's participants to solicit feedback about their experience and thoughts on their participation.
Phone Interviews	After the summer season, Navigant administered phone interviews with the four Unitil participants to solicit feedback about their experience and thoughts on their participation. Navigant also interviewed Unitil's battery storage system installer.
Data Management	Early in the summer demonstration season, Navigant and the Program Administrators performed a data transfer test of the whole-home, solar PV, and battery storage telemetry data to ensure data was being collected from the limited number of participants and could be readily analyzed. After the demonstration season the complete data was transferred to Navigant for analysis and QA/QC.
Telemetry Data Analysis	The evaluation measured demand and energy impacts of the energy storage, assuming the whole-home and solar PV data as the baseline. For National Grid, Navigant assessed the impact to participant bills with and without energy storage and applying the rates in effect at the time to determine bill impact.

Source: Navigant

The remainder of this section provides details the evaluation approach and methodology for participant research and impact analysis.

2.1 Participant Research

This section describes the participant research. It includes online surveys with National Grid participants and phone interviews with Unitil participants and Unitil's installer.

2.1.1 Online Surveys (National Grid Only)

Navigant administered a post-season online survey with the National Grid customers participating in the demonstration. The survey explored the following questions:

- What was the primary motivation for participants to obtain a battery and participate in the demonstration?
    - For participants with existing batteries, what was the motivation to participate in National Grid's demonstration? What value streams from the battery are most important to them?
    - For participants with new batteries, how important was National Grid's demonstration in the decision to purchase the battery?

  - If National Grid was to offer a 5-year guaranteed incentive, how would that affect the participants' decision to join the demonstration if they had existing batteries and their decision to purchase the battery if they did not have a battery already.

- What were participant usage patterns prior to participation?
- What are the barriers to full-scale deployment that the participants identify?
- Would participants continue to allow National Grid to control the system during peak periods in the future?

The surveys were administered via the Qualtrics platform from October 10 through October 20, 2019. Navigant obtained 41 completes out of a population of 65 participants[8] for a response rate of 63%. Appendix B provides the survey instrument.

2.1.2 Phone Interviews (Unitil Only)

Navigant conducted phone interviews with all four of the Unitil participants enrolled in the demonstration and one interview with a representative from Unitil's battery storage system installer.

The objectives of the interview with participating customers was to investigate the following:

- What is the primary motivation for participants to enroll in Unitil's demonstration? What value streams are most important to them?
- Would participants continue to allow Unitil to control the system during peak periods in the future?
- What are the barriers to full-scale deployment?

The objective of the interview with the battery storage system installer was to investigate the following:

- What are the barriers to full-scale deployment?

Navigant conducted the participant interviews in October 2019, and the installer interview in November 2019. Appendix A provides the interview guides for participants and the installer.

2.2 Telemetry Data Analysis

Using the whole-home, solar PV, and energy storage metered data, Navigant explored the following research questions:

- What percentage of days during the Summer System Peak Period did each battery storage system successfully charge and discharge for each participant (e.g., only charge via solar PV generation, charge completely, discharge during called event, discharge completely)?
- What is the whole-home usage, solar PV output, average battery charge or discharge each hour during the Summer System Peak Period for each participant?

[8] Survey population was the subset of devices confirmed as installed in either Massachusetts or Rhode Island that were accepted into the program prior to August 6, 2019 to ensure participants had sufficient experience with the program.

- What is the average kW output from batteries over the Summer System Peak Period for each participant?
- How does solar PV output and battery system performance (e.g., percent of maximum capacity dispatched) vary by solar PV orientation (for Unitil only, if available)?
- How does calling multiple events on consecutive days affect battery performance? Are batteries able to fully recharge between consecutive events?
- How does the solar PV and energy storage inverter configuration (e.g., AC coupled vs. DC coupled) and inverter rating affect the system's performance (if available)?

Navigant's impact evaluation activities included two subtasks, which are discussed in the following sections.

2.2.1 Impact Analysis

The impact evaluation is focused on addressing two key components of the evaluation, successful event participation and average demand savings during the event. Both components of the impact evaluation use telemetry and other data received from National Grid's and Unitil's vendors.

Because the objectives of National Grid's and Unitil's programs were somewhat different, the definition of success was also different. Table 2-2 provides the criteria for a successful event. These definitions are applied to assess and categorize event participation for each participating battery during an event.

Table 2-2: Criteria that Define a Successful Event

PA	Success
National Grid	Battery discharge during the event is >20% of the maximum expected battery discharge[9]
Unitil	The combination of solar and battery output during the event remains flat within 1 kW per site

Source: Navigant

To calculate the impact of each battery during an event in which it was identified as participating, the metered battery power was averaged over each 15-minute interval in the event period. If some intervals were missing during the event period, the remaining intervals were averaged without the missing intervals, assuming the missing intervals would have shown the same average discharge. If all intervals during the event period were missing, the battery power was assumed to be zero.[10] In the case of National Grid, average demand savings are based only on the batteries defined as successfully participating in the event. For Unitil, the average demand savings is based on all sites for all events.

2.2.2 Bill Impact Estimate (National Grid Only)

The bill impact estimate provides an order-of-magnitude comparison of the financial impact of participation versus the performance incentive. To estimate this bill impact, Navigant found the average daily electricity consumption for each participating battery device by summing the 15-minute charge and

[9] Navigant chose 20% of the maximum expected battery discharge as the cutoff for success to avoid excluding batteries that may have been adversely affected by consecutive events or sky conditions that limited charging of the batteries before the events; by this definition, while these batteries may have underperformed in an event they did successfully participate.

[10] Based on direction from EnergyHub regarding prolonged missing intervals for National Grid.

discharges over the day. Navigant multiplied this average daily consumption by 30 days to get a rough estimate of change in monthly energy consumption at the meter due to the cycling of the battery storage system. This assumes that the battery storage system was not previously cycled by the customer, which may slightly overestimate the increase in the customer bill. The resulting change in monthly consumption value was then monetized, assuming no net export for the month, which may slightly overestimate the increase in customer bill due to energy storage due to the net export rules in Massachusetts.

3. DATA SOURCES AND DATA REVIEW

Navigant used telemetry data from National Grid and Unitil for the impact evaluation. The data elements for analysis are described in Table 3-1. With the exception of the ISO-NE peak hour, EnergyHub provided the National Grid data. Unitil provided its own data.

Table 3-1: Data Requirements for the Evaluation

Data Requirement
Event Information (i.e., event date, event start time, event end time)
Participant Information (i.e., email address, solar PV orientation, inverter configuration)
Hourly Whole-Home Telemetry Data (i.e., hourly whole-home energy consumption, separate from solar PV generation and battery charge/discharge)
Hourly Solar PV Telemetry Data (i.e., hourly solar PV generation)
Hourly Energy Storage System Telemetry Data (i.e., hourly battery charge and hourly battery discharge)
ISO-NE Peak Hour (i.e., date and hour ending)
Rate Information (i.e., rate code for each participant, rate schedule for each rate code during summer and winter months)

Source: Navigant

3.1 Telemetry Data Completeness Check and QA/QC Overview

Navigant retrieved the telemetry data (from the EnergyHub Portal or from the PAs) for the Summer event periods and conducted a completeness check and QA/QC review. Table 3-2 summarizes the general questions addressed during Navigant's review.

Table 3-2: Data Completeness Check and QA/QC Review

Review	Questions Addressed
Completeness Check	• Was data provided for all enrolled devices? • How does the first timestamp compare to when the device was enrolled? • Was data provided after enrollment through the entire Summer Peak Period? (National Grid: Jul. 1–Aug. 31; Unitil: Aug. 1–Sep. 30) • Are there intervals with data missing or text errors? • Are there data fields that are entirely missing?
QA/QC Review	• What units was the data provided in? • Is the energy and power data in AC or DC? • What is the sign convention (+/-) for battery charging/discharging and buying/selling from the grid? • Are there unexpected outlier values? • Are the batteries performing as expected? • What is the time zone of the data provided?

Source: Navigant

3.1.1 Data Conventions for Analysis

After the initial completeness check and QA/QC review, Navigant adjusted the data so that similar conventions were used across the various manufacturers. The conventions used for the analysis are summarized in Table 3-3.

Table 3-3: Data Conventions for Analysis

Parameter	Convention
Time Zone	EDT (Eastern Daylight Time)
Time Starting vs. Time Ending	Time Starting
Interval	15-minute intervals
Units	kW (power); kWh (energy)
Battery Power Sign Convention	Positive = battery charging; Negative = battery discharging
Net Load Sign Convention	Positive = buying from grid; Negative = selling to grid
AC or DC	AC (post-inverter)

Source: Navigant

The remaining analysis summarized in this section, and report, reflects the results after Navigant aligned data conventions across all datasets.

3.2 National Grid Data Review

Navigant applied the following steps to review the telemetry data provided by National Grid.

1. **Data Completeness and Validity Check:** Navigant reviewed each participating battery's 15-minute telemetry data to determine if a 15-minute interval of data was provided for each battery during the Summer Peak Period and after the battery's enrollment date. Navigant also reviewed device metadata and event participation data. Navigant reviewed the available interval data for blank intervals or non-numerical values.[11]

2. **Data Convention and QA/QC Review:** Navigant updated the interval data provided to align with the data conventions summarized in Table 3-3. Navigant applied QA/QC checks to identify interval data with possible discrepancies and inaccuracies.

3. **Data Exclusion Based on Completeness, Data Validity, and QA/QC Review:** If more than 30% of a battery's intervals for a given day, was either missing, invalid, or flagged as part of QA/QC review, Navigant removed this data from the analysis.

The remainder of this section discusses the National Grid data received, Navigant's process for reviewing the data provided, the criteria used for excluding data from the analysis, and the resulting data available for analysis.

3.2.1 Data Received

Of the 63 devices in Massachusetts enrolled in the program by August 31, Navigant received 15-minute telemetry data for 56 devices. This discrepancy was due to participants enrolling in the program before

[11] Non-numeric values include text errors such as "#N/A, #VALUE, or FALSE"

their devices were fully installed and operational. The data fields provided in the 15-minute telemetry data that were used for calculations in the analysis are described in Table 3-4.

Table 3-4: National Grid Data Fields Used for Analysis

Name	Unit	Description
Battery Power	kW	Signed value indicating average power during leading 15-minute interval.
Site Power Demand	kW	Signed value indicating average power consumption from the grid during leading 15-minute interval.
Solar Power	kW	Value indicating average power produced during leading 15-minute interval.

Source: Navigant

In addition to the telemetry data, Navigant also received device metadata such as listed storage capacity (kWh), maximum discharge (kW), and maximum charge (kW), along with the device added date. Navigant also received guidance on the participation status of each device for each eligible event.[12] This data indicated that, of the 56 enrolled devices for which telemetry data was received, six devices never participated in any event during the summer season. Of these six devices, the telemetry data for four did not begin until after the last event of the season and the other two were installed but opted out of every event.[13] This left 50 devices that were identified as participating in at least one event throughout the summer season. These 50 devices were used for the remainder of the data review and impact and billing analysis.

Table 3-5: National Grid Battery Counts

Device Qualifier	Number of Devices
Identified as enrolled in the program by August 31, 2019[14]	63
Received telemetry data for the summer season, confirming the battery was operational during the season; however, no indication of event participation	56
Participated in at least one event during the summer season	50

Source: Navigant analysis

3.2.2 Data Completeness and Validity Checks

For the 50 devices identified as having participated in at least one event during the summer season, Navigant received battery power data for 94% of the expected intervals. The number of expected intervals for each device is the lesser of the number of 15-minute intervals between July 1 and August 31 or the number of 15-minute intervals between the devices' enrollment date and August 31.

Over this period, the telemetry was missing 6.4% of the battery power intervals, 12.2% of the solar power intervals, and 14.3% of the site power demand intervals. The greater number of missing solar and site power intervals is due to two sites that had no metered site power and three sites that had no metered

[12] Some battery integrators directly provided lists of participation status by device by event, while others indicated that devices participated in all events after a specified date for each device.

[13] While these two devices are classified as having opted out of all events, it is likely that this was caused by an issue that prevented the devices from participating in the events, rather than a traditional opt-out initiated by the customer.

[14] Some customers were enrolled in the program prior to the installation of a battery.

solar or site power. This is because these sites did not have the proper metering configuration. These sites were still analyzed as there was metered battery power that was used for determining impact.

3.2.3 Data Convention and QA/QC Review

Navigant progressed to a preliminary QA/QC review of the received telemetry data and encountered some discrepancies with the data conventions by device. In coordination with EnergyHub, Navigant made informed corrections to align the telemetry data for all devices into a single convention, which is laid out in Table 3-3. These corrections included:

1. Converting all timestamps to eastern standard time.

2. For devices that necessitated it, offsetting timestamps by one interval to ensure metered power referred to the leading 15-minute interval rather than the lagging 15-minute interval (i.e., period beginning rather than period ending)

3. Removing duplicate timestamps. The metered battery power did not vary among any of the duplicate timestamps, so the process of removing timestamps did not affect the analyzed impact.

4. For devices that necessitated it, converting sign conventions such that a negative power indicated solar power generation and energy storage dispatch and a positive power indicated energy storage charging and site power demand.

5. For devices that necessitated it, integrator reshared data that converted battery power and solar power to AC rather than DC (i.e., after the inverter).

6. For devices that necessitated it, converting all power values into units of kilowatts rather than watts.

Once the telemetry data was aligned to the same conventions, Navigant completed several additional QA/QC checks to confirm the quality of the data received. This included:

1. Checking that the peak solar power production was less than 20 kW and peak site power demand for each site was less than 20 kW; which are reasonable maximum values for a residential customer.

2. Checking that the peak battery power did not exceed the listed max discharge rate or max charge rate associated with the enrolled device.[15]

3. Checking that the various battery telemetry data fields were self-consistent within ±2%. This included battery power, stored energy, and state of charge.

No telemetry data was removed from the analysis as a result of these QA/QC steps.

3.2.4 Data Available for Analysis

To account for the findings of Sections 3.2.2 and 3.2.3, Navigant employed a single threshold for the exclusion of data beyond accounting for missing intervals, which is described in Table 3-6. While this exclusion process amounted to the exclusion of 137 device-days or 13,152 intervals, most of those

[15] About 0.1% of intervals featured battery power higher than the listed maximum power for the device. This was because for some devices the listed maximum power was the continuous rated power of the device, which is less than the actual rated maximum power rating. The intervals that exceeded the continuous power rating were below the maximum power rating.

intervals (12,672, or 96%) were already missing for an entire day. The remaining intervals excluded were due to partially missing data for a single day.

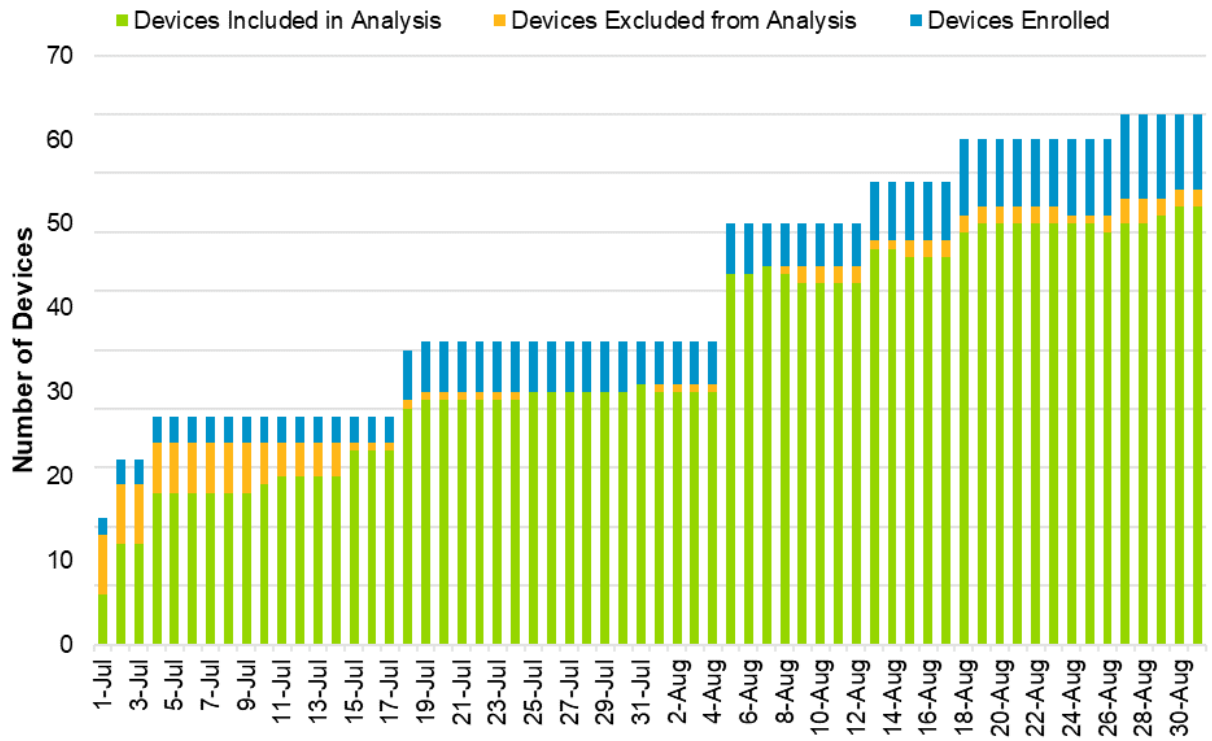
Table 3-6: Thresholds for Excluding National Grid Data from Analysis

Criteria	Threshold	Action	Outcome
Battery interval data for a given day are missing or have too many QA/QC issues	Greater than 30% of the battery's intervals on a given day are missing or have QA/QC issue(s)	Exclude the battery's data for the entire day from the analysis	137 device-days from 16 devices on 57 days excluded

Source: Navigant

Figure 3-1 shows the number of devices enrolled by day along with the number of devices included and excluded from analysis. Devices are included in the analysis when they are enrolled and meet the threshold in Table 3-6 (green). Devices are excluded from the analysis when they do not meet the threshold in Table 3-6 (orange). Also excluded from the analysis are devices that are enrolled and do not have telemetry (blue). In total, 94% of battery power data for the 50 devices that participated in at least one event in the summer season was available for analysis.

Figure 3-1: National Grid Data Review Summary



Source: Navigant analysis

3.3 Unitil Data Review

Navigant applied the same steps to the review the telemetry data provided by Unitil.

1. **Data Completeness and Validity Check:** Navigant reviewed each participating battery's 1-minute telemetry data and aggregated the data to 15-minute intervals to confirm data was provided for each battery during the Summer Peak Period

2. **Data Convention and QA/QC Review:** Navigant updated the interval data provided to align with the data conventions summarized in Table 3-3. Navigant applied QA/QC checks to identify interval data with possible discrepancies and inaccuracies.

3. **Data Exclusion Based on Completeness, Data Validity, and QA/QC Review:** If more than 30% of a battery's intervals for a given day, was either missing, invalid, or flagged as part of QA/QC review, Navigant removed this data from the analysis.

The remainder of this section discusses the National Grid data received, Navigant's process for reviewing the data provided, the criteria used for excluding data from the analysis, and the resulting data available for analysis.

The remainder of the section describes Unitil data received, Navigant's review of the data, and the steps taken to clean the data for analysis.

3.3.1 Data Completeness and Validity Check

Navigant received 1-minute interval data from the four enrolled devices for August 1 through September 30. The raw files contained both gateway (utility) and power conversion system (PCS) (battery) data with 64 data fields. Navigant selected the power fields listed in Table 3-7 for use in the impact analysis. Data was provided from August 1, 2019 through September 30, 2019.

Table 3-7: Unitil Data Used for Analysis

Name	Description
Net Import / Export Power (W)	Signed value indicating average power during leading interval
Generation Power (W)	Value indicating average solar power produced during leading interval
Measured Battery Charge/Discharge Power (W)	Signed value indicating average power during leading interval
Load Power (W)	Value indicating total home load during the leading interval
PCS Energy (Wh)	Value indicating average total stored energy of battery during leading interval
PCS State of Charge (%)	Percentage value indicating average state-of-charge (SOC) during leading interval

Source: Navigant

Table 3-8 summarizes the completeness of Unitil data used in the analysis. Less than 1% of all expected intervals were missing from the original data provided. The missing intervals were strictly between the hours of 6 p.m. and 6 a.m. on 1 p.m. to 5 p.m. event days and had no impact on the analysis.[16]

Table 3-8: Unitil Data Completeness

Site	Intervals Expected	Intervals Received	% of Intervals Missing (A)	% of Intervals Received with Battery Power Data Invalid (B)	% of Intervals Available with Valid Data for QA/QC (100%-A-B)
Site1	5,760	5,700	1.0%	0.0%	99%
Site2	5,760	5,696	1.1%	0.0%	99%
Site3	5,760	5,740	0.3%	0.0%	100%
Site4	5,760	5,744	0.3%	0.0%	100%
Total	**23,040**	**22,880**	**0.7%**	**0.0%**	**99%**

Source: Navigant

3.3.2 Data Convention and QA/QC Review

The telemetry was cleaned by removing all duplicate timesteps,[17] converted to kilowatts, and averaged over 15-minute intervals. Navigant performed additional QA/QC checks for Unitil telemetry data. These included the following:

- Checking whether the change in energy content and SOC match
- Checking whether changes in battery power (charge or discharge) were aligned with changes in the energy content or SOC
- Checking whether solar output was greater than rated solar PV size

No telemetry data was removed from the analysis as a result of these QA/QC steps.

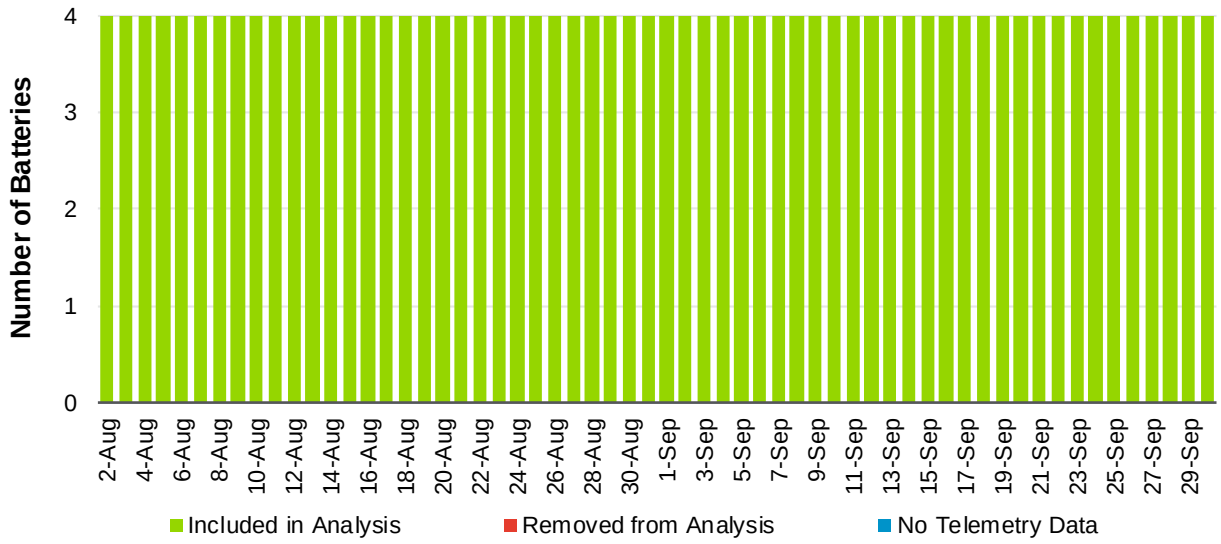
[16] Upon request from Navigant, Unitil was able to locate and provide data for the missing intervals. However, because the missing intervals had no impact on the analysis, Navigant proceeded with the original data and did not ask Unitil to provide the missing interval data.

