Guidehouse

# Battery Storage Pilot Program

## Interim Evaluation Report

Prepared for:

**Liberty Utilities**

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Reference No.: 208249
November 2022

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# Executive Summary

This Interim Evaluation Report describes the evaluation findings from Phase 1 of the Battery Storage Pilot Program (Pilot) from Liberty Utilities (Liberty). The evaluation period runs from December 2020 through August 2022 and includes 96 residential participants with 192 batteries (2 Tesla Powerwall battery units per participant). The Pilot is designed with the primary objective of driving avoided capacity costs from Regional Network Service (RNS), Local Network Service (LNS), and Forward Capacity Market (FCM) charges associated with monthly and annual coincident peak demand. The residential participants received additional benefits, including utilizing the batteries to provide bill savings from time-of-use (TOU) rates and to provide backup power in case of system outages.

This evaluation includes three main sections. The impact evaluation (Section 2.0) focuses on key target impacts for the Pilot, including reduction of coincident peak demand and associated capacity costs, energy shifting, and bill impacts associated with TOU rates, and overall cost-effectiveness. The technical evaluation (Section 3.0) provides additional analysis to understand variations in performance between participants, assess compliance of battery operation with program design, and to inform considerations for the design of Phase 2. The process evaluation (Section 4.0) provides insights from customer surveys to understand customers' experience with the Pilot, which can inform design and implementation considerations for Phase 2.

The impact evaluation addresses key criteria laid out in the Pilot Settlement Agreement (Docket DE 17-189, November 2018) for approval to move forward with Phase 2. These criteria include that (1) batteries reduce peak demand with an accuracy of 75% or greater, (2) batteries deliver capacity cost savings equal to or greater than projected savings, and (3) that implementation of Phase 2 is expected to generate a positive net present value (NPV) when applying the same benefit-cost methodology used in the original Pilot Settlement Agreement (Filing Cost Test). The results described in Section 2.1 indicate that criteria (1) and (2) were met in Phase 1, while the findings in Section 2.4 support criteria (3) and indicate that Phase 2 is expected to be generate benefits approximately equivalent to costs.

During Phase 1, the average monthly coincident peak performance was 79%, and annual coincident peak performance was 81%, both exceeding the target of 75%. The cost-effectiveness analysis assumes that future performance will match past performance. However, there is reasonable potential for even greater performance, as the evaluation identified issues with variations in participant performance that suggest that approximately one quarter of participants could perform significantly better after issues with battery programming are addressed. Additionally, improvements in event dispatch strategy associated with improved confidence in forecasting coincident peak hours could further increase peak reduction impacts.

On average, participants reduced their monthly bills by 33%, or $60. Approximately 39% of the energy reduction during on peak and critical peak hours occurred during event hours. Overall, customers generated net bill savings in 5 of 6 TOU season-periods, with only the winter off-peak period resulting in an increase in customer bills relative to baseline. For participants without solar, bill savings during summer months was similar to the maximum expected savings, while winter bill savings were somewhat lower than the maximum. For participants with solar, limitations for battery charging and discharging resulted in somewhat lower bill savings.

The batteries also generally complied with other rules for dispatch. The batteries are supposed to avoid net export, except during event hours. For participants both with and without solar, the batteries contributed to greater than one kWh per hour of net export in less than one percent of all hours during Phase 1. The batteries are also supposed to reserve 20% of energy for participants to be used only for backup power during system outages. The average hourly state of charge dropped below 20% in less than one percent of all non-outage hours.

The batteries also performed generally in line with the specifications provided by Tesla. Maximum observed charge rates were within 5% of nameplate (10 kW per participant) for 94% of customers, and maximum observed discharge rates were within 5% of nameplate for 96% of customers. The remaining customers had maximum charge and/or discharge rates below nameplate. Average battery efficiency was 87%, slightly below the nameplate roundtrip efficiency of 90%. Total efficiency is expected to be lower than roundtrip efficiency due to auxiliary and other losses, and many customers with high energy throughput exceeded 90% efficiency. The batteries appear to be losing energy capacity at a rate of approximately 2% per year, consistent with the nameplate lifetime of 10 year and assuming end-of-life after 20% degradation.