[17] For instances with multiple timesteps, the first occurrence of numerical data was used.

3.3.3 Data Available for Analysis

Because of the minimal QA/QC and completeness issues, Navigant used all provided Unitil data in the analysis. Figure 3-2 shows this in aggregate for the four devices over the entire reporting period in.

Figure 3-2: Unitil Data Review Summary



Source: Navigant analysis

4. ANALYSIS AND RESULTS

This section describes the analysis results for participant research, impact analysis, and National Grid bill impact estimates for the summer 2019 season. The section presents National Grid's summer season demonstration results then presents Unitil demonstration results.

4.1 National Grid Summer Season

As discussed in Section 3.2.1, 50 batteries participated in at least one event called by National Grid for the Summer season. These batteries participated through one of five energy storage integrators that partnered with the program throughout the season. Participating batteries ranged in size from 5 kW/10 kWh to 10 kW/27 kWh. Table 4-1 shows the selected size statistics for the participating batteries.

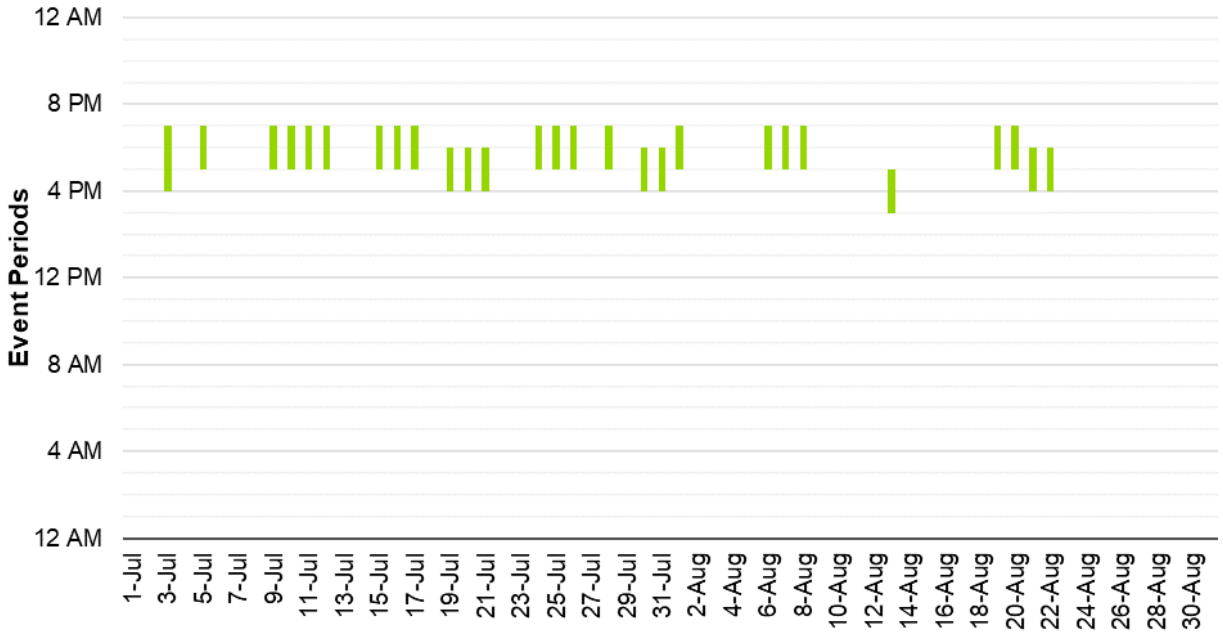
Table 4-1: Size Statistics for 50 Participating Batteries

Statistic	Max Discharge Rate (kW)	Storage Capacity (kWh)
Total	323.7	823.6
Average	6.5	16.5
Median	5.0	13.5

Source: Navigant analysis

National Grid called 27 events between July 3, 2019 and August 22, 2019. The first of these events lasted 3 hours while the others lasted 2 hours, and all the events occurred at some point between 3 p.m. and 7 p.m., as shown in Figure 4-1.

Figure 4-1: National Grid Summer Season Called Events



Source: Navigant Analysis

4.1.1 Participant Research

After the season was completed, Navigant administered an online survey to National Grid participants, achieving a total of 41 completes in a population of 65 participants[18] for a response rate of 63%. The survey was administered via the Qualtrics platform from October 10 through October 20, 2019. Appendix B provides the full survey guide, as programmed, while Appendix C contains the full survey results.

The participant survey had the following goals:

- Understand participant motivation for participation, including how motivations differed for those who had previously purchased batteries and those who recently purchased them, and the impact on motivations if National Grid was to offer a 5-year guaranteed incentive
- Understand participant battery system usage patterns prior to enrollment
- Identify barriers to full-scale deployment
- Assess participant interest in future program participation

Key takeaways from the National Grid survey results include the following:

- **Access to backup power is a primary motivation for participation.** Access to backup power was the primary motivation for most respondents in purchasing a battery backup system, and one of the most important factors in participants' decisions to enroll in the program.
- **Survey respondents rarely opt out of events.** Respondents reported extremely low opt-out rates, with 94% reporting they never opted out of an event. Participants also demonstrated low levels of event awareness, self-reporting low levels of event participation compared to their actual participation rate.
- **Survey respondents support the program.** Ninety-seven percent of respondents reported they would recommend the program to other National Grid customers, and 97% reported they were likely or very likely to continue with the program should it be offered in the future.

The remainder of this section elaborates on key findings for the following topics:

- Participant motivations for enrollment
- Battery usage patterns
- Participant understanding and awareness
- Barriers to full-scale deployment

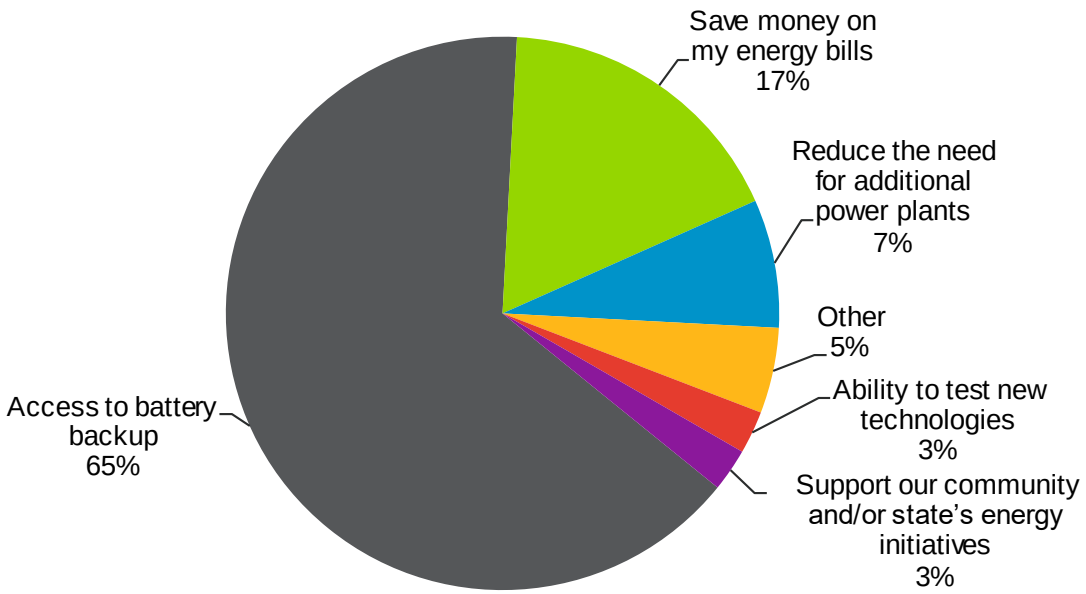
4.1.1.1 Participant Motivations for Enrollment

Eighty-seven percent of participants enrolled with battery storage systems they already owned, while 13% purchased a battery system when they enrolled in the ConnectedSolutions program. Access to battery backup was the most common motivation for purchasing a battery system (65% of respondents), saving

[18] Survey population was the subset of devices confirmed as installed in either Massachusetts or Rhode Island that were accepted into the program prior to August 6, 2019 to ensure participants had sufficient experience with the program.

money on energy bills was the second most common (17% of respondents). Figure 4-2 shows the full breakdown of responses.

Figure 4-2: Participant Motivations for Purchase (n = 40)



Q3. What was your primary motivation in purchasing a battery system?
Responses for "other" include "All of the above" and "Home security during power loss."
Source: Navigant analysis of online survey data

Of those participants who reported their primary motivation was access to battery backup or rated the importance of access to battery backup highly, 74% were at least a little concerned that the program might drain their battery system when they were counting on it to provide backup power (Figure 4-3). National Grid designed the program so that events are not called if a storm is predicted in the near future, but it is unclear how aware participants were of this aspect of the program design.

Figure 4-3: Participant Concern for Battery Drain (n = 39)

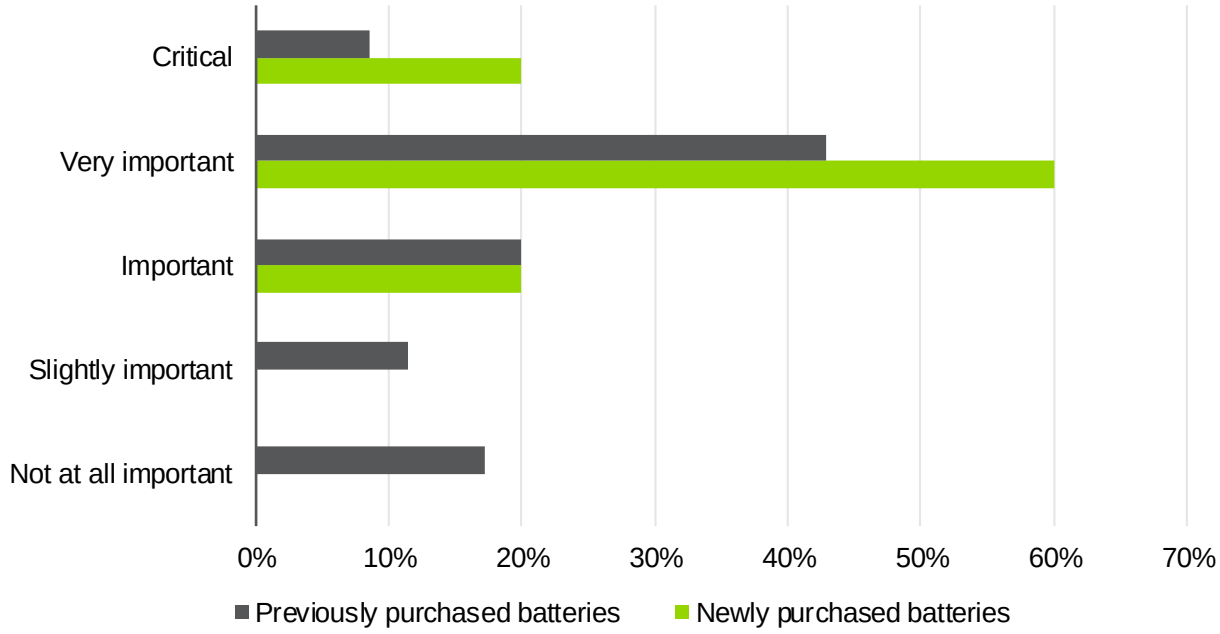
Q8. How concerned are you that the Connect Solution Program may have discharged batteries when you are counting on them for backup purposes?

Q8 was only asked to respondents who indicated access to battery backup was their primary motivation in Q3, or ranked access to battery backup above a 3 in Q7

Source: Navigant analysis of online survey data

Figure 4-4 shows the importance if National Grid were to offer a guaranteed 5-year incentive for those who enrolled with previously purchased batteries and those who purchased batteries when they enrolled. Those with newly purchased batteries were asked how important the guaranteed incentive was on their decision to purchase the battery, while those who already owned a battery were asked how important the guaranteed incentive was in their decision to enroll in the program. However, due to the small sample size of those who purchased batteries when they enrolled, strong conclusions cannot be drawn from this difference.

Figure 4-4: Importance of Potentially Offering a Guaranteed 5-year Incentive (n = 40)



Q5. How important was National Grid's guaranteed 5-year incentive in your decision to purchase a battery system? (For respondents who recently purchased their battery system, n = 5)

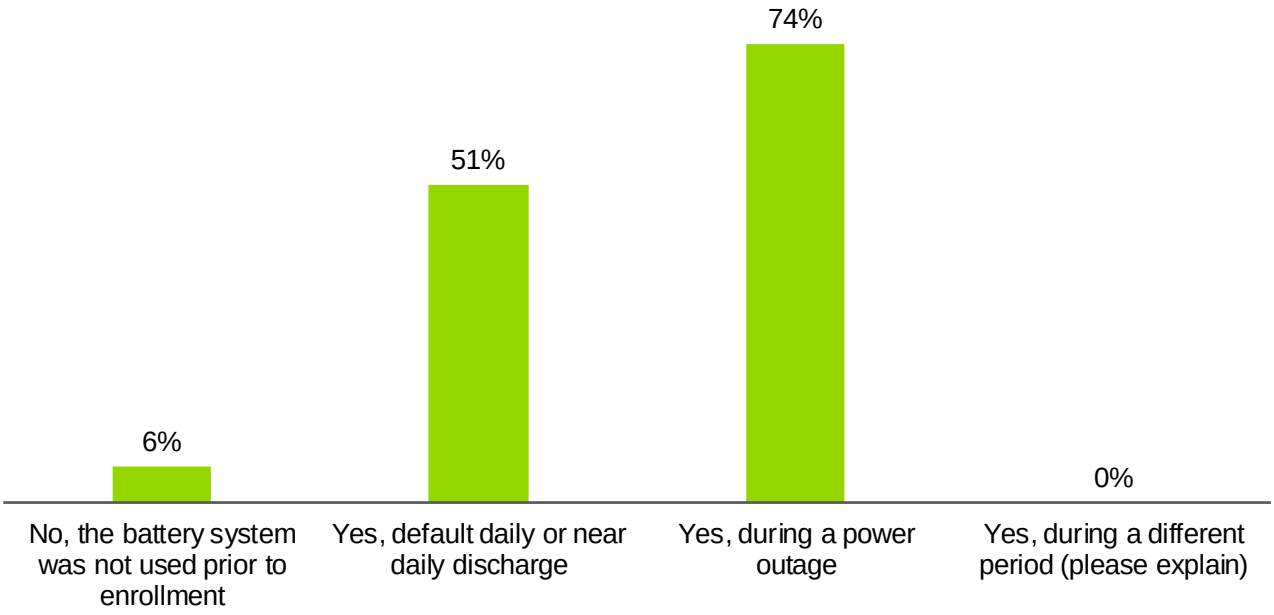
Q6. How important was National Grid's guaranteed 5-year incentive in your decision to enroll in ConnectedSolutions? (For respondents who enrolled with a previously purchased battery system, n = 35)

Source: Navigant analysis of online survey data

4.1.1.2 Battery Usage Patterns

A majority of participants who had a battery system prior to enrollment used their battery prior to program participation. Seventy-four percent of respondents used their batteries during power outages, while 51% have their batteries programmed to discharge on a daily or near daily basis, either due to the manufacturer's default programming or to participate in the SMART program.[19] Only 6% of respondents had never used their battery system prior to program participation.

Figure 4-5: Prior Battery Usage Patterns (n = 35)



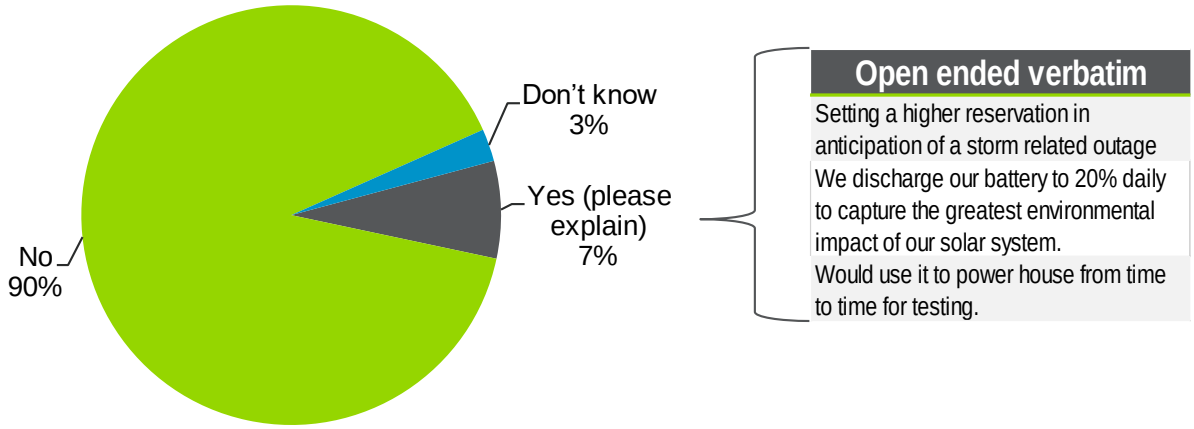
Q9. Before your enrollment in the ConnectedSolutions Battery Program, did you ever use your battery system? Select all that a pply. Q9 was only asked to respondents who enrolled with a previously purchased battery. Respondents could choose multiple responses.

Source: Navigant analysis of online survey data

During their participation in the program, 90% of participants did not manually engage their battery, either to charge or discharge their battery system. Those that did engage their battery system reported they did so either to test it or to capture the full benefit of their solar array.

[19] SMART stands for Solar Massachusetts Renewable Target. The SMART Program is a long-term sustainable solar incentive program sponsored by Eversource, National Grid and Unitil, and is designed to encourage the development of solar photovoltaic technology in Massachusetts. SMART program participants are required to discharge at least 52 full cycles per year, and many participants achieve this by discharging their battery daily.

Figure 4-6: Battery Usage Patterns During Program Enrollment (n = 40)

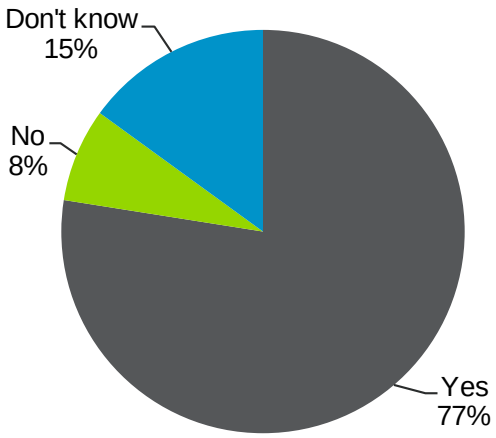


Q10. While enrolled in ConnectedSolutions, did you ever manually control (charge or discharge) your battery system outside of power outages, daily discharge requirements, and when National Grid utilized your battery as part of the program?
Source: Navigant analysis of online survey data

4.1.1.3 Participant Understanding and Awareness

Participants demonstrated low levels of awareness regarding their participation in events called by National Grid. When asked how many times National Grid dispatched their battery system during the season, only 77% of participants reported their battery systems were used as part of the program, despite the fact that all batteries were discharged at least once.

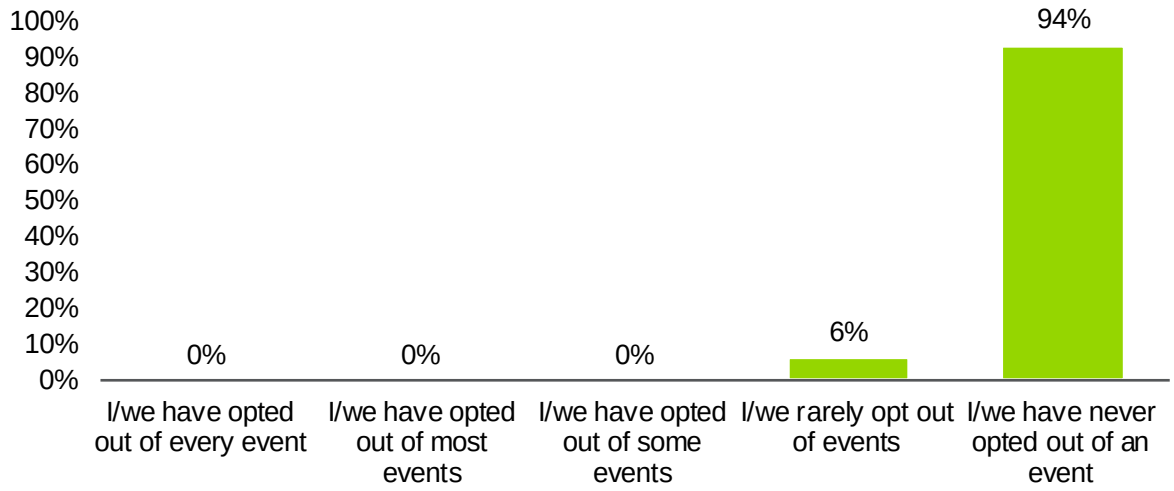
Figure 4-7: Awareness of Events (n = 40)



Q11. Has National Grid dispatched your energy storage this summer?
Source: Navigant analysis of online survey data

The ConnectedSolutions battery storage program has very low opt-out rates based on the participants that responded to the survey. Ninety-four percent of participants reported that they had never opted out of an event. Figure 4-8 shows that no participant reported opting out more frequently than rarely.

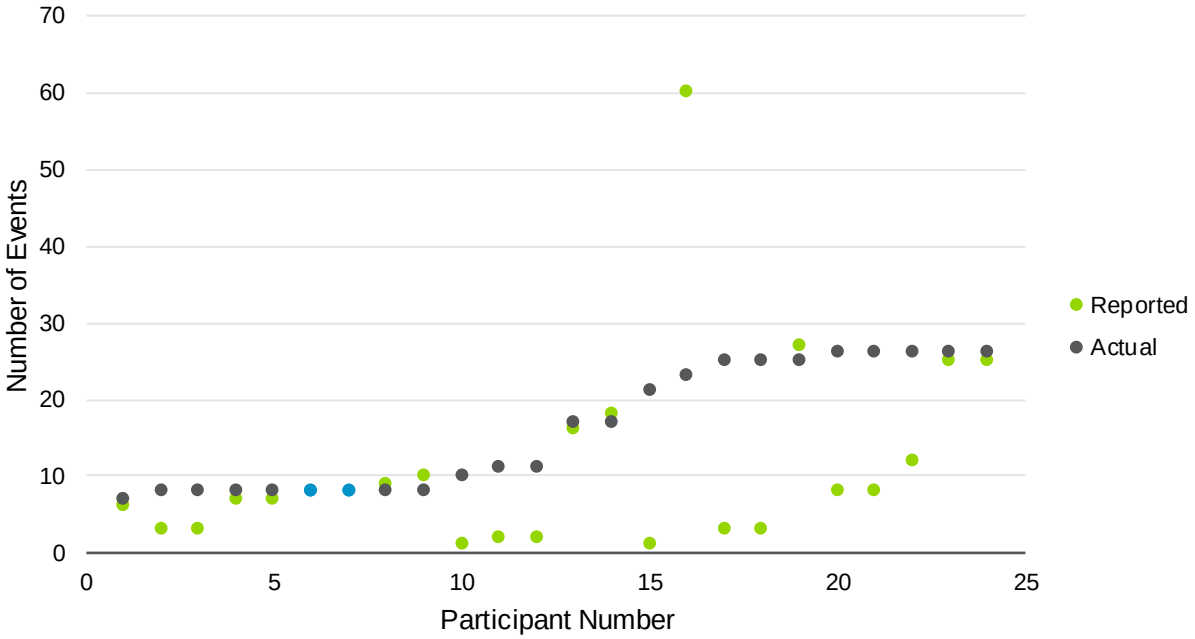
Figure 4-8: Opt-out Rate (n = 31)



Q13. How often have you chosen to opt out of events while enrolled in ConnectedSolutions?
Q13 was only asked to respondents who remembered events occurring
Source: Navigant analysis of online survey data

Figure 4-9 shows the actual versus reported participation rates for each survey respondent, with actual participation rates coming from the impact analysis. Only two participants (shown with blue dots) correctly reported their participation rate, while most participants underestimated their participation. The average difference between reported event participation and actual event participation was 4.75.

Figure 4-9: Actual versus Reported Participation Rates (n = 31)

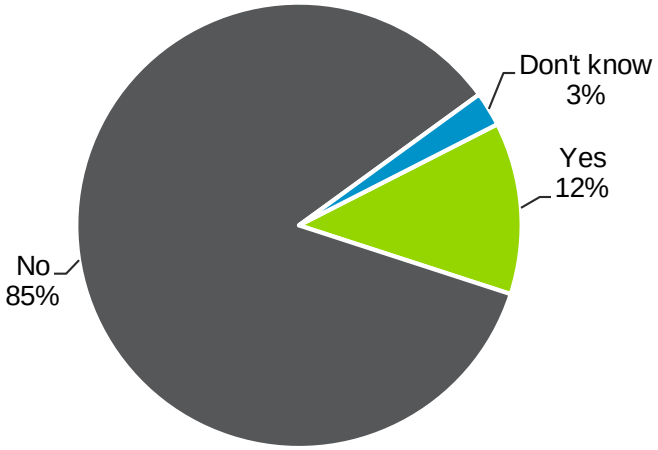


Q12. Approximately how many times has National Grid dispatched your battery system this summer?
Q12 was only asked to respondents who remembered events occurring. The graph displays data for respondents who are included in the impact analysis only. Blue dots represent participants who correctly reported the number of events they participated in.
Source: Navigant analysis of online survey data

4.1.1.4 Barriers to Full-Scale Deployment

Participants reported few technical difficulties with their battery systems, and those that did report issues largely mentioned problems that happened prior to their participation in the program. Eighty-five percent of participants reported no issues.

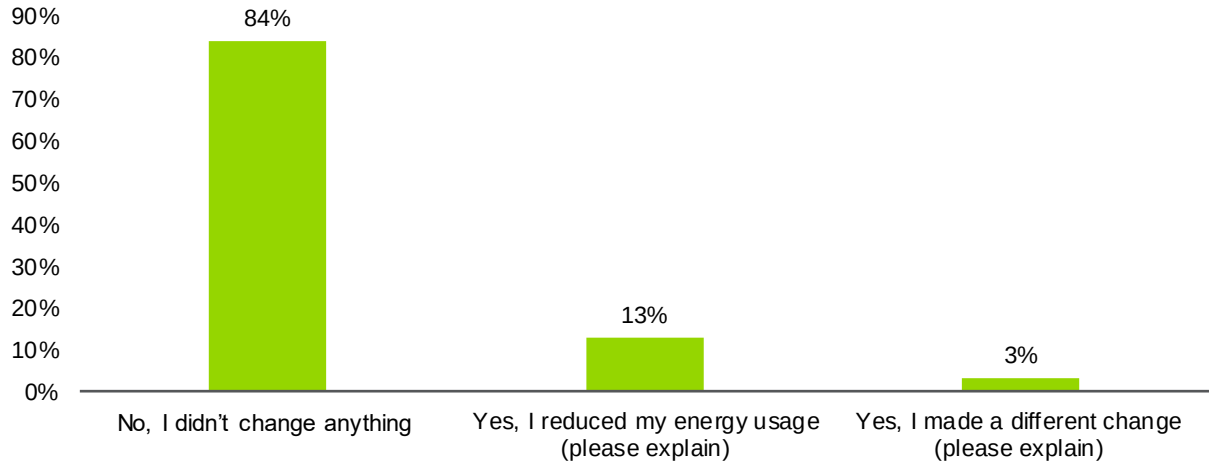
Figure 4-10: Technical Difficulties (n = 40)



Q15. Have you experienced any technical difficulties or malfunctions with your battery system?
Verbatim explanations of technical difficulties can be found in Appendix C
Source: Navigant analysis of online survey data

Figure 4-11 shows that most (84%) participants did not change their behavior due to an event being called. Those that did report changing their behavior largely chose to reduce their energy consumption by raising the temperature setting of their air conditioning or ceasing to charge EVs (80% of changes made). One participant reported they typically powered their home off their battery system from 10 p.m. to 10 a.m. and would disable this setting when a morning event was called.

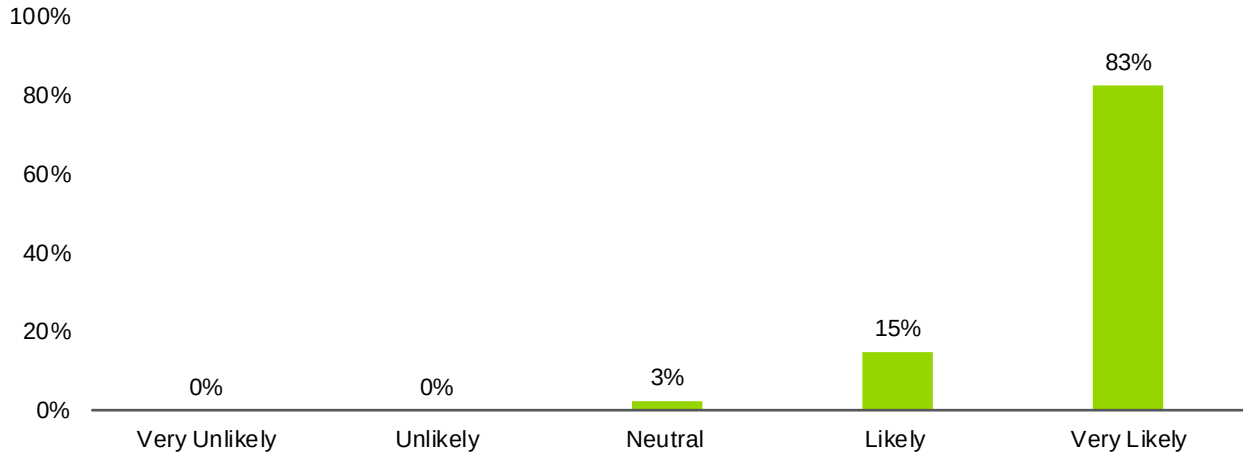
Figure 4-11: Behavioral Changes (n = 31)



Q17. Did participation in the program change anything about how you went about your day during periods when your battery system was dispatched by National Grid?
Q17 was only asked to respondents who remembered events occurring. Verbatim responses can be found in Appendix C.
Source: Navigant analysis of online survey data

Nearly all the survey respondents reported they were likely or very likely to continue with the program. Only one participant reported they were neither likely nor unlikely to continue and stated they did not have enough experience with the program to make that judgment.

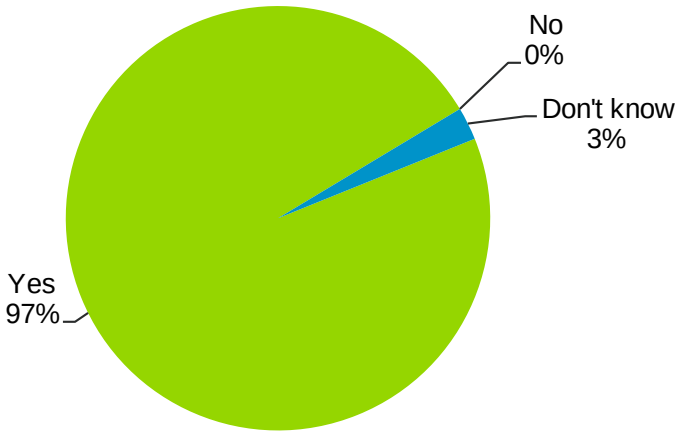
Figure 4-12: Likelihood to Continue (n = 40)



Q18. How likely are you to continue participating in the ConnectedSolutions Battery Program?
One response to Question 18 was recoded from "very unlikely" to "very likely"; based on the follow-up response, we believe the Q18 response was selected in error. The follow-up can be found in Appendix C.
Source: Navigant analysis of online survey data

Nearly all participants are likely to recommend the ConnectedSolutions program to other National Grid customers. Figure 4-13 shows that 97% of participants reported they were likely to recommend the program, while the participant who cited a lack of experience with the program was unsure. No respondents reported that they would not recommend the program.

Figure 4-13: Likelihood to Recommend (n = 40)



Q21. Would you recommend this program to other National Grid customers?
Source: Navigant analysis of online survey data

4.1.2 Impact Analysis

Navigant analyzed the impact of National Grid's program by determining the number of battery devices that successfully performed in each called event and by determining the average kilowatt output from these devices during events. Navigant also developed average hourly load profiles, analyzed performance of DC coupled battery systems, and assessed fleet-wide performance, which are included in Appendix D.

Key takeaways from the National Grid impact analysis include the following:

- **The program saved 139 kW on average per 2-hour event, with an average of 25 successfully participating battery devices.** Roughly consistent with the average savings per 2-hour event per device, the program saved 126 kW during the 2019 ISO-NE Peak Hour when 24 battery devices successfully participated.
- **Battery devices that successfully participated in 2-hour events saved an average of 5.5 kW per unit.**
- **On average, called events had 64% of the expected maximum impact given the maximum expected discharge of the batteries operational at the time of the event.** This is affected by some batteries opting out of events and also by lower relative performance by some devices, especially DC coupled batteries.
- **50 devices participated in at least one event this season. Of these, 32 successfully performed in every event they participated in, while 2 never successfully performed in any of the events they participated in.** Additionally, 8 devices that enrolled before the last event of the season never participated as they were not yet installed and operational (i.e., no telemetry data).
- **Consecutive event days appeared to have a negligible effect on impacts this season.** Weather had a larger effect on devices not being fully charged in time for the next event.
- **Successfully participating devices dispatched at a constant rate for the length of the event.** This also appears to be the case for DC coupled batteries.
- **The conventions (e.g., sign, time zone) associated with the telemetry data varied across manufacturers**. Navigant made informed corrections to align the telemetry data for all devices into a single convention.

The remainder of this section elaborates on key findings for the following topics:

- Event participation
- Average savings

4.1.2.1 Event Participation

Not all batteries participate to the same degree during each event. Navigant analyzed each batteries' discharge during events and established a threshold to define a successful discharge. For this analysis, Navigant defined success as the average battery discharge during the event being >20% of the maximum expected battery discharge to avoid excluding batteries that may be adversely affected by consecutive events or sky conditions that limited charging of the batteries before the events. Table 4-2 lists the participation category definitions used throughout the remainder of the National Grid impact analysis.

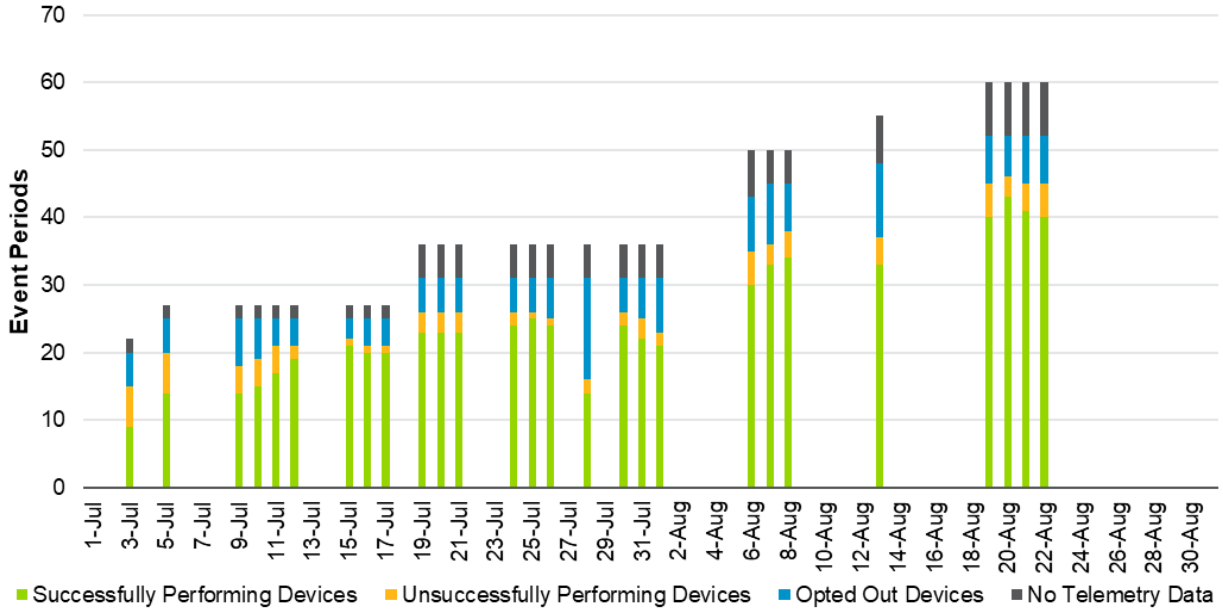
Table 4-2: Participation Category Definitions

Participation Category for Each Event	Definition
Successful	Average discharge >20% of maximum discharge
Unsuccessful	Average discharge <20% of maximum discharge or excluded by data QA/QC
Opted out	Battery manufacturer indicated the customer opted out of the event
No telemetry	Telemetry never received, indicating device was not operational during the season

Source: Navigant

While 50 devices participated in at least one event, the actual participation for each event varied, largely due to increasing enrollment over the season. Figure 4-14 provides the number of batteries by participation category for each event, out of all 63 batteries enrolled in the program before the end of August.[20] The figure shows that every event featured multiple batteries opting out[21] and multiple batteries that were enrolled in the program but did not have telemetry data on the day of the event. On average, 63% of devices enrolled on a given event day successfully participated in the event. Excluding enrolled devices without telemetry data, that number rises to 71%.

Figure 4-14: Number of Devices per Date by Participation Category Event



Source: Navigant analysis

Table 4-3 shows the breakdown of the 50 participating batteries by the percent of events that they participated in where they performed successfully (as defined in Table 4-2). Of batteries with available telemetry data that did not opt out of an event, the majority successfully performed in that event. Two-thirds of the batteries successfully performed in every event they participated in, and 90% of the batteries successfully performed in more than 60% of the events they participated in. Meanwhile, two devices

[20] Note that three batteries enrolled on August 27, 2019, and therefore are not seen in the figure.
[21] Note there were two devices for which telemetry data was available from the start of the season which opted out of every event.

never successfully performed in any event throughout the season. Apart from missing data indicating bad connectivity, it is unclear why the performance of these devices was consistently unsuccessful.

Table 4-3: Number of Devices by Percent of Participated Events with Successful Performance

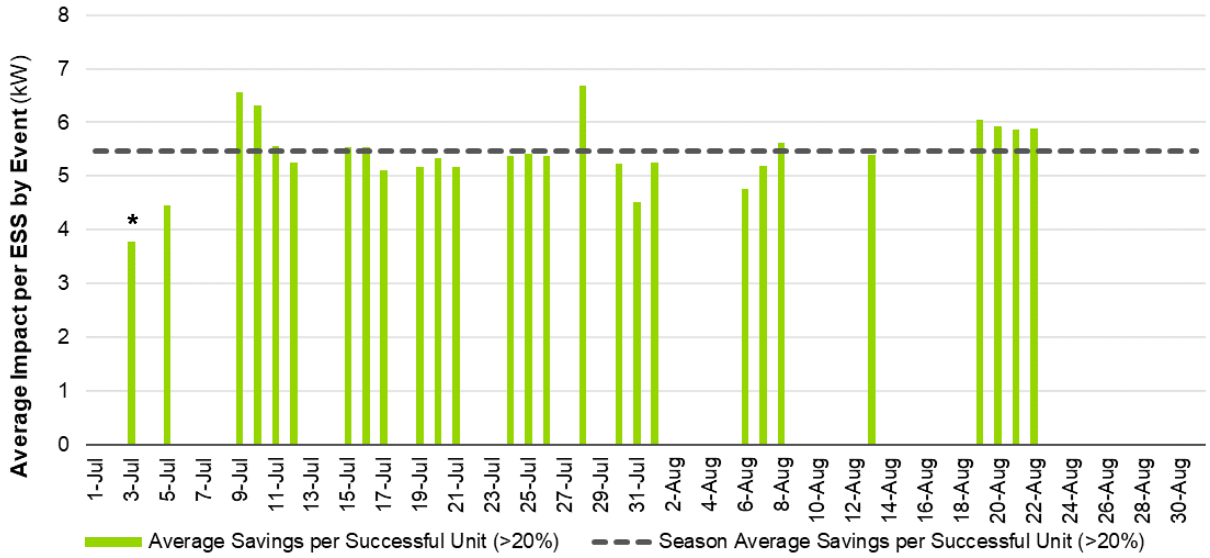
Percent of Events that Device Successfully Performed	Number of Devices	Percent of Devices
100%	32	64%
> 80% & < 100%	8	16%
> 60% & ≤ 80%	5	10%
> 40% & ≤ 60%	1	2%
> 20% & ≤ 40%	2	4%
> 0% & ≤ 20%	0	0%
0%	2	4%

Source: Navigant analysis

4.1.2.2 Average Savings

Taking the participation categories into consideration, Figure 4-15 shows the average impact of devices that successfully performed by event day, along with the season average impact for 2-hour events of 5.5 kW per successfully performing unit. This event average is weighted by the number of successfully performing devices per event.

Figure 4-15: Average Event Savings per Successfully Performing Participating Unit by Date



** First event was 3-hour duration, while all other events were 2-hour duration.*
Source: Navigant analysis

Most events stay around this average value. The average savings per successful unit for the July 30 event (coincident with the ISO-NE peak hour) was close to this at 5.2 kW. As for some of the events with outlier performance, weather and newly enrolled batteries appear to be the main drivers:

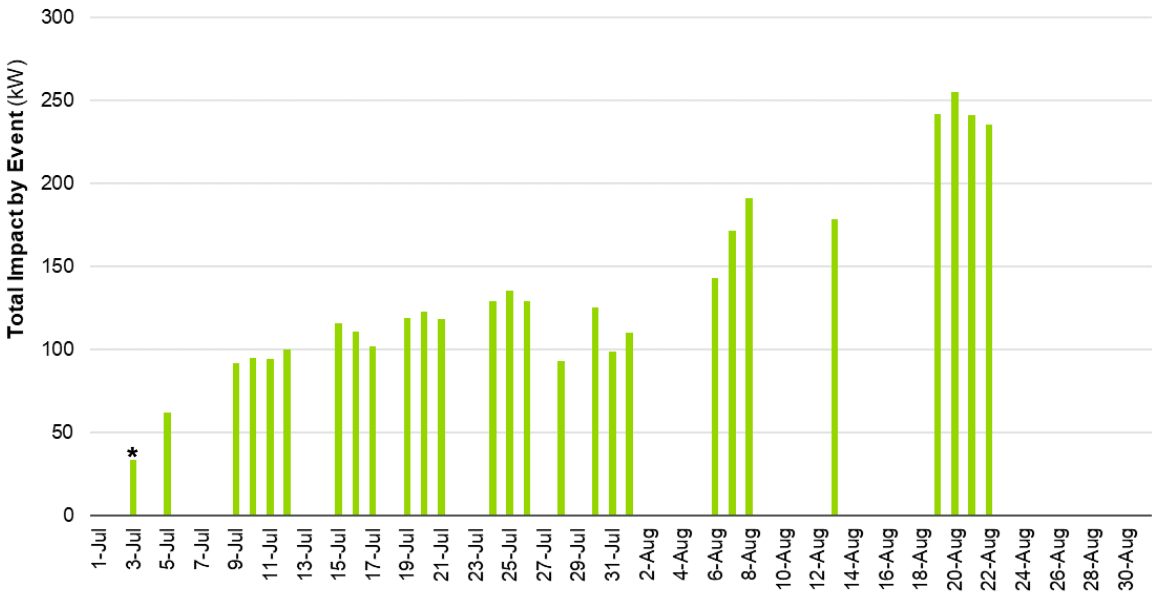
- July 3 was the longest lasting event at three hours, which reduced the average power impact
- July 5 was a hot but cloudy day in Massachusetts, which limited the ability of batteries to charge before the event
- July 28 featured one of the battery integrators with smaller batteries opting out of the event, leading to a higher average impact per unit but a lower total impact for the event
- July 31 was the day after an event and a rainy day in Massachusetts, which limited the ability of batteries to charge before the event
- August 6 featured 16 newly enrolled batteries that had enrolled on August 5 that all underperformed (between -20% and 65% of maximum expected discharge)

Figure 4-15 also shows that there is not a major effect of consecutive event days on the impact of the event. The best counter example of the events from July 9–July 12 is due to a number of smaller batteries beginning to participate in events rather than the batteries not fully recharging in time for the next event.

Navigant explored the events on a more granular level by examining average hourly load profiles. These profiles are discussed in Appendix D.1, but show that event dispatch is largely constant over the course of the event as expected. This is also the case for DC coupled systems, which are explored in depth in Appendix D.2.

Multiplying the average event savings per unit (shown in green in Figure 4-15) by the number of units that successfully performed in each event (shown in green in Figure 4-14) gives the total program impact over the season, which is shown in Figure 4-16. This largely mirrors the increase in enrollment over the course of the season since the average savings is relatively flat. Note that the ISO-NE Peak Hour for 2019 (July 30 from 5 p.m. to 6 p.m.) coincided with the July 30 event, meaning that this program reduced the ISO-NE System Peak Load by 126 kW with the 24 successfully performing devices participating in the called event.

Figure 4-16: Total Average Savings by Event



** First event was 3-hour duration, while all other events were 2-hour duration.*
Source: Navigant analysis

Navigant also explored event savings as a percentage of all devices eligible to participate at the time of an event, which is further discussed in Appendix D.3. Eligible batteries include the event participation categories of successful, unsuccessful, and opted out. On average, the savings for any event represented 64% of the available fleet capacity. This reduction is due to a portion of the batteries opting out of events and because some participating batteries underperformed relative to their maximum expected discharge. This underperformance may be caused by devices not fully charging before an event. As discussed in Appendix D.2 for DC coupled batteries, this may also be caused by inverter efficiency losses or device settings that are not currently captured in the maximum expected discharge calculation.

Finally, the summer season impact is summarized in Table 4-4.

Table 4-4: National Grid Impact Analysis Summary

Metric	Value
Average Impact in 2-Hour Event per Successfully Performing Unit	5.5 kW
Average Impact as Percent of Maximum Expected Discharge	64%
Average Total Impact per 2-Hour Event	139 kW
Average Number of Successfully Performing Units per 2-Hour Event	25

Source: Navigant analysis

4.1.3 Bill Impact Estimate

While participating customers receive an incentive in exchange for National Grid to cycle their battery, the customer still pays for any electricity that is lost due to inefficiencies in the ESS charge/discharge cycle. However, Navigant estimated that for customers that participated in at least one event this amounts to a bill increase of less than $10 per month for most customers and $36 per month for the highest affected customer. While a consideration for both current and prospective participants, this is less than the performance incentive that participants should receive for the summer season given the $225/kW incentive and the 5.5 kW average impact per successfully performing unit.

4.2 Unitil Summer Season

Four sites (shown in Table 4-5) enrolled in the Unitil summer program, each with a PV array size ranging from 3.8 kW to 5 kW. All sites had a 13 kWh/5 kW battery installed.