Guidehouse engaged with customers at two points, once during the enrollment phase and again at the close of the pilot. The objective was to gain insights into motivations for participation, barriers and challenges encountered, behaviors pre and post pilot, and comprehension of the program. Guidehouse found that customers were most motivated by the ability to provide backup power to their home and, for solar PV customers, the ability to pair battery storage with their PV system. Guidehouse also found that the most successful method of program outreach was through bill inserts and the Liberty Utilities website.

Customers generally reported overall satisfaction with the program, with 79% of customers indicating that they would recommend the program to a friend. Some customers reported experiencing challenges both during the installation process and during the pilot. These challenges were primarily associated with the lack of communication and clarity from the battery storage installer. Some customers did express concerns about optimizing their storage and the ability to access their battery after an outage, but these concerns were overall fewer in number.

Overall, Guidehouse saw an increase in awareness of participant’s utility bills and consumption, with customers spending more time reviewing their bill and changing their heating and cooling patterns. Several customers also noted taking advantage of off-peak time-of-use rates when charging their EV. The level of comprehension of the battery storage system slightly increased at the close of the pilot, but awareness of TOU rates remained relatively unchanged throughout the pilot.

Based upon the evaluation findings, Guidehouse recommends Liberty consider the following recommendations for Phase 2, pending approval. First, we recommend that Liberty coordinate with Tesla to identify and remediate any programming issues resulting in consistent underperformance during peak events from batteries for a subset of participants. Second, we recommend that Liberty coordinate with Tesla to explore resources which might help to improve confidence in forecasting coincident peak hours, thereby supporting event dispatch strategies which deliver greater battery output during coincident peak hours and reduced output during non-coincident hours. Lastly, we recommend that Tesla improve the level of communication and customer service to participants and consider documenting and sharing the overall process with customers to help improve the customer experience.

# 1.0 Pilot and Evaluation Overview

This Interim Evaluation Report describes the evaluation findings from Phase 1 of the Battery Storage Pilot Program (Pilot) from Liberty Utilities (Liberty). Section 1.1 describes background and objectives for the Pilot, while Section 1.2 describes the scope and objectives of the evaluation.

## *1.1 Pilot Overview*

The Pilot is being executed in multiple phases, as follows:

- Phase 1 will begin once Liberty has installed at least 100 batteries (50 customers) at participating residential customers' homes.
- Phase 2 will begin in August 2022 and proceed until 36 months after the beginning of Phase 1 (November 2023).
- A potential Bring Your Own Device (BYOD) program may be implemented in which additional customers who acquire and install batteries through third parties may utilize TOU rates and/or participate in events to reduce coincident peak demand.

These phases are described further in the subsections below.

### 1.1.1 Phase 1

Liberty Utilities' Battery Storage Pilot Program will be executed in two phases. In Phase 1, Liberty deployed Tesla Powerwall 2 batteries[1] at 96 participating residential customers' homes. Each participant home was provided with two batteries. Liberty owns the batteries, while participants pay either an upfront fee or a monthly payment for ten years. All participants in Phase 1 are subject to seasonal TOU rates. The batteries were expected to be operated as follows:

1. **Outage Reserve.** At all times, 20% of available battery energy is held in reserve to guarantee a minimum amount of available backup power in case of an outage. This reserve is used only in cases of an outage and is not available for dispatch at times of system peak or to support energy arbitrage.
2. **Dispatch at Coincident Peak.** During forecasted coincident peak demand conditions[2], Liberty dispatches batteries to maximize coincident peak demand reduction. On the day of forecasted coincident peak events, Liberty takes control of the batteries at midnight to charge overnight before the event and discharge during the event.
3. **Customer Energy Arbitrage.** At all other times, participant batteries may be dispatched automatically to deliver additional participant value through time-of-use (TOU) bill

[1] Each Tesla Powerwall 2 battery has an effective energy storage capacity of 13.5 kWh and a peak continuous discharge (and charge) capacity of 5 kW. For more details, please see:
Tesla, *Powerwall 2 Datasheet – North America*, accessed August 2020
https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall%202_AC_Datasheet_en_northamerica.pdf

[2] Batteries are dispatched to offset coincident peak demand charges from ISO-NE associated with Regional Network System demand, Local Network System demand, and Forward Capacity Market demand.

savings. All participants will be placed on TOU rates. Batteries will be discharged for these purposes only during Critical Peak hours.

a. For customers without Distributed Generation, batteries will be charged during Off Peak hours when rates are lowest and discharged during Critical Peak hours. These customers are not permitted to sell stored energy to the grid and may use storage only to offset household electricity requirements (i.e., net export is not allowed).

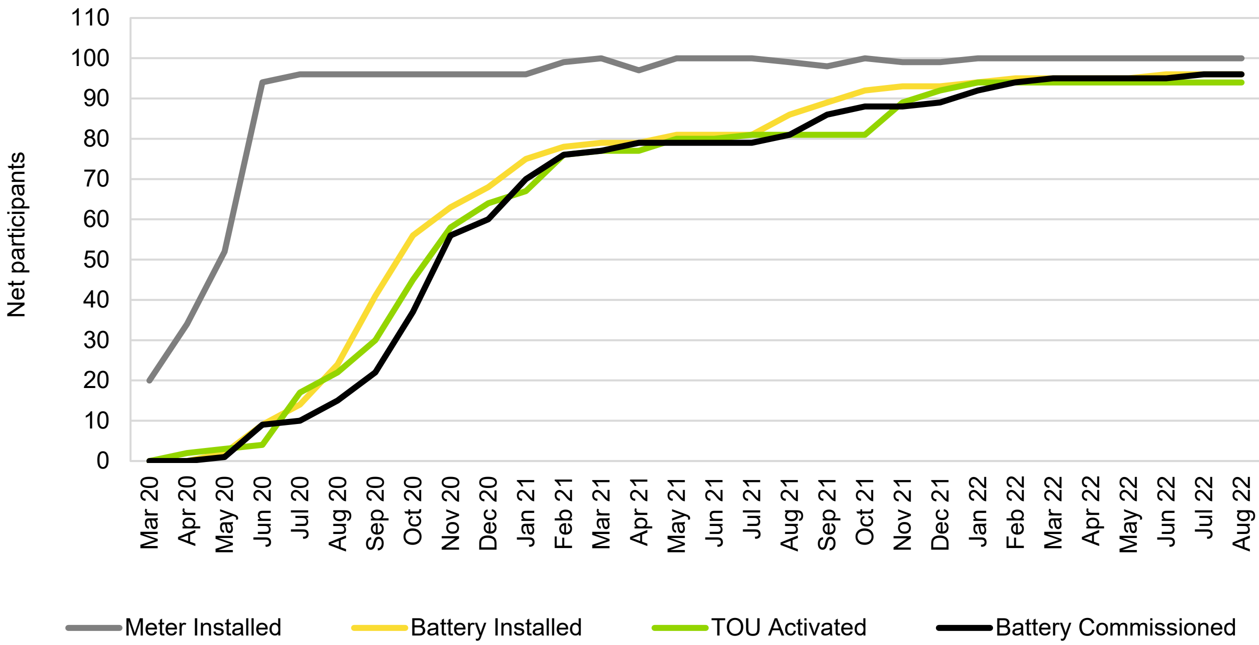
b. For net-metered customers (i.e., customers with Distributed Generation), batteries will not be permitted to charge from the grid, except when Liberty is in control (i.e., battery charge rate is limited by distributed generation production rate). At all other times, batteries may only be charged by excess generation (i.e., generation power that exceeds load and would otherwise be exported to the grid). Battery discharge will be maximized during critical peak hours. Although net export may be permitted from other Distributed Generation (e.g., rooftop solar), battery discharge may not cause or increase net export. In other words, battery discharge may not exceed the customer's net load (net load = customer load - distributed generation).

Phase 1 began on November 20, 2020; as of that date 50 customers had batteries installed and commissioned, for a total of 100 batteries (two per customer). Figure 1 summarizes deployment progress through August 31, 2022. As of this date, Liberty made the following progress deploying batteries to pilot participants:

- Installed new meters for 100 participants
- Installed batteries for 96 participants
- Commissioned batteries (given authority to connect) for 95 participants
- Activated TOU rates for 94 participants

For most participants, TOU rates were activated for the first billing cycle after the battery was installed (approximately 4 weeks after installation, on average). However, for 10 participants with solar PV systems, TOU rates were activated prior to battery installation (approximately 15 weeks before battery installation, on average), as moving those customers to the TOU provided greater bill savings during those months versus continuing service on Residential Rate D. On average, batteries were commissioned approximately 5 weeks after installation.