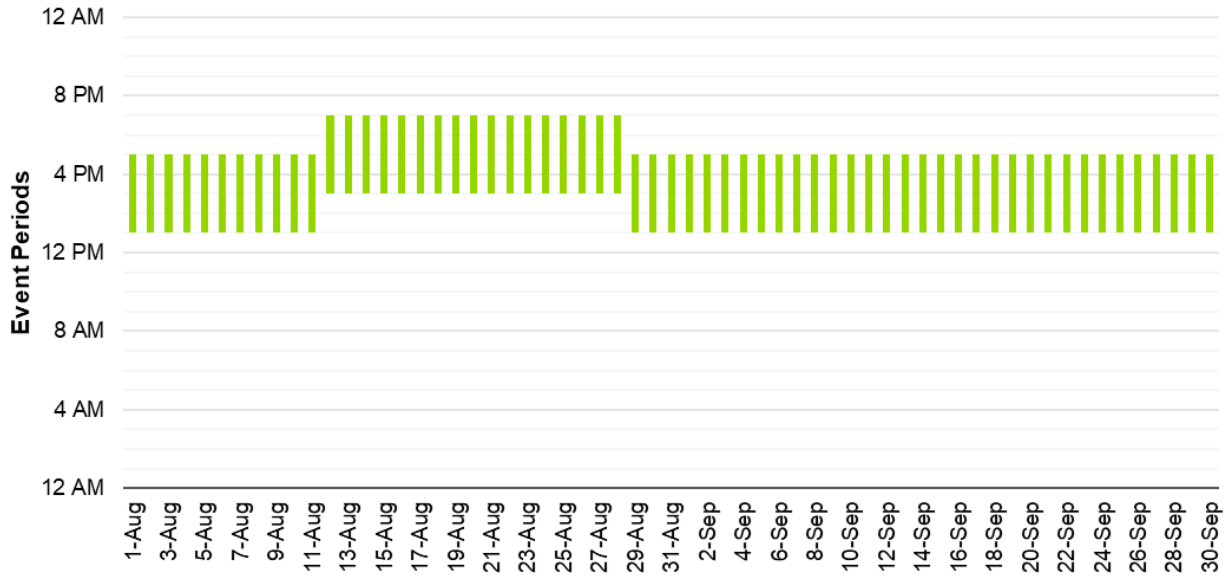
Table 4-5: Unitil Summer Participants

Site	PV Size (kW)	PV Orientation	Battery Capacity (kWh)	Battery Max Discharge Rate (kW)
Site1	4.2	Southeast	13	5
Site2	5.0	Southwest	13	5
Site3	3.9	Southeast	13	5
Site4	3.8	South	13	5

Source: Unitil

Unitil called 4-hour events every day from August 1 through September 30 (61 days total). All sites participated in all events. The events from August 1 through August 11 and August 29 through September 30 lasted from 1 p.m. to 5 p.m. while the events from August 12 to August 28 last from 3 p.m. to 7 p.m.

Figure 4-17: Unitil Summer Season Events



Source: Navigant analysis

4.2.1 Participant Research

This section describes participant research for Unitil, including phone interviews with the four Until customer participants and an interview with Unitil's participating installer.

4.2.1.1 Participant Interviews

Navigant conducted phone interviews with all four participants near the end of the summer demonstration season in October 2019. The participant interviews had the following goals:

- Understand motivations for participation
- Assess interest in future participation
- Identify barriers to full-scale deployment

Key takeaways from the Unitil participants include the following:

- **Access to backup power is a primary motivation for participation.** All four participants reported that access to emergency backup power is the main benefit of having a battery system installed at their home.
- **The program design was unclear to participants.** Participants displayed limited understanding of the program's design. Participants reported conflicting or inaccurate information regarding when events were called, the existence of a battery reserve, and the degree of control they have over their batteries.
- **Difficulty scheduling the battery installations was participants' main complaint.** Two of the four participants reported difficulty scheduling the installation of their battery; however, despite this, all four participants reported they were satisfied with the battery installer.

- **Current participants are unlikely to remain enrolled.** Should the daily discharge required by the current program design be continued, half of the interviewees reported that they would not remain enrolled.

The remainder of this section elaborates on key findings for the following topics:

- Participant motivations for enrollment
- Participant understanding and awareness
- Installation experience
- Barriers to full-scale deployment

4.2.1.2 Participant Motivations for Enrollment

All four participants reported that gaining access to emergency backup power was their primary motivation in applying to the program. Three of the four reported they had considered purchasing a battery storage system to complement their solar PV arrays prior to participating in the program, but had yet to purchase one, largely due to the cost.

When asked if and why battery storage systems were superior to backup generator systems, all asserted that battery storage systems were superior to generator backup. Participants provided reasons including the lack of fossil fuel and gas fumes, the ease of use in the case of an outage due to the battery being wired directly into the house, and not requiring any extension cords.

Participants expressed varying levels of concern about the possibility that the Unitil program might drain the batteries when they were counting on them for backup purposes. One participant reported they had minimal concerns about the battery potentially being drained at a key moment, as "before, we had no battery. Now, it might be drained, but [they're] no worse off than before. Not really a huge deal." Other participants expressed higher levels of concerns, which were tempered by a belief that the program would not completely drain their batteries, ensuring they would have at least a little power left for personal use in case of emergency.

4.2.1.3 Participant Understanding and Awareness

The intended program design was unclear to participants on a number of levels. Multiple participants remarked that they believed there to be a reserve power level, below which the program would not drain their battery storage system, and a 20% reserve was seen in the impact analysis. Another participant reported they had not realized that the program design would involve their battery being used daily. They had believed the program would operate similarly to what they understood was a more typical demand response program, only calling events on days where higher than average demand was predicted. This participant conceded that the lack of understanding may be their own fault but indicated they would have appreciated a Unitil representative explaining the program in more detail so they fully understood what they were committing to.

One participant also reported low levels of understanding about their ability to control their battery. They reported that they did not believe they had any level of control over when their battery was engaged; however, standard installations do allow homeowners to activate their battery systems at their discretion.

4.2.1.4 Installation Experience

Half of the participants reported that the installers needed to reschedule several times before the batteries were installed, causing some disruption. One participant cited that the installer rescheduled five separate appointments, often on short notice. However, outside of the scheduling issues, all four participants reported high satisfaction with the battery installer and reported that they were extremely cooperative, professional, and helpful during the installation.

Participants also reported significant delays between acceptance into the program and installation of their battery system. While participants did not recall the exact length of time, all participants reported at least a 3-4-month delay, with two participants reporting a delay of 6 months or more. No participants reported having to make any substantial changes to their house or yard to accommodate the battery system.

4.2.1.5 Barriers to Full-Scale Deployment

Participants reported that they did not notice any changes when the battery system took over, nor did they feel the need to adjust anything about their day-to-day routine to accommodate the battery system. No participants reported any technical difficulties at this time.

Despite the minimal impact on participants' lives, only one participant reported they were likely to continue with the program should it be offered after the demonstration period (this participant did not provide a reason for their desire to continue participating). Two of the three remaining participants reported they would not continue with the program should the daily discharge required by the program design be continued. Both participants said they "didn't see the point" in participating once the demonstration period ended. The final participant reported they were extremely unlikely to continue with the program regardless of program design or the potential for a bill credit reward for further participation, as obtaining a battery storage system had been their main goal in enrolling. All three participants who reported they were unlikely to continue with the program did concede they were willing to wait to see what Unitil would offer them before conclusively ruling out further participation.

4.2.1.6 Installer Interview

Navigant conducted a phone interview with Unitil's battery installer at the end of the summer demonstration season in November 2019. The installer interviews had one main goal, to identify barriers to full-scale deployment.

Key takeaways from the Unitil installer include the following:

- **Many stakeholders expressed safety concerns.** The battery installer reported that safety concerns were expressed by participants, in part due to several highly publicized battery fires in the last several years. They also reported that code enforcement and inspection requested additional inspection from the fire department in order to assess the risk of battery fires and discuss methods of fire suppression.

- **Organized and clear program administration will be key moving forward.** While recognizing that the program is still under development, the battery installer reported that the main challenge facing an expanded program is developing and streamlining the program administration, to limit delays and ensure any required data is being collected and recorded in a usable format.

The remainder of this discussion elaborates on key findings for the following topics:

- Participant interactions

- Installation process
- Program administration

4.2.1.7 Participant Interactions

The battery installer reported that participants were pleased with the program overall. They reported that many of the questions they received were tied to unfamiliarity with the technology, such as how the battery system will interact with their existing electrical system or what its impact on their solar systems would be. The installer also reported a number of safety-based concerns, largely stemming from unfamiliarity with the technology, as well as a number of highly publicized battery fires, such as the fires caused by Samsung phones in 2016 and the Tesla vehicle battery fires in 2019. The installer reported they were largely able to alleviate these concerns by thoroughly explaining the safety features of the batteries and by relying on material provided by the battery vendor.

4.2.1.8 Installation Process

The only issue reported by the battery installer was tied to inspections: inspectors were unfamiliar with the technology and the risks it posed. Inspectors requested that the system for at least one participant be inspected by the fire department, and the installer reported that they had to educate both the inspectors and the fire department about the technology. All parties were satisfied by the reassurances of safety, and the installer reported they were hosting an informational session for local fire departments in early December 2019 to provide information about and increase familiarity with battery systems such as those involved in the program. Other than the fire risk concerns, the installer reported no further issues with the installation process.

4.2.1.9 Program Administration

An increase in program size could result in more success, due to increased availability from vendors and economies of scale, but to fully capture these benefits, the program administration will need to be clarified. While the installer did not have any complaints about the current iteration of the program administration, they reported the greatest challenge they believe Unitil will face in developing a full-scale program is ensuring the process and paperwork is capable of supporting the increased demand without slowing down the approval and installation process to the point where customer satisfaction is impacted. However, the installer recognizes that the program is a work in progress in its current iteration and is currently satisfied with the program and their participation.

4.2.2 Impact Analysis

Navigant conducted an impact analysis for each battery system. The analysis had the following goals:

- Assess whether the batteries flattened PV load during events
- Identify demand savings enabled by the batteries during events

Key takeaways from the analysis include the following:

- **Combining battery storage with solar PV achieved a flattened output profile during portions of events.** The batteries were successful at balancing the solar PV plus battery storage output for the first 2 hours of the 4-hour event for 71% of events; however, the battery storage was successful for 14% of events to balance the solar PV plus battery storage output for the full 4-hour event duration.

- **The combined solar PV plus battery storage performed better during the 1 p.m. to 5 p.m. events**. Batteries were able to balance the solar PV plus battery storage output for longer during the 1 p.m. to 5 p.m. events than the 3 p.m. to 7 p.m. events, which was due to greater solar PV output during the 1 p.m. to 5 p.m. periods; however, the battery storage was not charging between 1 p.m. and 3 p.m., which reduced its potential state of charge.

- **The site with a smaller solar PV array facing south did not perform as well as sites with larger solar PV arrays facing southeast**. The site that had the smallest solar PV array was also the only site with south facing solar PV rather than southeast. This site struggled to charge in the mornings throughout September and was less successful at balancing its solar PV plus battery storage output. Meanwhile, the site with the largest PV array was the most successful at balancing the PV plus battery output.

- **The average output from the battery storage during the 4-hour events was 1.3 kW and 5.2 kWh**. In addition to the size and/or direction of the PV and weather conditions affecting the charging of the batteries, it appears the system controller stopped battery charging at 1 p.m., even for events that start at 3 p.m.

The remainder of this section elaborates on key findings for the following topics:

- Observed solar PV and battery storage performance
- Battery storage demand impacts
- Balancing of solar PV plus battery storage

Appendix E includes additional analysis of the Unitil telemetry data. This includes analysis of the average hourly load profiles by event period, daily performance of the solar PV and battery storage systems over the summer season, and analysis of the daily state of charge.

4.2.2.1 Site Characteristics

The batteries within Unitil's program are dispatched to flatten the solar PV output profile so the total output from the battery and the PV system stays constant. This prevents large fluctuations in the home's net load from the grid. Table 4-6 shows the target output for each site. This target output is determined by analyzing what PV plus battery output was maintained most often during the event periods. Site3 is the only site where the balanced PV plus battery output does not equal the PV array size.

Table 4-6: Solar PV and Battery Storage Characteristics per Site

Site	PV Array Size (kW)	Orientation	Battery Capacity (kWh)	Battery Max Discharge Rate (kW)	Target PV plus Battery Output (kW)
Site1	4.2	Southeast	13	5	4.2
Site2	5.0	Southwest	13	5	5.0
Site3	3.9	Southeast	13	5	3.9
Site4	3.8	South	13	5	3.8

Source: Navigant analysis

4.2.2.2 Observed Solar PV and Battery Storage Performance

All four enrolled Unitil batteries participated in all event days. The batteries averaged 1.3 kW discharge over the 4-hour event periods. The total discharge for the four batteries averaged 5.1 kW per event and there was minimal difference between the 1 p.m. to 5 p.m. events and the 3 p.m. to 7 p.m. events in terms of battery discharge. However, there was more variability in average solar output across the events, which was due to changing sky conditions and lower solar insolation later in the period. The average output of the solar PV and battery storage system per site and per event period during the summer season is summarized in Table 4-7.

Table 4-7: Average Solar PV and Battery Storage Output During Event Periods

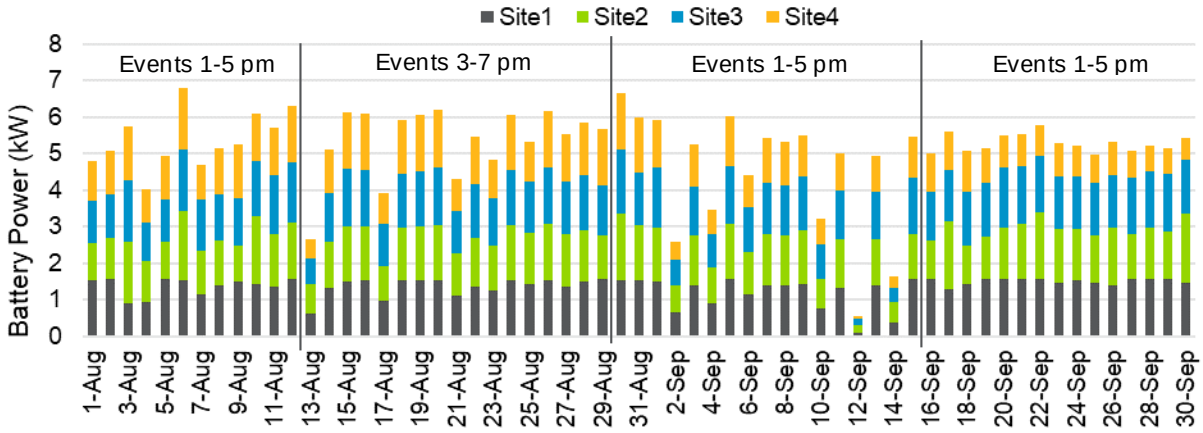
Site	Dates	Event Time	PV (kW)	Battery Discharge (kW)	PV plus Battery (kW)
Site1	Aug 1–Aug 11	1–5 p.m.	1.6	1.3	2.9
	Aug 12–Aug 28	3–7 p.m.	0.5	1.4	1.9
	Aug 29–Sep 14	1–5 p.m.	1.2	1.2	2.4
	Sep 15–Sep 30	1–5 p.m.	1.4	1.5	2.9
	All Summer Events		1.1	1.3	2.5
Site2	Aug 1–Aug 11	1–5 p.m.	3.0	1.3	4.3
	Aug 12–Aug 28	3–7 p.m.	1.8	1.4	3.1
	Aug 29–Sep 14	1–5 p.m.	2.3	1.2	3.5
	Sep 15–Sep 30	1–5 p.m.	3.2	1.4	4.6
	All Summer Events		2.5	1.3	3.8
Site3	Aug 1–Aug 11	1–5 p.m.	2.2	1.3	3.6
	Aug 12–Aug 28	3–7 p.m.	0.9	1.4	2.3
	Aug 29–Sep 14	1–5 p.m.	1.6	1.2	2.8
	Sep 15–Sep 30	1–5 p.m.	2.1	1.5	3.6
	All Summer Events		1.7	1.4	3.0
Site4	Aug 1–Aug 11	1–5 p.m.	2.0	1.3	3.2
	Aug 12–Aug 28	3–7 p.m.	0.8	1.3	2.1
	Aug 29–Sep 14	1–5 p.m.	1.2	1.0	2.3
	Sep 15–Sep 30	1–5 p.m.	1.4	0.9	2.2
	All Summer Events		1.3	1.1	2.4
All Sites	Aug 1–Aug 11	1–5 p.m.	8.8	5.3	14.1
	Aug 12–Aug 28	3–7 p.m.	4.0	5.4	9.5
	Aug 29–Sep 14	1–5 p.m.	6.3	4.6	10.9
	Sep 15–Sep 30	1–5 p.m.	8.0	5.3	13.3
	All Summer Events		6.6	5.1	11.7

Source: Navigant analysis

4.2.2.3 Daily Battery Discharge

The average daily battery discharge varied throughout the summer season. Variations are likely due to sky conditions whether limiting the charging of the battery before an event (cloudy) or not requiring as much battery discharge during an event (sunny). Figure 4-18 displays the daily variation.

Figure 4-18: Unitil Aggregate Average Battery Performance per Event



Source: Navigant analysis

4.2.2.4 Balancing of Solar PV plus Battery Storage

Navigant evaluated the ability of the combined PV and battery system to maintain the target load for each event. The team determined the number of 15-minute intervals hours where the combined solar PV plus battery storage system was within 1 kW of the target load by site; the target load is provided in Table 4-6.

Table 4-8 shows the percentage of events that each site's solar PV plus battery output was able to stay balanced for durations ranging from 15 minutes to 4 hours. Batteries were able to successfully balance the solar PV plus battery output for 2 hours during 71% of the event days. However, batteries were only successful at balancing the PV plus battery output for the full 4-hour events during 14% of event days. On average, batteries were more successful during the 1 p.m. to 5 p.m. events than the 3 p.m. to 7 p.m. events, and the August 1 p.m. to 5 p.m. events were more successful than the September 1 p.m. to 5 p.m. events. No batteries were able to discharge for the full 4 hours during the 3 p.m. to 7 p.m. events.

Site1 was the least successful of the Unitil batteries and was never able to balance the load for the full 4 hours. In contrast, Site2 was the most successful and balanced the output for the full 4 hours for 30% of all events. Site2's 5 kW PV array is the largest of the Unitil sites, which may have contributed to its high success rate. This finding suggests that sites with larger PV arrays may be able to balance the PV plus battery output for longer durations.

Table 4-8: Percent of Events that Achieved the Targeted Solar PV plus Battery Output

Duration[22]	Month	Event Type	Site1	Site2	Site3	Site4	All
15 min	Aug 1–Aug 11	1–5 p.m.	100%	100%	100%	100%	100%
	Aug 12–Aug 28	3–7 p.m.	100%	100%	100%	100%	100%
	Aug 29–Sep 14	1–5 p.m.	94%	100%	100%	94%	97%
	Sep 15–Sep 30	1–5 p.m.	100%	100%	100%	100%	100%
	All Summer Events		98%	100%	100%	98%	99%
1 hour	Aug 1–Aug 11	1–5 p.m.	100%	100%	100%	100%	100%
	Aug 12–Aug 28	3–7 p.m.	94%	94%	100%	94%	96%
	Aug 29–Sep 14	1–5 p.m.	82%	82%	88%	82%	84%
	Sep 15–Sep 30	1–5 p.m.	100%	100%	100%	100%	100%
	All Summer Events		93%	93%	97%	93%	94%
2 hours	Aug 1–Aug 11	1–5 p.m.	73%	82%	100%	82%	84%
	Aug 12–Aug 28	3–7 p.m.	0%	53%	76%	59%	47%
	Aug 29–Sep 14	1–5 p.m.	65%	65%	71%	59%	65%
	Sep 15–Sep 30	1–5 p.m.	94%	94%	100%	88%	94%
	All Summer Events		56%	72%	85%	70%	71%
3 hours	Aug 1–Aug 11	1–5 p.m.	36%	64%	73%	73%	61%
	Aug 12–Aug 28	3–7 p.m.	0%	24%	0%	0%	6%
	Aug 29–Sep 14	1–5 p.m.	18%	41%	53%	24%	34%
	Sep 15–Sep 30	1–5 p.m.	19%	81%	94%	0%	48%
	All Summer Events		16%	51%	52%	20%	35%
4 hours	Aug 1–Aug 11	1–5 p.m.	0%	45%	45%	45%	34%
	Aug 12–Aug 28	3–7 p.m.	0%	0%	0%	0%	0%
	Aug 29–Sep 14	1–5 p.m.	0%	12%	12%	6%	7%
	Sep 15–Sep 30	1–5 p.m.	0%	69%	19%	0%	22%
	All Summer Events		0%	30%	16%	10%	14%

Source: Navigant analysis

[22] Duration is the total amount of time that the solar PV plus battery storage output was balanced at any point during the event period, not necessarily consecutive time periods or at the beginning of the interval.

5. FINDINGS AND CONSIDERATIONS

This section identifies the key findings and considerations from the process and impact evaluation of National Grid's and Unitil's battery programs from Summer 2019. The National Grid conclusions are provided in Table 5-1 and Table 5-2 within Section 5.1. The Unitil conclusions are provided in Table 5-3 and Table 5-4 within Section 5.2.

5.1 National Grid Conclusions

Table 5-1: National Grid Findings

Research Category	Findings
Participant Motivations and Lessons Learned	**Access to backup power is a primary motivation for participation.** Access to backup power was a majority of respondent's primary motivation in purchasing a battery backup system, and one of the most important factors in participants decisions to enroll in the program.
	Survey respondents rarely opt out of events. Survey respondents reported extremely low opt-out rates, with 94% reporting they never opted out of an event. They also demonstrated low levels of event awareness, reporting low levels of event participation compared to their actual participation rate.
	Survey respondents support the program. Ninety-seven percent of respondents reported they would recommend the program to other National Grid customers, and 97% reported they were likely or very likely to continue with the program should it be offered in the future.
Energy Storage System Performance	**The program saved around 139 kW per event on average, including 126 kW during the 2019 ISO-NE Peak Hour.**
	Battery devices that successfully participated in 2-hour events saved an average of 5.5 kW per unit.
	On average, called events had 64% of the expected maximum impact given the maximum expected discharge of the batteries operational at the time of the event. This is affected by some batteries opting out of events and also by lower relative performance by some devices, especially DC coupled batteries.
	50 devices participated in at least one event this season. Of these, 32 successfully performed in every event they participated in, while 2 never successfully performed in any of the events they participated in. Additionally, 8 devices that enrolled before the last event of the season never participated as they were not yet installed and operational (i.e., no telemetry data).
	Consecutive event days appeared to have a negligible effect on impacts this season. Weather had a larger effect on devices not being fully charged in time for the next event.
	Successfully participating devices dispatched at a constant rate for the length of the event. This includes DC coupled batteries.
	The conventions (e.g., sign, time zone) associated with the telemetry data varied across manufacturers. Navigant made informed corrections to align the telemetry data for all devices into a single convention.

Table 5-2: National Grid Recommendations and Considerations

Research Category	Recommendations and Considerations
Participant Motivations and Lessons Learned	**Recommendation 1:** Ensure customers are aware National Grid knows backup is important to them. Two manufacturers include the existence of a battery reserve in their marketing materials, and one offers the option, but National Grid does not make this clear in the marketing materials. Create a consistent battery reserve level and publicize both the battery reserve and the restriction of events prior to storms. This will help alleviate customer concern about batteries being depleted when they are being relied upon to provide power in an emergency
Energy Storage System Performance	**Recommendation 2:** National Grid to encourage EnergyHub to work with manufacturers and/or integrators to align all details of the telemetry data so the data fields are consistent.
	Consideration 1: Further explore the factors behind why the per event average fleet performance was 64% of the maximum expected impact, which includes underperformance of devices (especially DC coupled batteries) and opt outs. A subsequent analysis would confirm the appropriate maximum expected discharge to use for different battery makes and models after accounting for battery settings and inverter configurations, and investigate why some batteries failed to participate in some events despite being operational.
	Consideration 2: Explicitly monitor enrollment date versus operational date for devices to ensure devices that can perform in events are performing.
	Consideration 3: Monitor batteries and potentially troubleshoot batteries that are consistently not performing or routinely opting out of events.

5.2 Unitil Conclusions

Table 5-3: Unitil Findings

Research Category	Findings
Participant Motivations and Lessons Learned	**Access to backup power is a primary motivation for participation.** All four participants reported that access to emergency backup power is the main benefit of having a battery system installed at their home.
	The program design was unclear to participants. Participants displayed limited understanding of the program's design. Participants reported conflicting or inaccurate information regarding when events are called, the existence of a battery reserve, and the degree of control they have over their batteries.
	Difficulty scheduling the battery installations was participants' main complaint. Two of the four participants reported difficulty scheduling the installation of their battery; however, despite this, all four participants reported they were satisfied with the battery installer.
	Current participants are unlikely to remain enrolled. Should the daily discharge required by the current program design be continued, half of the interviewees reported that they would not remain enrolled.
	Many stakeholders expressed safety concerns. The battery installer reported that safety concerns were expressed by participants, in part due to several highly publicized battery fires in the last several years. They also reported that code enforcement and inspection requested additional inspection from the fire department in order to assess the risk of battery fires and discuss methods of fire suppression.
	Organized and clear program administration will be key moving forward. While recognizing that the program is still under development, the battery installer reported that the main challenge an expanded program would face is developing and streamlining the program administration, to limit delays and ensure any required data is being collected and recorded in a usable format.
Energy Storage System Performance	**Combining battery storage with solar PV achieved a flattened output profile during portions of events.** The batteries were successful at balancing the solar PV plus battery storage output for the first 2 hours of the 4-hour event for 71% of events; however, the battery storage was successful for 14% of events to balance the solar PV plus battery storage output for the full 4-hour event duration.
	The combined solar PV plus battery storage performed better during the 1 p.m. to 5 p.m. events. Batteries were able to balance the solar PV plus battery storage output for longer during the 1 p.m. to 5 p.m. events than the 3 p.m. to 7 p.m. events, which was due to greater solar PV output during the 1 p.m. to 5 p.m. periods; however, the battery storage was not charging between 1 p.m. and 3 p.m., which reduced its potential state of charge.

Research Category	Findings
	The site with a smaller solar PV array facing south did not perform as well as sites with larger solar PV arrays facing southeast. The site that had the smallest solar PV array was also the only site with south facing solar PV rather than southeast. This site struggled to charge in the mornings throughout September and was less successful at balancing its solar PV plus battery storage output. Meanwhile, the site with the largest PV array was the most successful at balancing the PV plus battery output.
	The average output from the battery storage during the four-hour events was 1.3 kW and 5.2 kWh. In addition to the size and/or direction of the PV and weather conditions affecting the charging of the batteries, it appears the system controller stopped battery charging at 1 p.m., even for events that start at 3 p.m.

Table 5-4: Unitil Considerations

Research Category	Considerations
Participant Motivations and Lessons Learned	**Consideration 1:** Ensure customers are aware Unitil knows backup is important to them. A 20% battery reserve was seen in the data and observed by participants. This will help alleviate customer concern about batteries being depleted when they are being relied upon to provide power in an emergency.
	Consideration 2: Educate participants more fully about the program design upon enrollment to ensure participants understand their commitment.
	Consideration 3: Ensure internal processes and data protocols are well established and defined. This will help limit delays in enrollment and installation and help keep customer satisfaction high.
Energy Storage System Performance	**Consideration 4**: Consider different approaches to increase event success, for example, reduce the duration of events from 4 hours to 2 hours or reduce the targeted output of the combined solar PV plus battery output during events.
	Recommendation 1: Discuss with the battery manufacturer why the battery charging stopped at 1 p.m. for events that occurred from 3 p.m. to 7 p.m.
	Consideration 5: Continue the evaluation into summer 2020 to include June, July, and August when solar insolation is typically stronger, and any control algorithm updates have been implemented.

APPENDIX A. INTERVIEW GUIDES

A.1 Unitil 2019 Participant Interview Guide

Research Objective	Interview Question Numbers
What is the primary motivation for customers to participate in Unitil's demonstration? What value streams are most important to them?	Q1-4
Would customers continue to allow Unitil to control the system during peak periods in the future?	Q6-9
What are the barriers to full-scale deployment that the participants identify?	Q5, Q7-13

[INTRO SCRIPT] Thank you for your time today. Navigant is conducting an evaluation of Unitil's Solar PV/battery storage demonstration program. The primary goal of our discussion today is to help me understand your participation in Unitil's program and identify ways Unitil can improve the program for you and future participants.

Just a reminder that I am recording this call, so I can focus on the discussion rather than notetaking. I will not share this recording beyond my immediate Navigant team and will only use it to clarify my notes after the call.

Are you ready to get started?

1. Can you explain how you learned about this program?

2. Why did you decide to participate?

3. What would you say is the most valuable part of having a battery storage system at your house?

4. How much did having a battery backup during power outages factor into your decision to enroll in the program?

    a. Have you used the batteries during an outage since they were installed?

    b. How would you compare having a battery backup system available during outages to having a generator? Which do you prefer?

5. What level of concern, if any, do you have that the Connect Solution Program may be draining batteries when you are counting on them for backup purposes?

    a. *[Interviewer should ask respondent to please explain the reason for their response]*

6. How was the installation process?

a. How long did it take from the time you enrolled to when the system was installed?

b. Did you encounter any issues with the installation? *[If yes, probe for respondent to describe the issues]*

c. Did you have to change anything on your property, such as in your yard or on your house, to accommodate the battery system?

7. Will you continue to participate after the demonstration period if a program is offered? *[Note to interviewer in case there are questions: The demonstration ends 9/30/2021].*

8. Did an event being called change anything about how you used your home or your battery?

9. Did you notice anything when the battery system took over?

10. Did you encounter any problems with the battery system or the program?

a. If yes, please describe

11. Have you told anyone besides Unitil staff about your participation in this program? *[If yes, probe to understand who they talked to, through what channels (face to face, social media, etc), and the nature of the conversation (positive recommendation, etc)]*

a. What was their response?

12. Would you have purchased a battery storage system if Unitil had not covered the cost of purchase and installation for you?

a. If no, why not?

b. If no, would a financial incentive like an annual bill credit have been enough to convince you?

i. How much of an annual bill credit?

c. If yes, why would you have purchased the battery storage system?

i. What would you have been willing to pay for it?

13. Do you think other people would want a battery storage system like yours through Unitil's program? Why or why not?

14. Do you have any other comments or suggestions about the program or your experience that you would like to share?

A.2 Battery System Installer Interview Guide

The key objective to this interview is to understand barriers to full-scale deployment identified by the ESS installer.

[INTRO SCRIPT] Thank you for your time today. Navigant is conducting an evaluation of Unitil's Solar PV/battery storage demonstration program. The primary goal of our discussion today is to help me understand your participation in Unitil's program and identify ways Unitil can improve the program for you and future participants. We would also like your input and perspective on opportunities and barriers to full-scale deployment of Unitil's demonstration program to other residential customers.

Is it okay if I record this call so I can focus on the discussion rather than notetaking? I will not share this recording beyond my immediate Navigant team and will only use it to clarify my notes after the call.

Are you ready to get started?

1. How did your company become involved in Unitil's storage demonstration program?

    a. Does your company have prior experience with battery installation? How much experience?

2. How frequently were you in contact with Unitil about the program during the program design process?

    a. What was the nature of your communication? Did you provide input on the program design?

3. How frequently were you in contact with Unitil during the program deployment and installation process?

    a. What was the nature of your communication?

4. What do you think customers appreciate about having battery storage in their homes?

5. Did Unitil customers share any concerns about having battery storage in their homes?

6. Unitil mentioned that the fire department had concerns about the batteries posing a fire risk. Were you aware of this? Do you know if customers were aware of this? Did they mention anything about the potential for fire?

7. Did customers share any (other) concerns about Unitil's battery storage program?

8. Do you have any feedback on the design of Unitil's battery storage program, based on your experience as an installer?

    a. What do you feel are the best aspects of the program?

    b. What could be improved?

9. Next, I have a few questions about the battery installation process:

    a. How long did it take from the time you were put in contact with the customer to the installation being finished?

b. Did you encounter any issues with the installations? *[If yes, probe for respondent to describe the issues]*

c. Did you have to alter anything on customers' property, such as in the yard or inside their house?

d. Have you had any contact with customers since the installation was completed, for example, to perform maintenance or answer questions? If so, why, and what was discussed?

e. Do you have any additional comments or recommendations about the installation process that you want to mention?

10. What do you think the biggest challenge Unitil, customers or installers would face if the program became more widely available to customers?

11. Do you have any other comments or suggestions about the battery storage program or your experience that you would like to share?

APPENDIX B. SURVEY GUIDE

B.1 National Grid 2019 ConnectedSolutions Summer Participant Survey

Table B-1. Survey Characteristics

Characteristics	Description
Statement of purpose	Identify customer motivations and value streams to assess scalability of the energy storage demand response program
Qualified respondent	National Grid customer with a battery storage system who has enrolled in the Connection Solutions program
Population size	65
Target number of completes	50
Estimated survey length	15 questions, 5 minutes
Survey timeline	Close of season (likely September 2019)
Survey mode	Online

Table B-2. Research Objectives

Research Objective	Survey Questions
What was the primary motivation for customers to obtain a battery and participate in the program?	Q2-7
How would National Grid offering of a 5-year guaranteed incentive affect the customers' decision to join the demonstration if they had existing batteries and to purchase the battery if they did not have a battery already	Q5-6
What are the barriers to full-scale deployment that the participants identify?	Q10-15
Would customers continue to allow National Grid to control the system during peak periods in the future?	Q11-13
What were customer usage patterns prior to participation?	Q8-9

Start of Block: Verification

Landing Thank you for taking a few moments to answer these questions about National Grid's **Connected**Solutions Battery Program. This is a 5-minute survey and all responses will remain anonymous.

Q1 Do you participate in National Grid's **Connected**Solutions battery program?

- ○ Yes (1)
- ○ No (2)

End of Block: Verification

Start of Block: Motivations

Q2 Did you own your battery system prior to your enrollment in the program?

- ○ Yes, I enrolled with a previously purchased battery system (1)
- ○ No, I bought a battery when I enrolled (2)

Q3 What was your primary motivation in purchasing a battery system?

- ○ Reduce my environmental impact (1)
- ○ Access to battery backup (2)
- ○ Ability to test new technologies (3)
- ○ Save money on my energy bills (4)
- ○ Reduce the need for additional power plants (5)
- ○ Support our community and/or state's energy initiatives (6)

Own battery before? = No, I bought a battery when I enrolled

- ○ To participate in the **Connected**Solutions Program (7)

Own battery before? = No, I bought a battery when I enrolled

- ○ To increase the SMART program incentive (8)
- ○ Other: (97) _____

Display This Question:

If Own battery before? = No, I bought a battery when I enrolled

Q4 How important a factor was National Grid's **Connected**Solutions program in your decision to purchase a battery system?

- ○ Critical (1)
- ○ Very important (2)
- ○ Important (3)
- ○ Slightly important (4)
- ○ Not at all important (5)

Display This Question:

If Own battery before? = No, I bought a battery when I enrolled

Q5 How important was National Grid's guaranteed 5-year incentive in your decision to purchase a battery system?

- Critical (1)
- Very important (2)
- Important (3)
- Slightly important (4)
- Not at all important (5)

Display This Question:

If Own battery before? = Yes, I enrolled with a previously purchased battery system

Q6 How important was National Grid's guaranteed 5-year incentive in your decision to enroll in **Connected**Solutions?

- Critical (1)
- Very important (2)
- Important (3)
- Slightly important (4)
- Not at all important (5)

Q7 Please rank how important each of the following was in your decision to enroll in National Grid's **Connected**Solutions Battery Program.

	Not at all important (1)	Slightly Important (2)	Important (3)	Very Important (4)	Critical (5)
Reduce need for peaking power plants (1)	○	○	○	○	○
Reduce my environmental impact (2)	○	○	○	○	○
Reduce the need for additional power plants (3)	○	○	○	○	○
Support my community and/or state's energy initiatives (4)	○	○	○	○	○
Access to battery backup (5)	○	○	○	○	○
Ability to test new technologies (6)	○	○	○	○	○
Receive participation incentives (7)	○	○	○	○	○
Guaranteed incentives over time (8)	○	○	○	○	○

Display This Question:

If Rank importance all = Access to battery backup [Important]

Or Rank importance all = Access to battery backup [Very Important]

Or Rank importance all = Access to battery backup [Critical]

Or primary motivation? = Access to battery backup

Q8 How concerned are you, if at all, that the **Connected**Solution Program may have discharged batteries when you are counting on them for backup purposes?

- ○ Very concerned (1)
- ○ A little concerned (2)
- ○ Not at all concerned (3)

End of Block: Motivations

Start of Block: Previous usage patterns

Display This Question:

If Own battery before? = Yes, I enrolled with a previously purchased battery system

Q9 Before your enrollment in the **Connected**Solutions Battery Program, did you ever use your battery storage system? Select all that apply.

- ☒ No, the battery system was not used prior to enrollment (1)
- ☐ Yes, default daily or near daily discharge (2)
- ☐ Yes, during a power outage (3)
- ☐ Yes, during a different period (please explain) (4)

_____

End of Block: Previous usage patterns

Start of Block: Current usage patterns

Q10 While enrolled in **Connected**Solutions, did you ever manually control (charge or discharge) your battery system outside of power outages, daily discharge requirements, and when National Grid utilized your battery as part of the program?

- ○ Yes (please explain) (1) _____
- ○ No (2)
- ○ Don't know (98)

Q11 Has National Grid dispatched your battery system this summer?

- ○ Yes (1)
- ○ No (2)
- ○ Don't know (98)

Display This Question:

If Event awareness? = Yes

Q12 Approximately how many times has National Grid dispatched your energy storage system this summer?

_____

Display This Question:

If Event awareness? = Yes

Q13 How often have you chosen to opt out of events while enrolled in **Connected**Solutions?

- I/we have opted out of **every event** (1)
- I/we have opted out of **most events** (2)
- I/we have opted out of **some events** (3)
- I/we **rarely** opt out of events (4)
- I/we have **never** opted out of an event (5)
- Don't know (98)

Display This Question:

If Opt out #? = I/we have opted out of <u>every event</u>

Or Opt out #? = I/we have opted out of <u>most events</u>

Or Opt out #? = I/we have opted out of <u>some events</u>

Or Opt out #? = I/we <u>rarely</u> opt out of events

Q14 Please describe the reason(s) you have chosen to opt out of event(s).

_____

Q15 Have you experienced any technical difficulties or malfunctions with your battery system?

- Yes (1)
- No (2)
- Don't know (98)

Display This Question:

If tech difficulties? = Yes

Q16 Please describe the technical difficulties or malfunctions you have experienced.

_____

End of Block: Current usage patterns

Start of Block: Barriers to full scale deployment

Display This Question:

If Event awareness? = Yes

Q17 Did participation in the program change anything about how you went about your day during periods when your battery system was dispatched by National Grid? For example, did you reduce your energy usage when you knew you were running off of battery power? Select all that apply.

- ☒ No, I didn't change anything (1)
- ☐ Yes, I reduced my energy usage (please explain) (2)
  _____
- ☐ Yes, I made a different change (please explain) (3)
  _____

Q18 How likely are you to continue participating in the **Connected**Solutions battery program?

- ○ Very unlikely (1)
- ○ Unlikely (2)
- ○ Neutral (3)
- ○ Likely (4)
- ○ Very likely (5)
- ○ Don't know (98)

Display This Question:

If Likely continue? = Very unlikely

Or Likely continue? = Unlikely

Or Likely continue? = Neutral

Or Likely continue? = Don't know

Q19 Please explain the reason for your response.

_____

Display This Question:

If Likely continue? = Very unlikely

Or Likely continue? = Unlikely

Or Likely continue? = Neutral

Or Likely continue? = Don't know

Q20 What change(s) to the **Connected**Solutions Program would encourage you to continue participating?

_____

Q21 Would you recommend this program to other National Grid customers?

- ○ Yes (1)
- ○ No (2)
- ○ Don't know (98)

Display This Question:

If recommend? = No

Q22 Why not?

_____

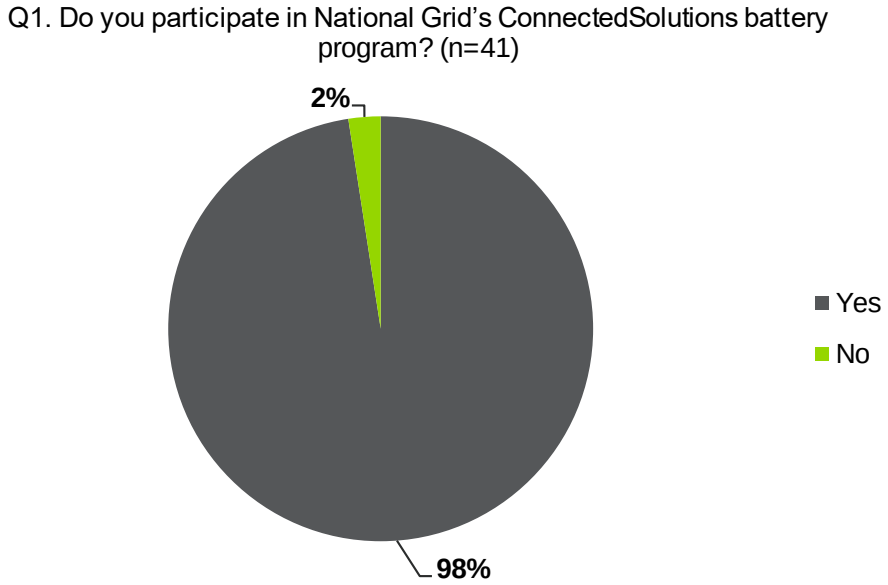
Q23 Please confirm your email address in order to receive your $10 Amazon ® gift card. Gift cards will be emailed out 2-4 weeks after survey completion.

○ Email Address (1) _____

End of Block: Barriers to full scale deployment

APPENDIX C. FULL SURVEY RESULTS

C.1 Verification

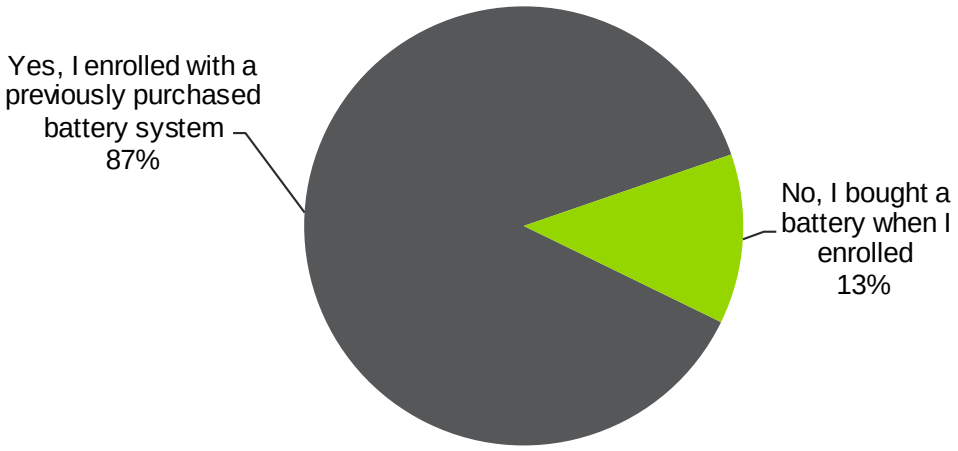


** The respondent who reported they did not participate in the program was screened out, and as such, all further questions were asked of the remaining 40 respondents only.*

Source: Navigant analysis of online survey data

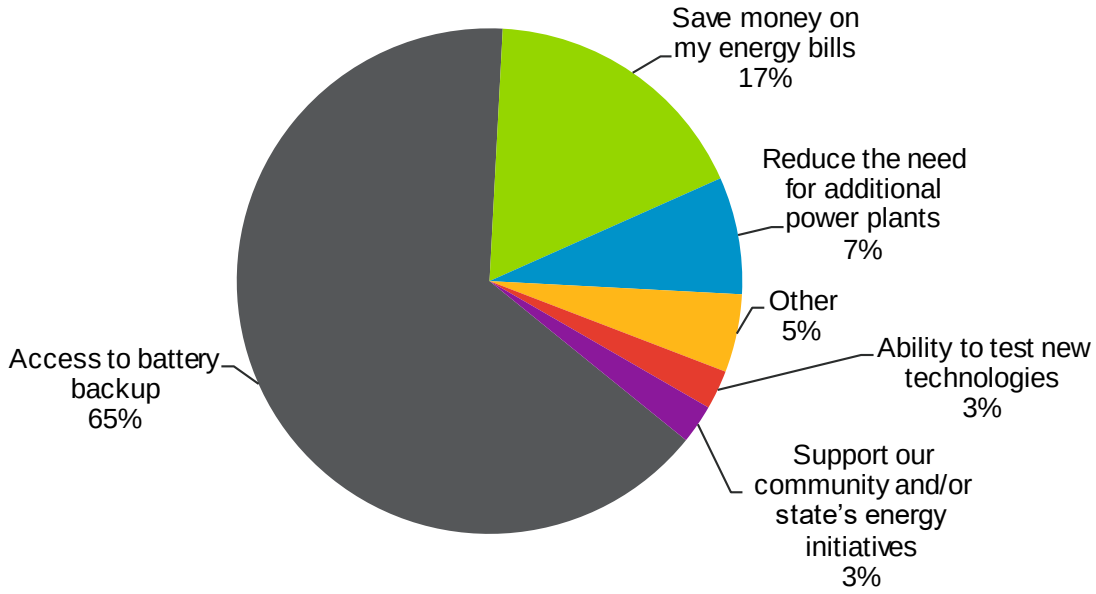
C.2 Motivations

Q2. Did you own your battery system prior to your enrollment in the program? (n=40)



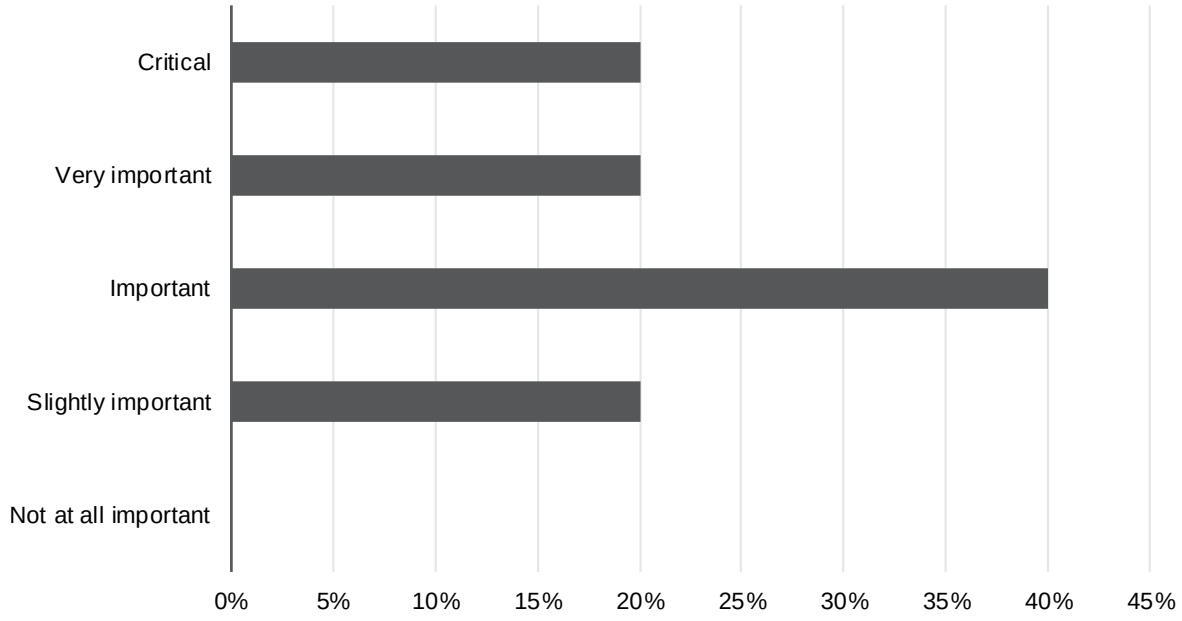
Source: Navigant analysis of online survey data

Q3. What was your primary motivation in purchasing a battery system? (n=40)



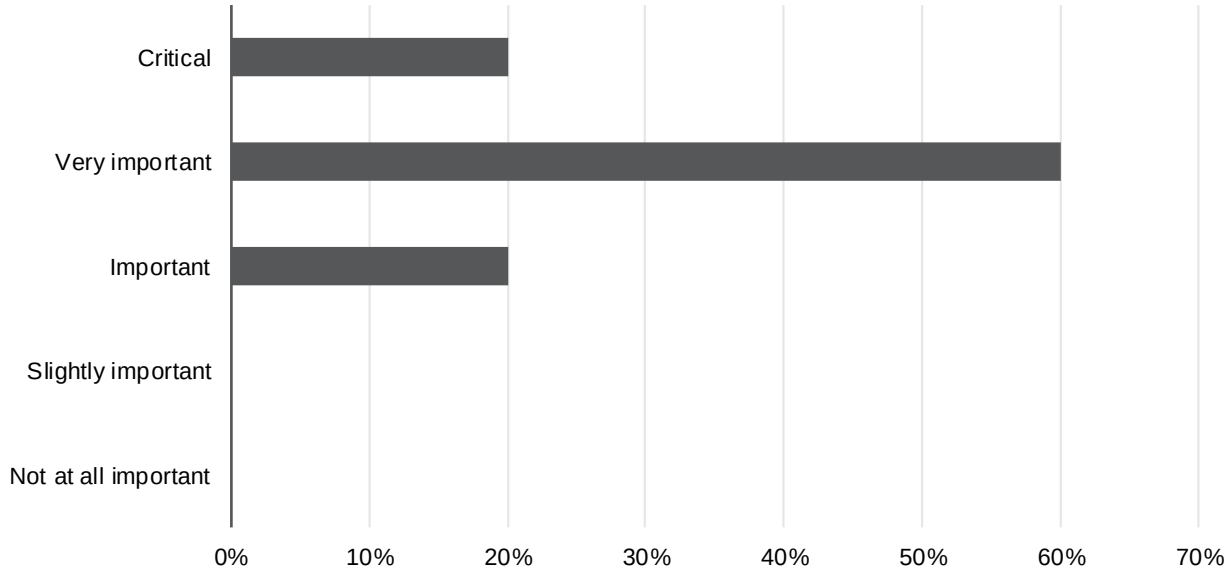
Source: Navigant analysis of online survey data

Q4. How important a factor was National Grid's ConnectedSolutions program in your decision to purchase a battery system? (n=5)



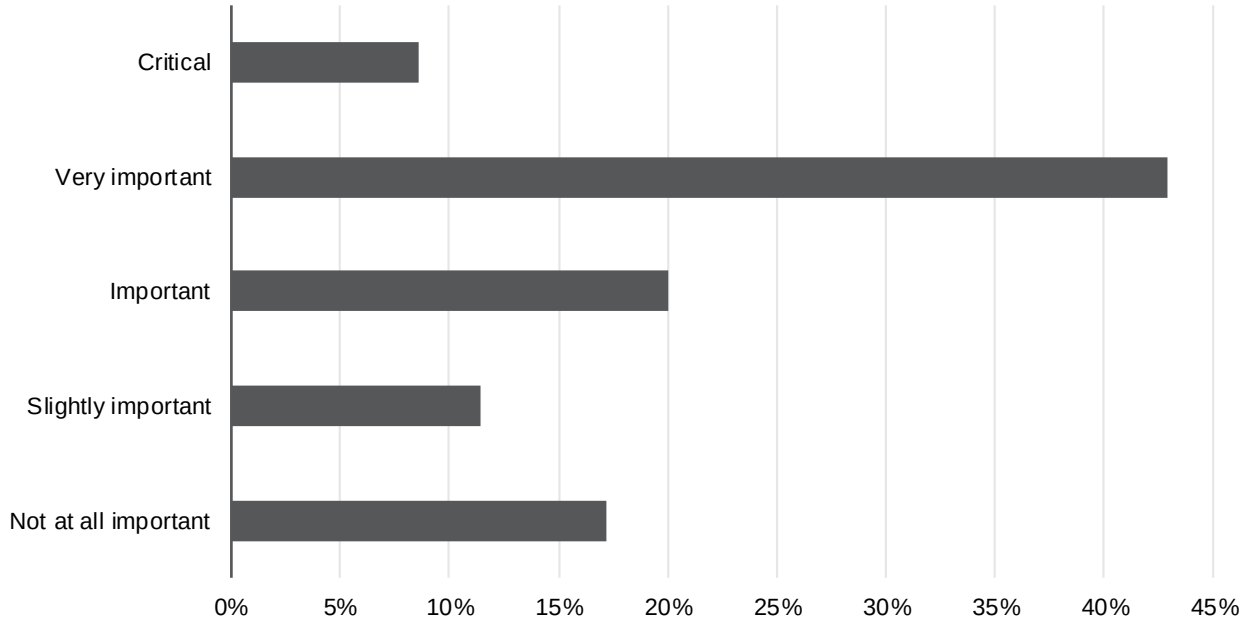
** Question 4 was only asked to respondents who purchased a battery when they enrolled*
Source: Navigant analysis of online survey data

Q5. How important was National Grid's guaranteed 5-year incentive in your decision to purchase a battery system? (n=5)

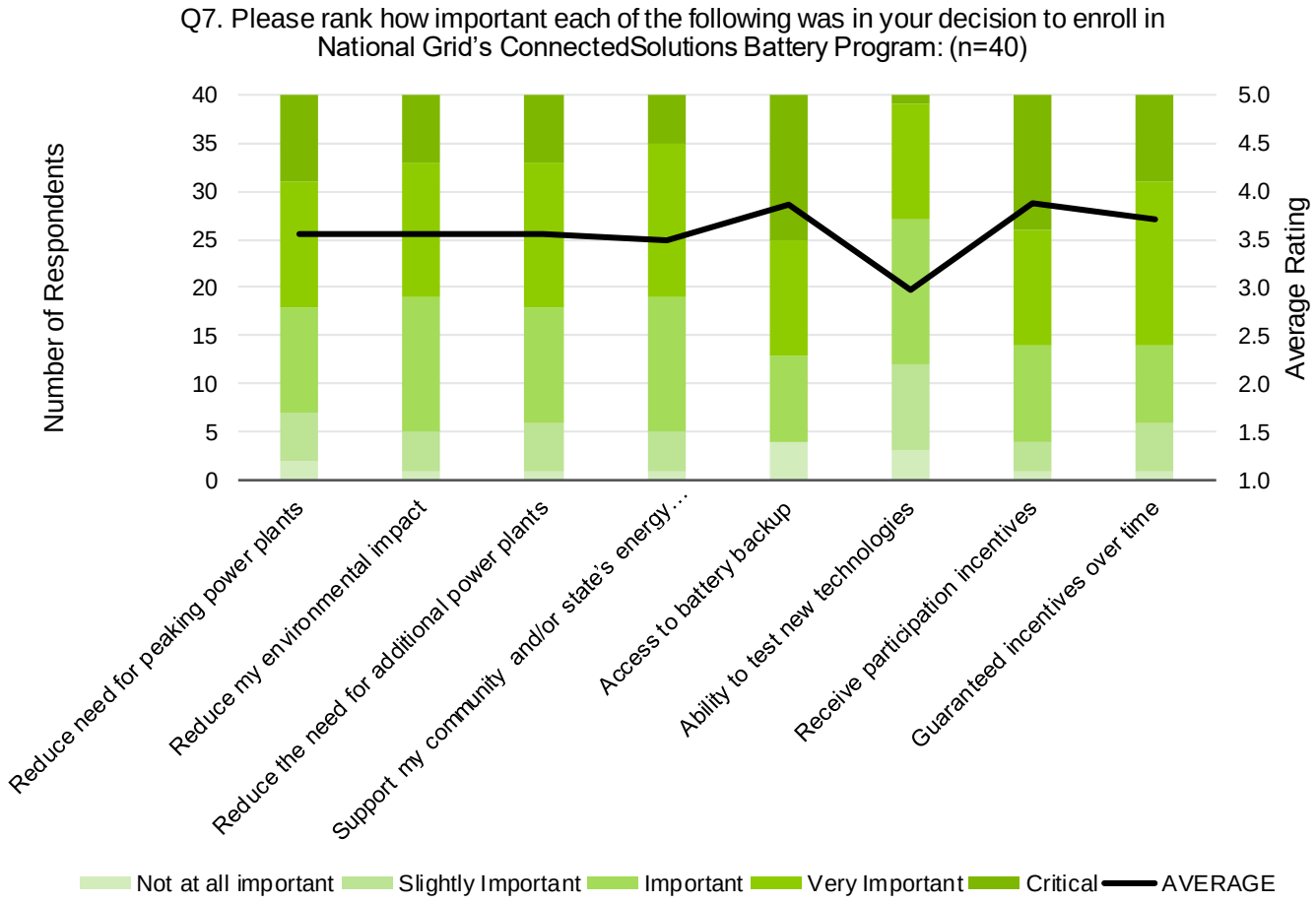


** Question 5 was only asked to respondents who purchased a battery when they enrolled*
Source: Navigant analysis of online survey data

Q6. How important was National Grid's guaranteed 5-year incentive in your decision to enroll in ConnectedSolutions? (n=35)



** Question 6 was only asked to respondents who enrolled with a previously purchased batteries*
Source: Navigant analysis of online survey data

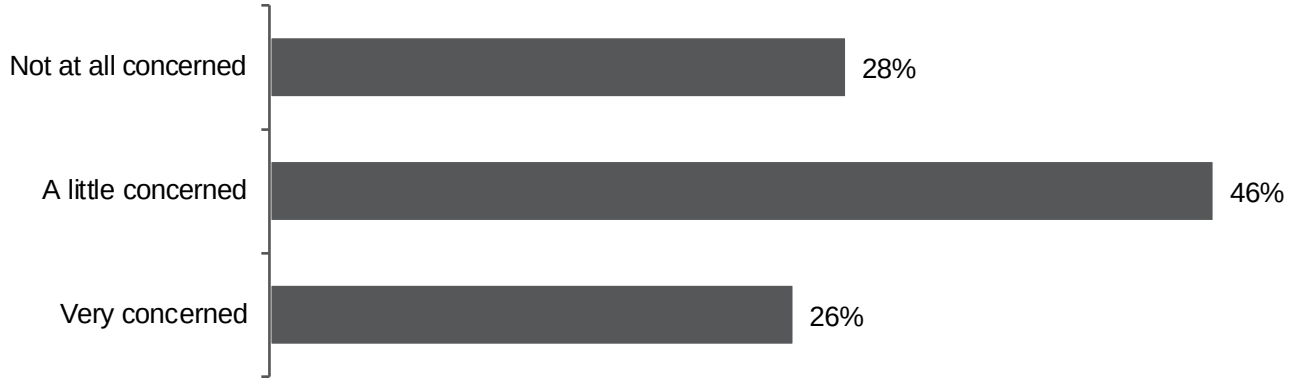


Source: Navigant analysis of online survey data

Response	Total Population Average (n=40)	Previously Owned Battery Average (n=35)	Newly Purchased Battery Average (n=5)
Reduce need for peaking power plants	3.6	3.7	2.6
Reduce my environmental impact	3.6	3.7	2.8
Reduce the need for additional power plants	3.6	3.7	2.8
Support my community and/or state's energy initiatives	3.5	3.6	3.0
Access to battery backup	3.9	3.7	4.6
Ability to test new technologies	3.0	3.0	2.6
Receive participation incentives	3.9	3.9	3.8
Guaranteed incentives over time	3.7	3.7	3.6

Source: Navigant analysis of online survey data

Q8.How concerned are you that the Connect Solution Program may have discharged batteries when you are counting on them for backup purposes? (n=39)

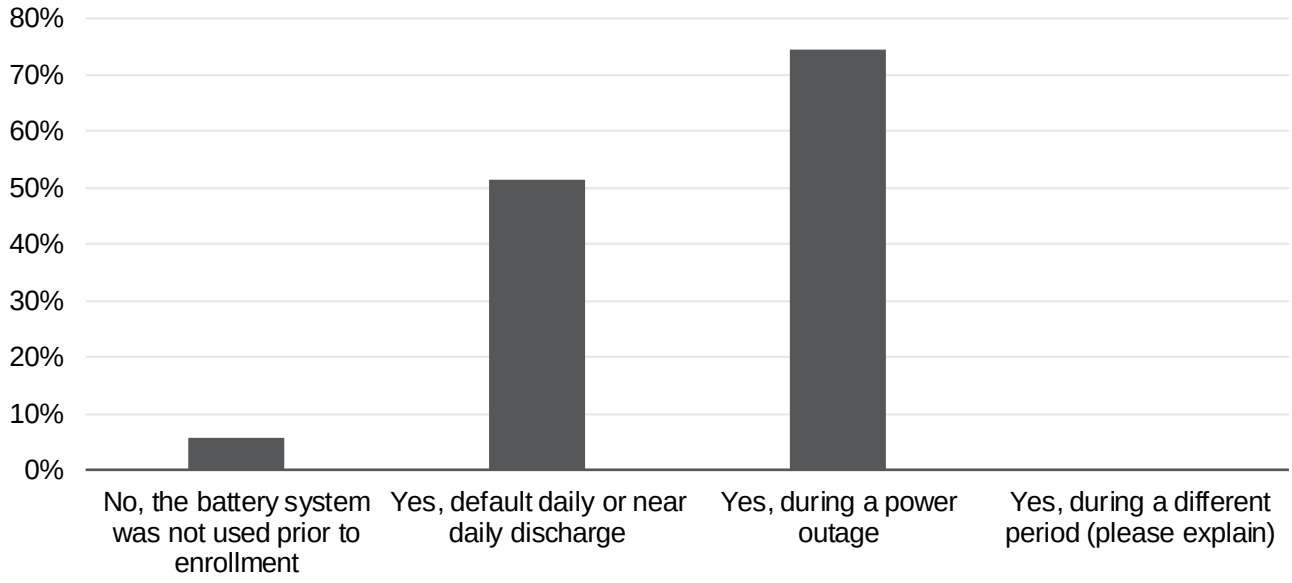


** Question 8 was only asked to respondents who indicated access to battery backup was their primary motivation in Question 3, or ranked access to battery backup above a 3 in Question 7*

Source: Navigant analysis of online survey data

C.3 Previous Usage Patterns

Q9. Before your enrollment in the ConnectedSolutions Battery Program, did you ever use your battery system? Select all that apply. (n=35)

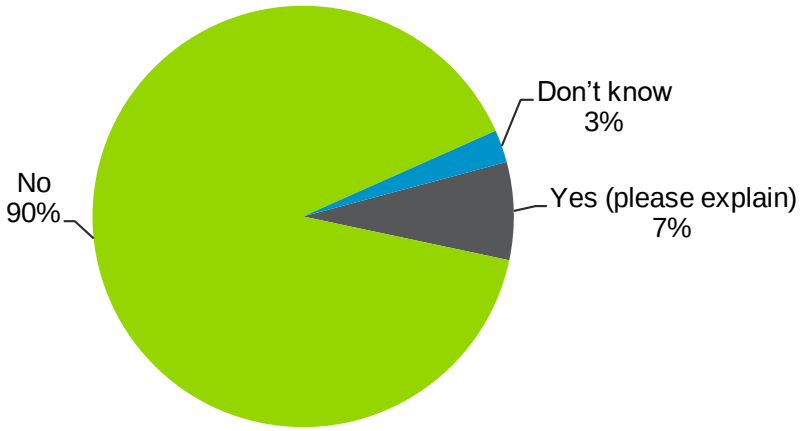


** Question 9 was only asked to respondents who enrolled with a previously purchased battery. Respondents could choose multiple responses.*

Source: Navigant analysis of online survey data

C.4 Current Usage Patterns

Q10. While enrolled in ConnectedSolutions, did you ever manually control (charge or discharge) your battery system outside of power outages, daily discharge requirements, and when National Grid utilized your battery as part of the program? (n=40)

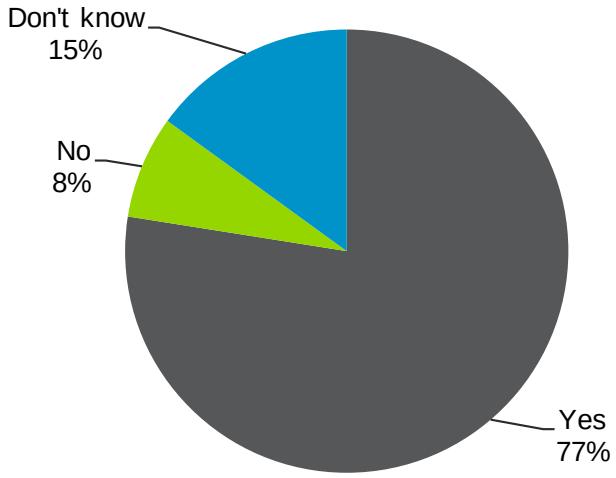


Source: Navigant analysis of online survey data

Customer verbatims for Q10:

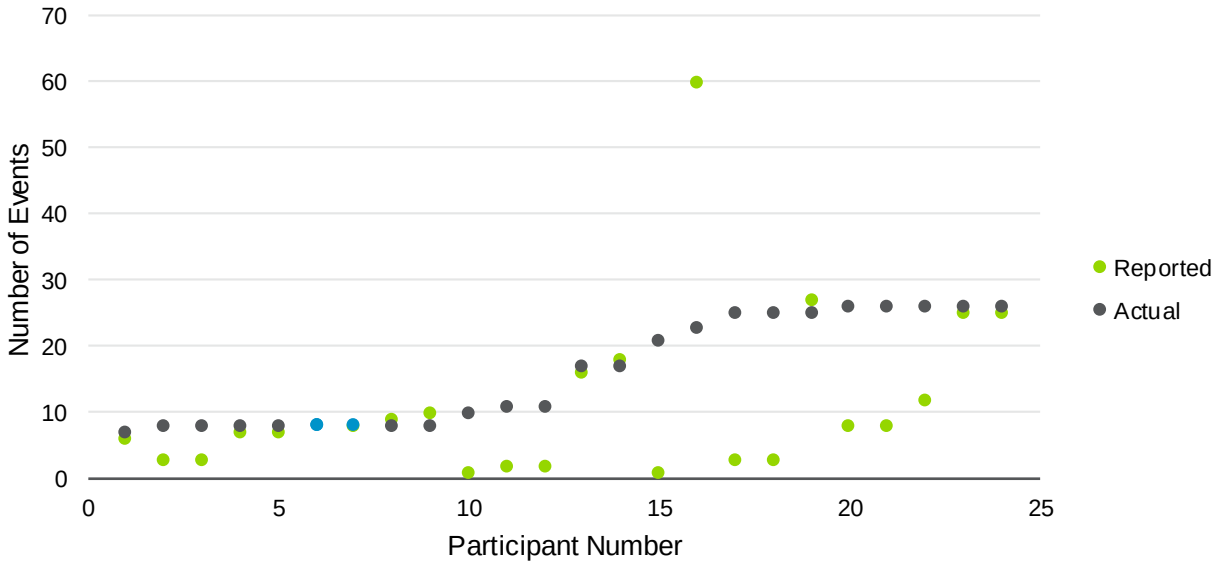
- Setting a higher reservation in anticipation of a storm related outage.
- We discharge our battery to 20% daily to capture the greatest environmental impact of our solar system.
- Would use it to power house from time to time for testing.

Q11. Has National Grid dispatched your energy storage this summer? (n=40)



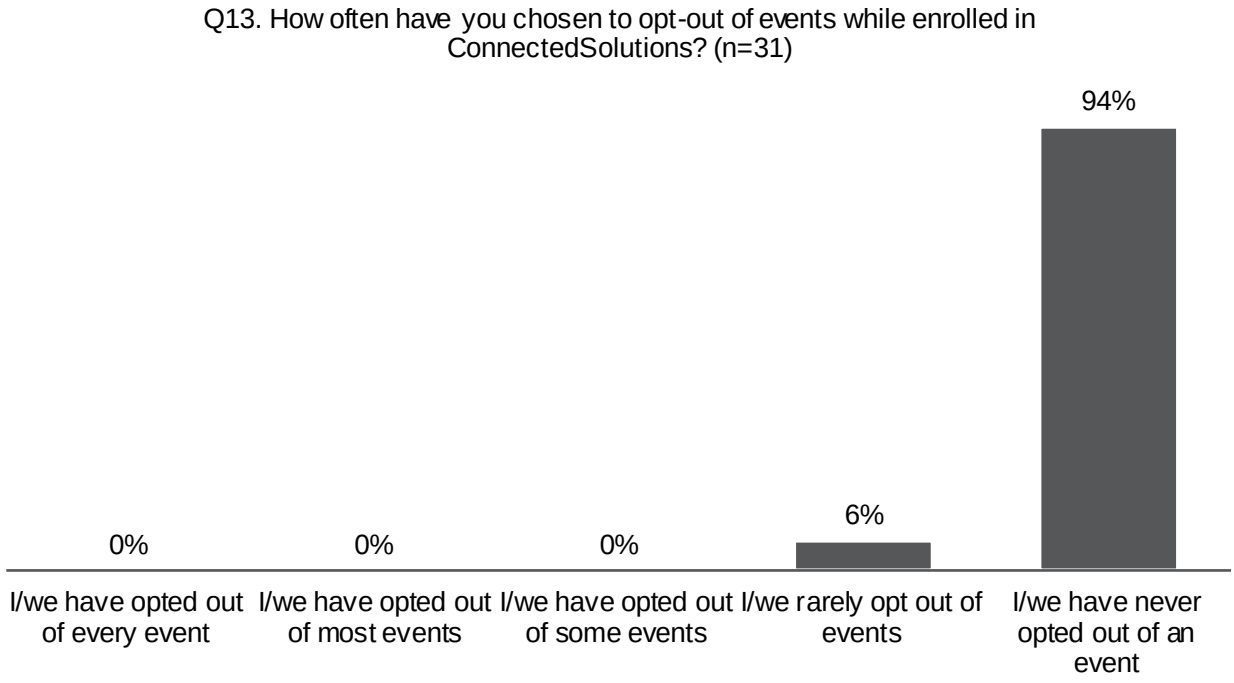
Source: Navigant analysis of online survey data

Q12. Approximately how many times has National Grid dispatched your battery system this summer? (n=31)



** Question 12 was only asked to respondents who remembered events occurring. The graph displays data for respondents who are included in the impact analysis only. Blue dots represent participants who correctly reported the number of events they participated in.*

Source: Navigant analysis of online survey data

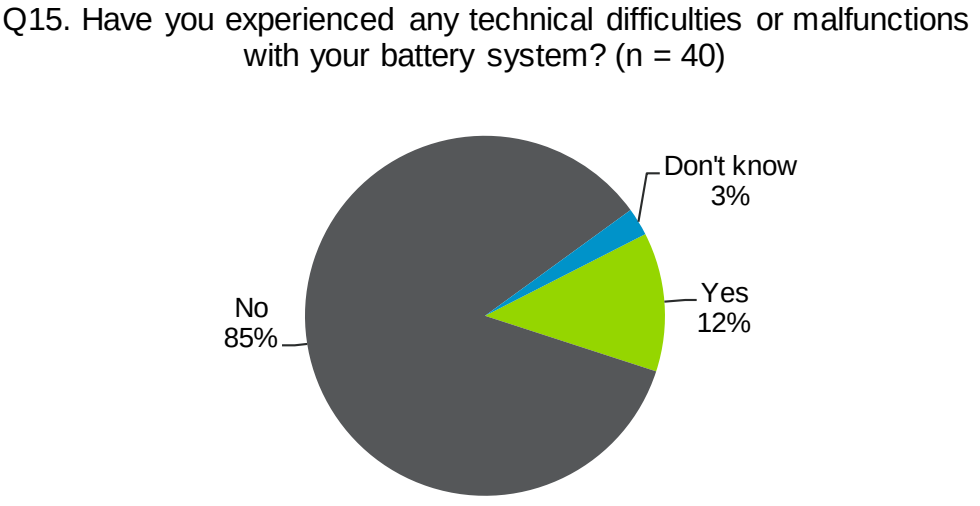


** Question 13 was only asked to respondents who remembered events occurring*
Source: Navigant analysis of online survey data

Question 14: "Please describe the reason(s) you have chosen to opt out of event(s). "

Customer verbatims for Q14:

- House to [sic] hot, needed it to be cooler
- X



Source: Navigant analysis of online survey data

Question 16: "Please describe the technical difficulties or malfunctions you have experienced." (n=5)

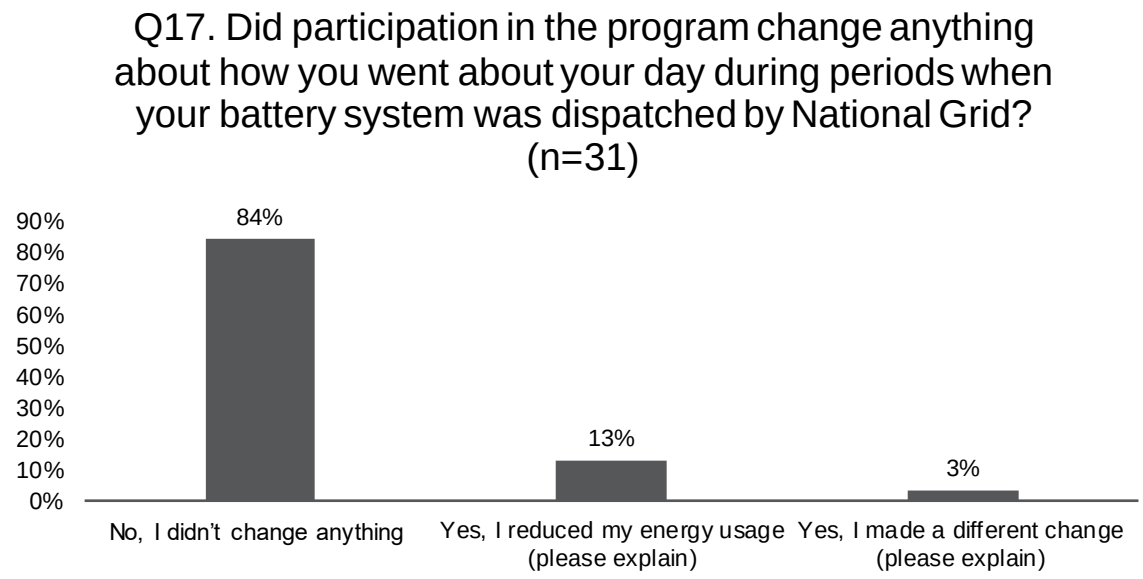
Customer verbatims for Q16:

Open ended verbatim

- BEFORE enrolling in the program, my battery system failed due to hardware issues with the original installation. It took a couple of months to receive replacement components.
- Feb - April 2019 we had software issues and produced little power, the techs had a hard time working on our system because they were unfamiliar with the battery attached to the system.
- Needed replacement part, had to be rebooted.
- [Manufacturer] has had to come and fix it a couple of times.
- [Manufacturer] metering issue has caused battery to be taken offline.

** Question 16 was only asked to respondents who indicated they encountered technical difficulties with their battery storage systems.*

C.5 Barriers to Full-scale Deployment

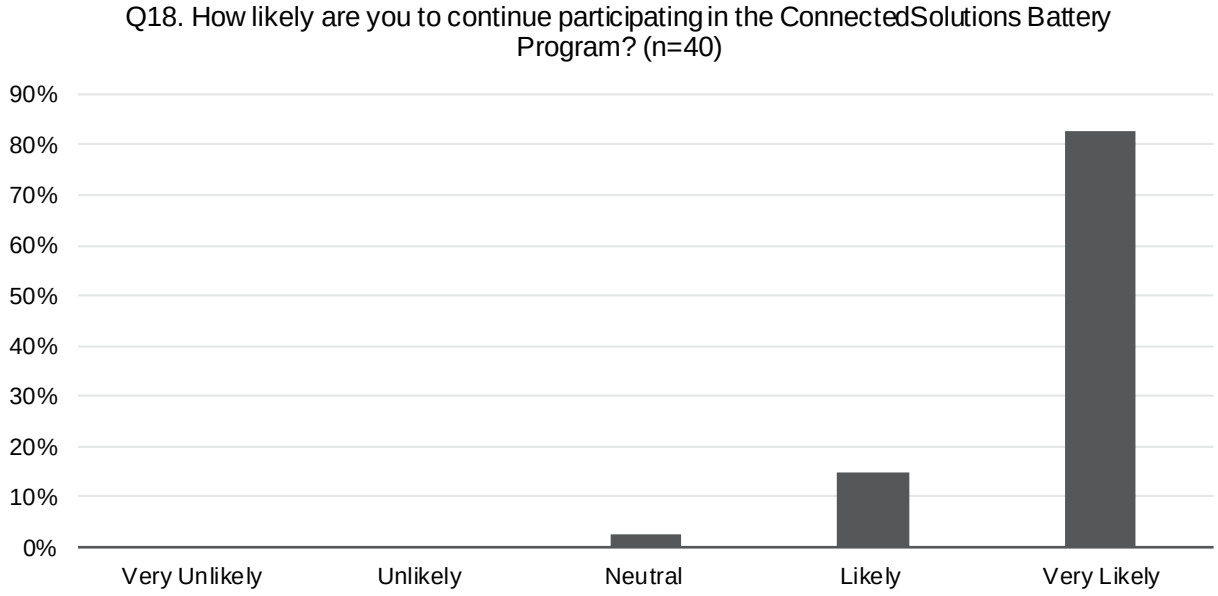


** Question 17 was only asked to respondents who remembered events occurring*
Source: Navigant analysis of online survey data

Customer verbatims for Q17:

- We set our smart thermostat on eco through the day during the summer while we were not home
- Adjusted thermostat

- Less air conditioning used on dispatch days
- Stopped charging EV's and turned up AC to reduce its usage
- When a morning event was scheduled I changed my previous nightly setup to not discharge the battery. Normally I run on the battery between 10pm and 10am



** One response to Question 18 was recoded from "very unlikely" to "very likely;" based on the follow-up response, we believe the Q18 response was selected in error.*

Source: Navigant analysis of online survey data

Question 19: "Please explain the reason for your response. " (n=2)

Customer verbatims for Q19:

- Allowing the grid to access power stored on batteries will help avoiding power outages all together.*
- I have not been in the program long enough to have a full opinion of the program.

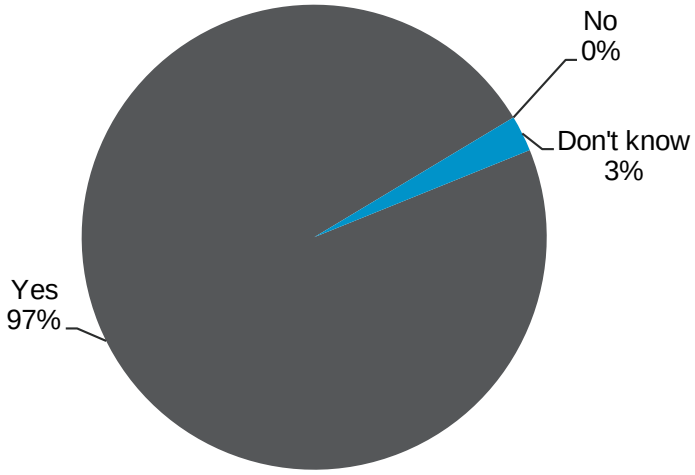
***** *Question 19 was only asked to respondents who rated their likelihood to continue neutral or lower. The starred response was the follow-up for the recoded Q18 answer.*

Question 20: "What change(s) to the ConnectedSolutions Program would encourage you to continue participating?" (n=2)

- Higher payouts
- too early to tell

***** *Question 20 was only asked to respondents who rated their likelihood to continue neutral or lower.*

Q21. Would you recommend this program to other National Grid customers?
(n=40)



Source: Navigant analysis of online survey data

Question 22: "Why not?" (n=0)

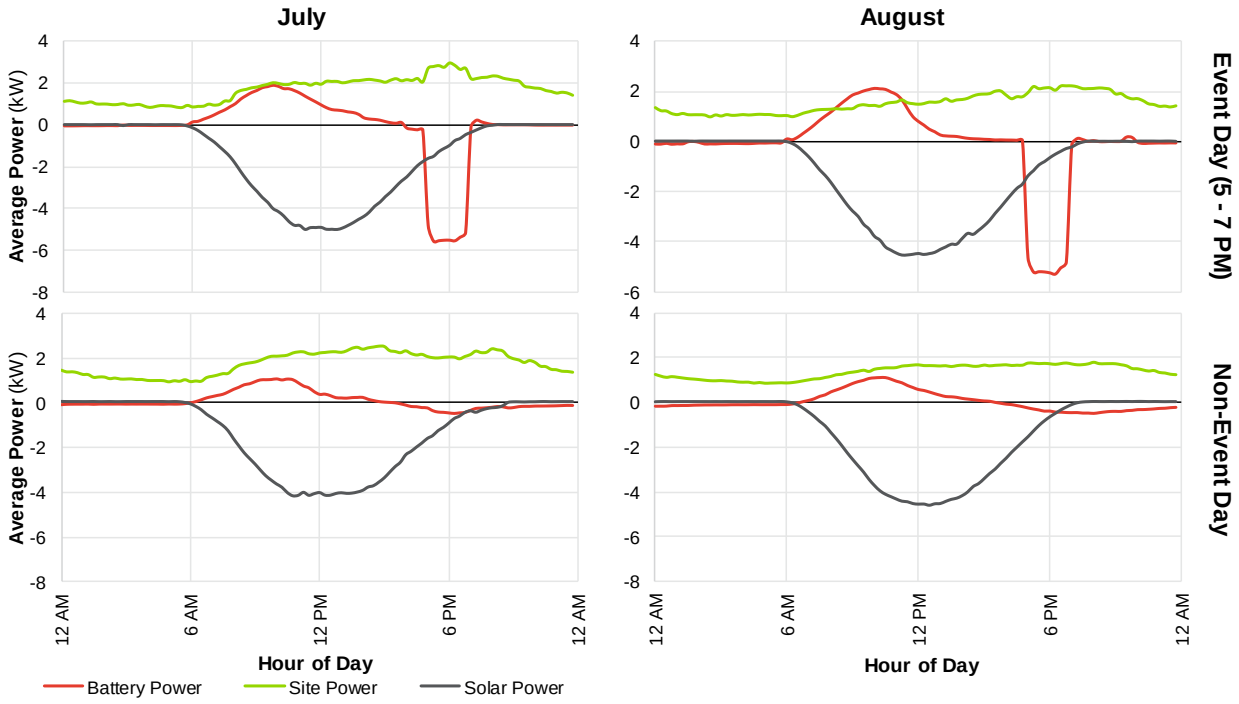
** Question 22 was only asked to respondents who indicated they would not recommend the program and received no responses.*

APPENDIX D. ADDITIONAL NATIONAL GRID IMPACT ANALYSIS

D.1 Average Daily Load Profiles

Beyond the average impact over the entirety of an event, Navigant also explored the average 15-minute power profiles for event days and non-event days. Since 2-hour events starting at 5 p.m. were the most common events called (12 of 18 in July and 7 of 9 in August), days with these events are averaged for participating batteries to represent the typical event. These daily load profiles are shown in Figure D-1.

Figure D-1: Average Daily Load Profiles by Day Type and by Month



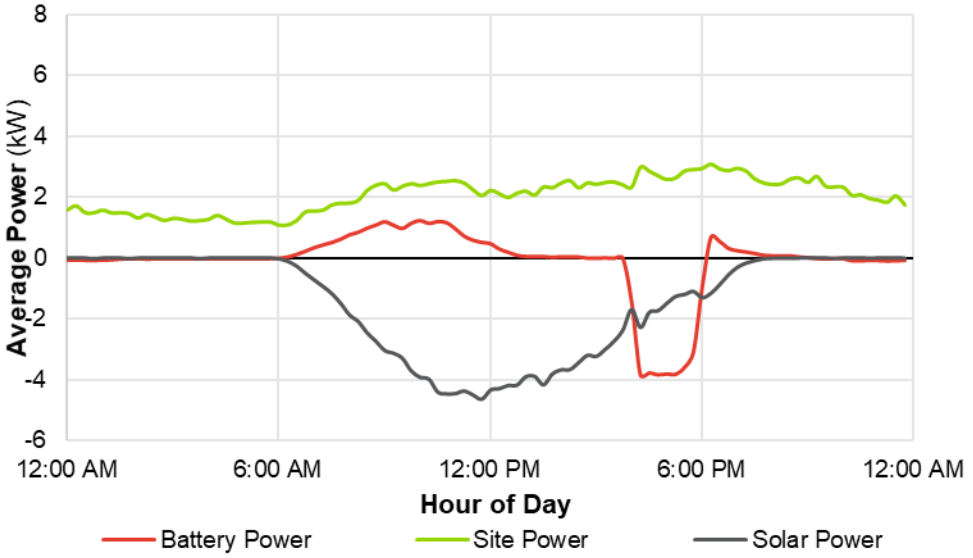
Source: Navigant Analysis

As intended, the energy storage dispatch occurs at a relatively constant rate on average over the course of the event. If anything, there is a slight decline in power over time, which seems to be caused by the decrease from the maximum power output to the continuous power output for some batteries (though other battery models do not exhibit this behavior).

D.2 Performance of DC Coupled Batteries

Another consideration is regarding the performance of DC coupled batteries, that is, batteries that share a single inverter with a solar PV system. For AC coupled batteries – where there are separate inverters for the solar PV and battery – there should not be an issue with solar PV and battery power discharging at the same time. But with DC coupled batteries, the single inverter could be a limiting factor in how much power can be discharged. If so, there could be an inverse relationship between solar power production and energy storage dispatch, thereby limiting the battery's impact. To explore this, Figure D-2 shows the average daily profile for the 15 known DC coupled batteries that participated in any of the 7 events that started at 4 p.m. and lasted for 2 hours. It appears that the inverter configuration did not affect the shape of the energy storage output over the course of the event.

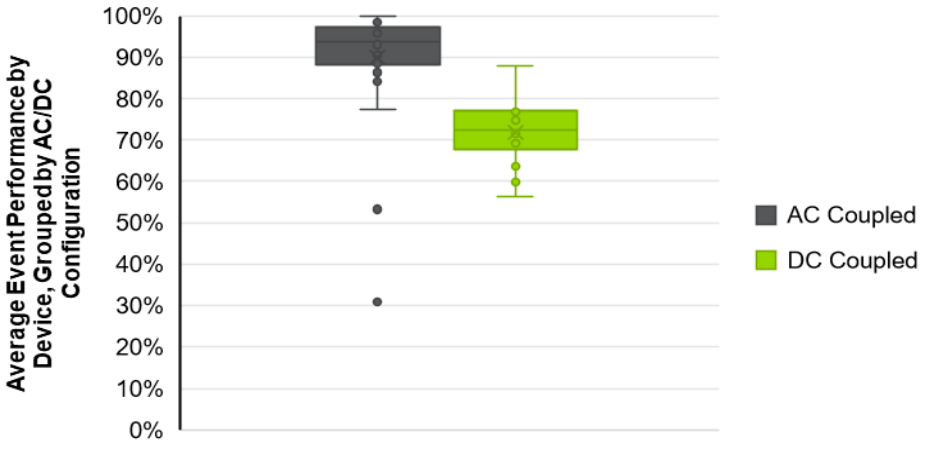
Figure D-2: Average Daily Load Profile for DC Coupled Devices for 4 p.m. – 6 p.m. Events



Source: Navigant Analysis

However, in looking at the per event impact by configuration, DC coupled batteries consistently performed at a lower percentage of their maximum expected discharge than AC coupled batteries. This can be seen in Figure D-3, which shows the average event performance relative to the devices' maximum expected discharge for each event they participated in, grouped by inverter configuration.

Figure D-3: Average Event Performance by Battery, Grouped by Inverter Configuration



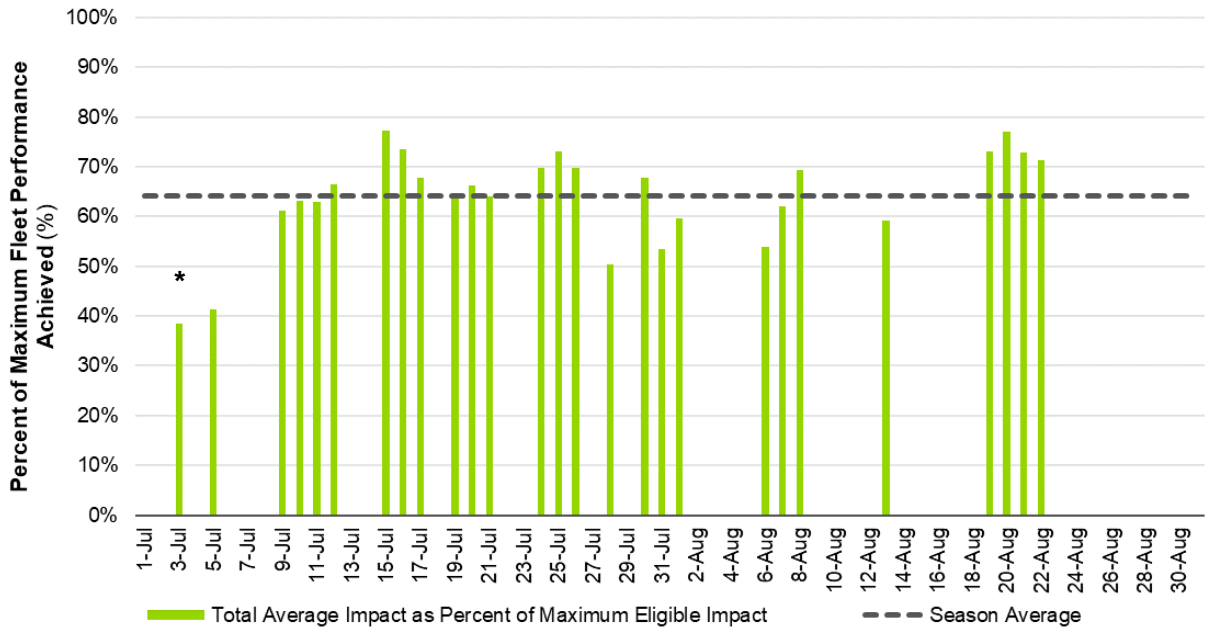
Source: Navigant Analysis

This implies that there is some confounding variable for DC coupled batteries that decreases the devices' impact and/or causes an inflated maximum expected discharge. This could be inverter losses, which are captured in the AC metered data but may not be accounted for in the maximum expected discharge if the listed maximum power rating is in DC. It may also be a battery setting which systematically reduces battery output, such that the maximum power rating of the device should not be used for the expected maximum discharge. For example, one of the DC coupled battery models has a listed maximum continuous power rating of 5 kW, but a note that 3.3 kW should be used to preserve battery life. The average per unit impact per event for batteries of this model is 3.4 kW, implying this recommended power may have been used rather than the full rated power output.

D.3 Fleet Performance

The assessment of fleet performance compares the total savings by event from Figure 4-16 to the sum of the energy storage capacity of the batteries identified as having either successfully performed, unsuccessfully performed, or opted out of the event. This is shown in Figure D-4. This leads to an average percent of maximum fleet performance achieved of 64%. Note that many of the same outlier events discussed in Section 4.1.2.2 also show up here.

Figure D-4: Fleet Performance

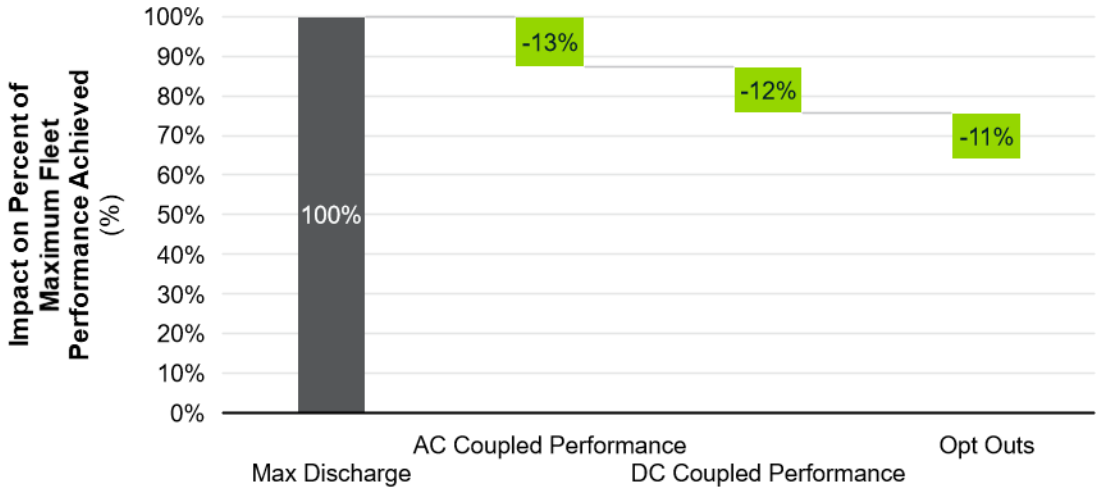


** First event was 3-hour duration, while all other events were 2-hour duration.*
Source: Navigant Analysis

The fleet performance of 64% is caused by batteries that participate in events not discharging to their maximum potential and by batteries opting out of events. If the denominator was instead all enrolled batteries rather than batteries that could perform, there would also be a third factor of batteries that are enrolled in the program before they are operational, but this is not included in Figure D-4. The impact of these factors on bringing the achieved fleet performance as a percent of maximum down is shown in Figure D-5. The first two impacts are if AC coupled systems and DC coupled systems that participated in events had discharged to their maximum potential. Combined, they show that the fleet performance of batteries that participated in events is 75%. Note that these two battery types had about the same impact on fleet performance, despite there being more than twice as many AC coupled batteries that participated in events this summer than DC coupled batteries.[23] This is because DC coupled batteries tended to perform worse than AC coupled batteries, as illustrated in Figure D-3. Event opt outs had about half of the level of impact as batteries not discharging to their maximum potential in events. Note that here opt outs are not necessarily customer initiated.

[23] 35 AC-coupled batteries versus 15 DC-coupled batteries.

Figure D-5: Impact on Fleet Performance by Source



Source: Navigant Analysis

APPENDIX E. ADDITIONAL UNITIL IMPACT ANALYSES

E.1 Average Daily Load Profiles

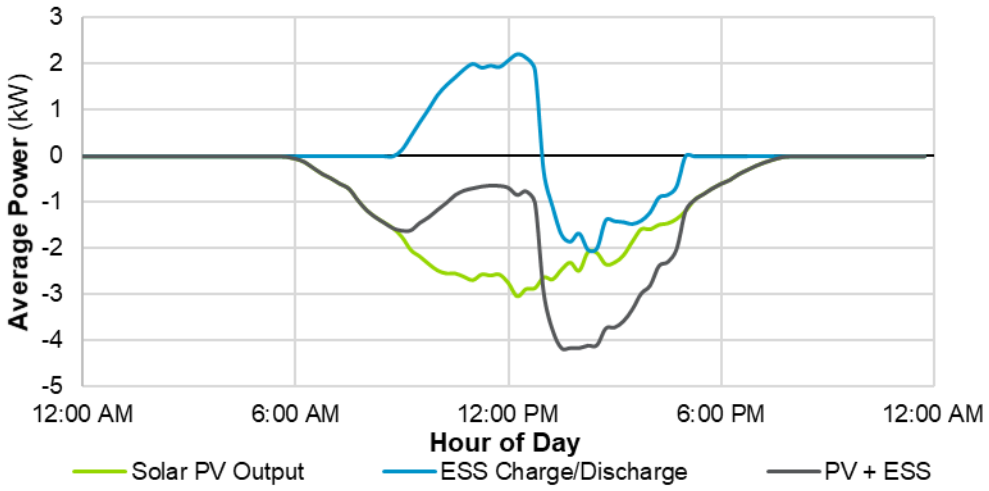
Navigant researched whether the combination of solar PV and battery storage could flatten out the solar curve such that there is a consistent electricity output across the Summer Peak Period. This section provides the net effect of the battery storage on the average PV generation hourly load profile throughout the Summer Peak Period for each event period.

Figures D-1 through D-4 show the average hourly solar PV generation, ESS charge/discharge and net solar PV plus battery output for the following timeframes, respectively: Aug 1 – Aug 11 (1 p.m. – 5 p.m. event); Aug 12 – Aug 28 (3 p.m. – 7 p.m. event); Aug 29 – Sep 14 (1 p.m. – 5 p.m. event); Sep 15 – Sep 30 (1 p.m. – 5 p.m. event). Note that positive loads (above the x-axis) indicate buying from the grid while negative loads (below the x-axis) indicate selling to the grid.

By aggregating the multiple days in each period, there is little variation across the Summer Peak Period in the solar PV, battery charging profiles, and peak battery discharge. PV production tends to start around 5:30 a.m., peaks at noon, and ends at 6 p.m. The batteries charge 100% off the solar PV from 8 a.m. to 1 p.m., peaking at 2 kW. For the 1 p.m. – 5 p.m. events, the batteries immediately begin discharging when the charging stops. In contrast, there is a two-hour period before the 3 p.m. – 7 p.m. event starts when the battery is neutral (Figure E-2), although does not appear to have reached 100% SOC. The battery discharge length varies but tends to peak at 4 kW. However, note that the Aug 29 – Sep 14 ESS charging, PV generation, and ESS discharging (Figure E-3) are all slightly less than the other profiles, suggesting that weather could have impacted the PV generation and the resulting ESS charging and discharging magnitudes.

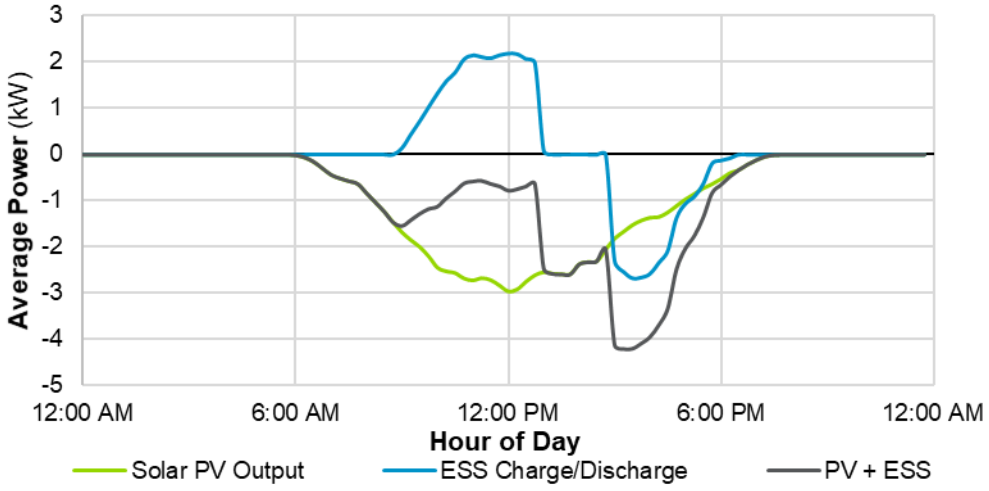
The battery discharge profiles vary across the timeframes. The Aug 1 – Aug 11 and Sep 15 – Sep 30 profiles (Figures E-1 and Figure E-4, respectively) have flatter and longer discharge profiles than the Aug 12 – Aug 28 and Aug 29 – Sep 14 profiles (Figure E-2 and Figure E-3, respectively). This finding suggests that 1 p.m. – 5 p.m. events are more successful than 3 p.m. – 7 p.m. events and confirms that there may have been some weather issues impacting the solar generation and resulting ESS charging during the Aug 29 – Sep 14 period (Figure E-3). In the Aug 1 – Aug 11 and Sep 15 – Sep 30 profiles (Figures E-1 and Figure E-4, respectively), the ESS output appears to balance the PV output at the beginning of the event, with the Aug 1 – Aug 11 ESS discharge lasting longer than the Sep. 15 – Sep. 30 ESS discharge. In contrast, the discharge profiles in Figure E-2 and Figure E-3 are not “flat” and do not last as long.

Figure E-1: Average Daily Load Profile for Aug 1 to Aug 11



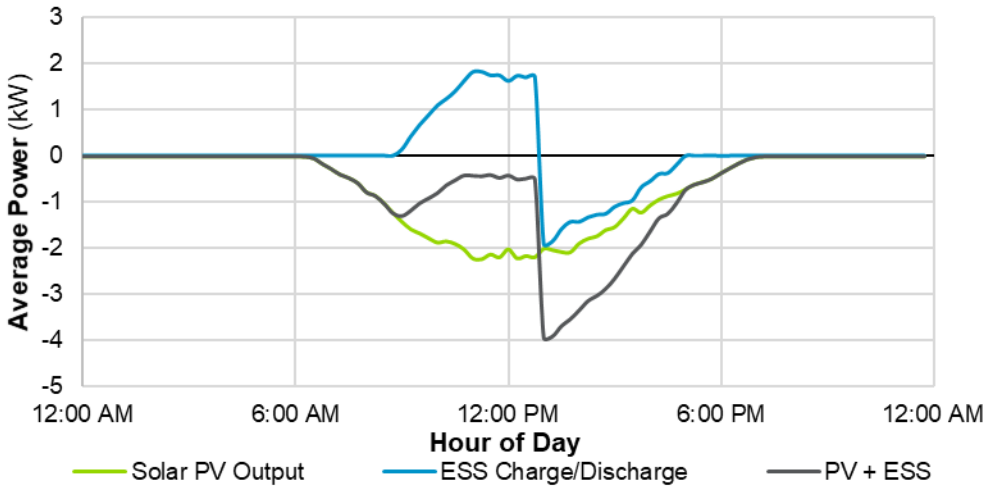
Source: Navigant analysis

Figure E-2: Average Daily Load Profile for Aug 12 to Aug 28



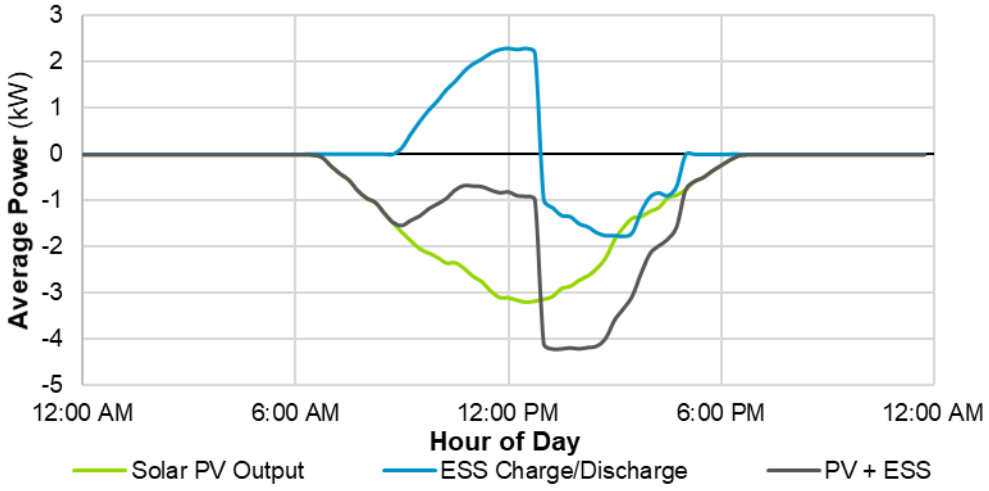
Source: Navigant analysis

Figure E-3: Average Daily Load Profile for Aug 29 to Sep 14



Source: Navigant analysis

Figure E-4: Average Daily Load Profile for Sep 15 to Sep 30

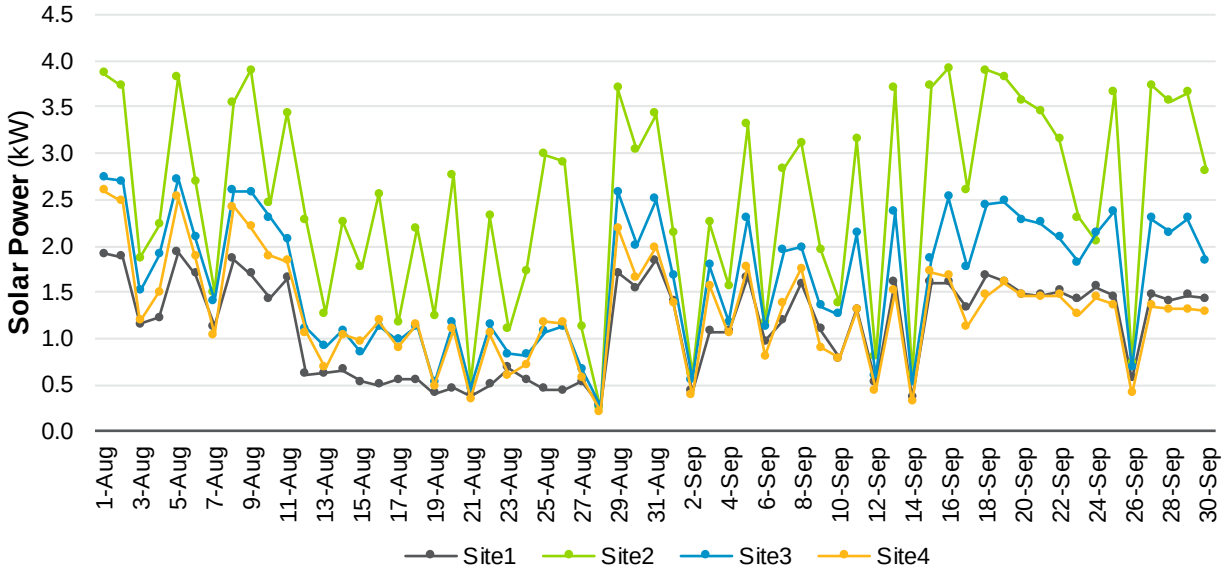


Source: Navigant analysis

E.2 Solar PV plus Battery Storage Load Balancing Analysis

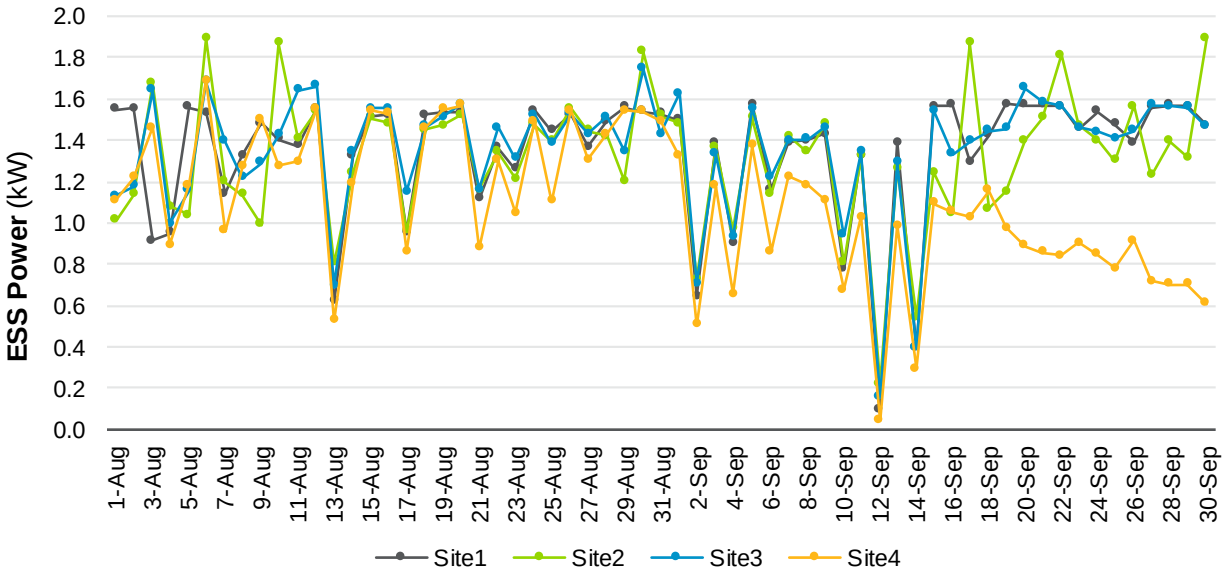
In addition to the event period averages, Navigant analyzed day-to-day trends in how the batteries were able to balance the solar PV plus battery output throughout the demonstration period. The average PV output and the average battery output during the event periods are shown in Figure E-5 and Figure E-6, respectively.

Figure E-5: Average PV Output per Event



Source: Navigant analysis

Figure E-6: Average Battery Output per Event

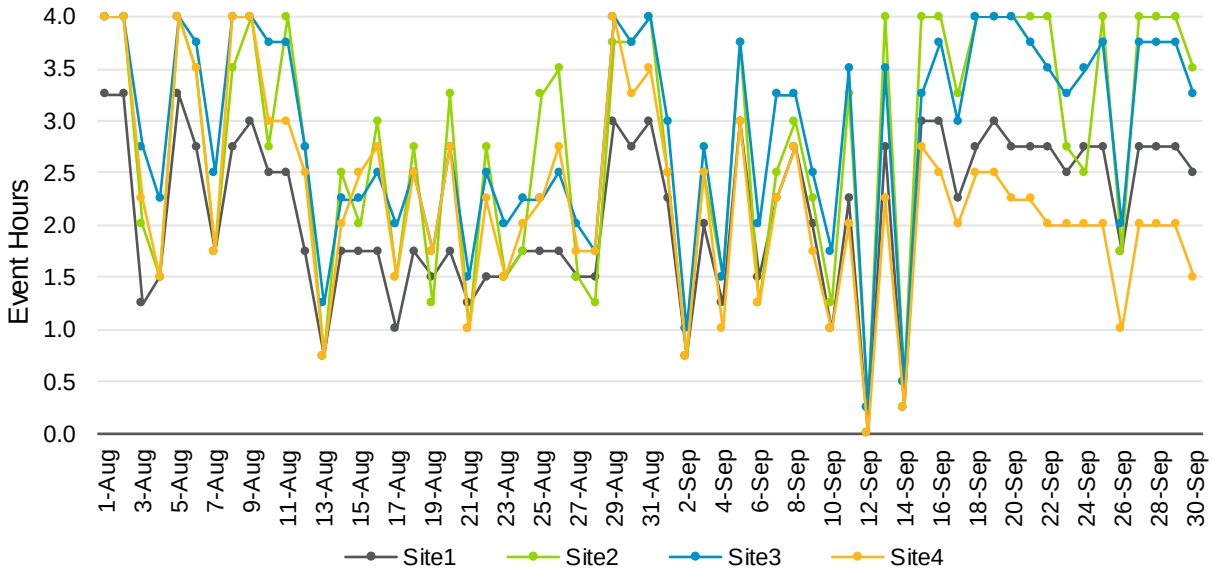


Source: Navigant analysis

The PV output varies from site-to-site based on the array size, and from day-to-day based on weather and when the events were called. For example, the PV output from Aug. 12 – 28 is the lowest because the average PV output was lower during the 3 p.m. – 7 p.m. events.

In general, days with high solar PV output have low battery output (e.g. Sep. 17) and days with lower Solar PV output have high battery output (e.g. Aug. 30). This confirms that the batteries modulate their output based on the solar PV output to maintain a constant PV plus battery output. The number of hours per day that each participant was able to balance the PV plus battery output is shown in Figure E-7.

Figure E-7: Hours of Successful Solar PV plus Battery Storage Output Balancing per Event



Source: Navigant analysis

Days with significant decreases in the number of hours balanced were consistent across the batteries. This suggests that factors impacting the PV output for all sites (e.g. sky conditions) could indirectly impact how long the battery is able to sustain the maximum PV plus battery output.

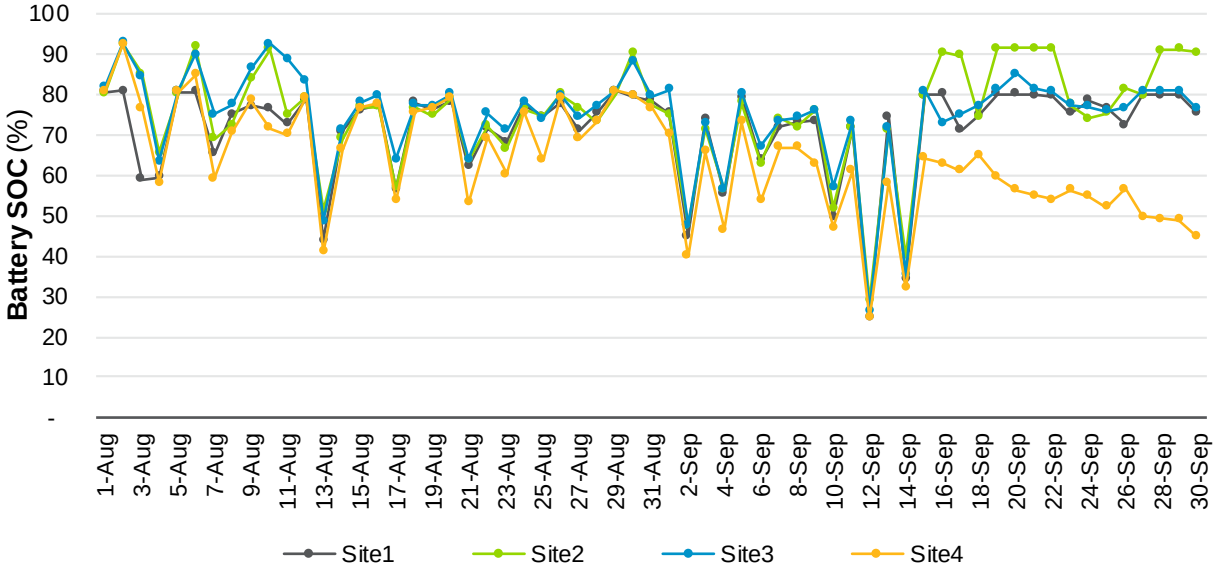
Figure E-7 also shows the number of hours that Site4 balances the PV plus battery output decreasing rapidly in September. In addition, Site4's 3.8 kW PV array is the smallest and it is the only array facing south. This finding suggests that smaller arrays and/or south-facing arrays may be unable to fully charge the battery off the PV output in the morning hours before the event is called.

E.3 Battery Storage State of Charge Analysis

Navigant analyzed the starting and ending state of charge (SOC) of every battery before and after all events were called to identify performance trends. The starting and ending SOC of each battery before every event day is in Figure E-8 and Figure E-9, respectively.

The starting SOC varies significantly day-to-day with a range of 30% to 93%. The graph is very similar to Figure E-7. Days with a low starting SOC are consistent across devices, suggesting that factors impacting the PV output for all sites (e.g. weather) can impact how much a battery is able to charge. In addition, Site4's starting SOC significantly decreases in September, suggesting that sites with small PV arrays and/or south-facing array may not able to fully charge the batteries before the event is called.

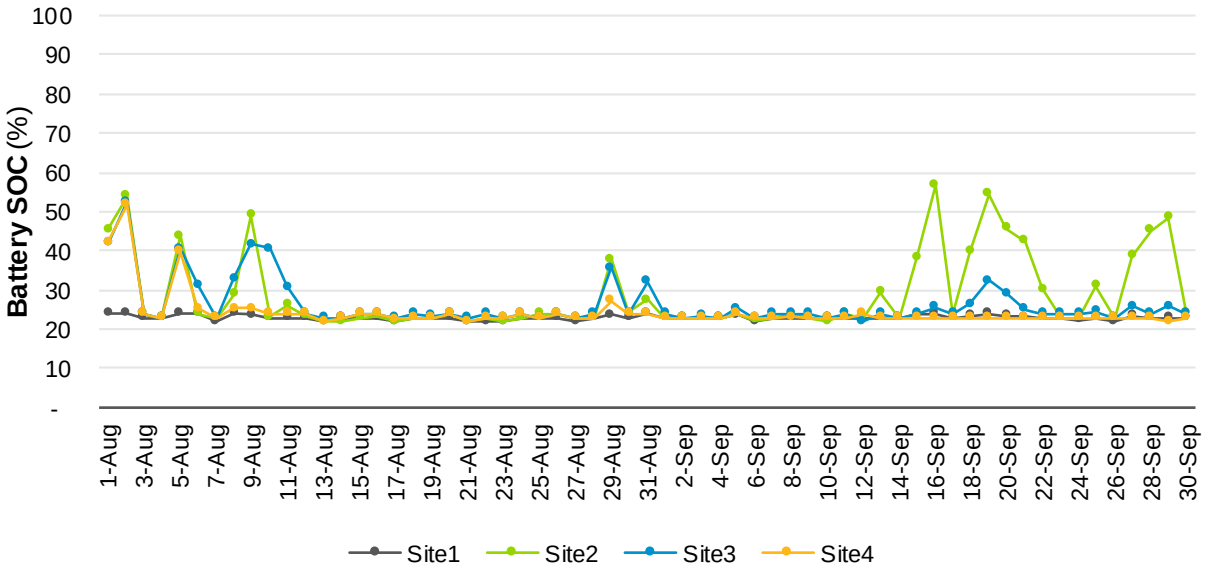
Figure E-8: Starting SOC per Event



Source: Navigant analysis

Like Figure E-8, Navigant mapped the ending SOC after each event day. The resulting trends are shown in Figure E-9. The ending SOC is more consistent across batteries and event days than the starting SOC. The ending SOC typically hovered around 22% on most days, suggesting that there is always at least 20% reserve. Days with a high ending SOC also have high solar PV plus battery output balancing in Figure E-9 (e.g. Sep. 16). This validates that the battery did not have to discharge fully during these event days because there was significant PV generation to balance the PV plus battery output. In addition, Site2 often has the highest ending SOC, suggesting that its large 5 kW PV array may help it balance the PV plus battery output without fully depleting the battery.

Figure E-9: Ending SOC per Event



Source: Navigant analysis