**Figure 1. Cumulative Battery Deployment Progress through Phase 1**




*Source: Guidehouse*

### 1.1.2 Phase 2

The Pilot Settlement Agreement indicated that Liberty may apply for Phase 2 approval after the end of Phase 1. According to the Agreement, in order to commence Phase 2, Phase 1 of the program must:[3]

- **Deliver Peak Demand Impacts.** Dispatch stored energy from the batteries to meet peak demand with an accuracy of 75% or greater. That is, must deliver at least 75% of its projected demand reduction during the monthly Liberty distribution system coincident peak demand hours *and* the annual ISO-NE system coincident peak demand hours during either the full Phase 1 period or the most recent 12-month period.
- **Deliver Cost Savings.** Realize Regional Network Service (RNS), Local Network Service (LNS), and Forward Capacity Market (FCM) cost savings as a fraction of program costs that are equal to or greater than those projected in the cost-benefit analyses, after accounting for actually observed (rather than projected) rates and clearing prices.
- **Demonstrate the Value of Phase 2.** Demonstrate to the Commission that the investment necessary to implement both Phase 1 and Phase 2 has a positive net present value (NPV), after updating all input assumptions to reflect the most recently updated actual or projected values.

[3] The State of New Hampshire Before the Public Utilities Commission, *Liberty Utilities (Granite State Electric) Corp. d/b/a Liberty Utilities Petition to Approve Battery Storage Pilot Program*, Docket No. DE 17-189 Settlement Agreement, November 2018

- **No Material Adverse Change.** Confirm that there has been no material adverse change in any relevant circumstances or criteria.

If Phase 2 is approved, Liberty will purchase and deploy additional Tesla Powerwall 2 batteries up to a maximum of 500 batteries (250 customers) between both phases.

### 1.1.3 BYOD Program

The Bring Your Own Device Program is a potential program in which additional customers who acquire and install batteries through third parties (instead of Liberty) will have the option to use Liberty's TOU rates and/or participate in events to reduce coincident peak demand. The program would allow for an additional 500 batteries (or 2,500 kW of capacity) and require at least 25% of participants to be enrolled in the TOU rates. This potential program would be developed with input from stakeholders and implemented using a well-defined process and timeline.

## *1.2 Evaluation Overview*

This evaluation is intended to assess the performance of the Pilot in order to help determine whether to move forward with Phase 2, inform recommendations to support successful implementation of Phase 2, and provide additional insights to support the design of potential related future programs and investments.

The scope of this Interim Evaluation Report aligns with the requirements set forth in the Pilot Settlement Agreement and with subsequent communication with the Staff of the New Hampshire Public Utilities Commission ("Staff"), now Department of Energy ("DOE"), on the evaluation plan scope, deliverables, and timeline, which were approved on December 3, 2020. The Phase 1 evaluation period began on December 1, 2020 and ended on August 31, 2022.

This evaluation comprises of three components:

1. **Impact Evaluation** (Section 2.0) Evaluation of the impact of the program on participant coincident peak demand and energy use by time of day, the consequent benefits, and the associated program benefit-cost analysis (BCA).
2. **Technical Evaluation** (Section 3.0)**:** Evaluation of how the batteries perform relative to expectations and how certain factors drive variations in performance.
3. **Process and Customer Experience Evaluation** (Section 4.0)**:** Evaluation of the execution of the Pilot and key details concerning customer experiences, behaviors, demographics, and comprehension.

# 2.0 Impact Evaluation

The impact evaluation (Section 2.0) focuses on key target impacts for the Pilot, including reduction of coincident peak demand and associated capacity costs, energy shifting, and bill impacts associated with TOU rates, and overall cost-effectiveness.

This analysis addresses key criteria laid out in the Pilot Settlement Agreement (Docket DE 17-189, November 2018) for approval to move forward with Phase 2. These criteria include that (1) batteries reduce peak demand with an accuracy of 75% or greater, (2) batteries deliver capacity cost savings equal to or greater than projected savings, and (3) that implementation of Phase 2 is expected to generate a positive net present value (NPV) when applying the same benefit-cost methodology used in the original Pilot Settlement Agreement (Filing Cost Test). The results described in Section 2.1 indicate that criteria (1) and (2) were met in Phase 1, while the findings in Section 2.4 support criterion (3) and indicate that Phase 2 is expected to be generate benefits approximately equivalent to costs.

## *2.1 Coincident Peak Demand Impacts*

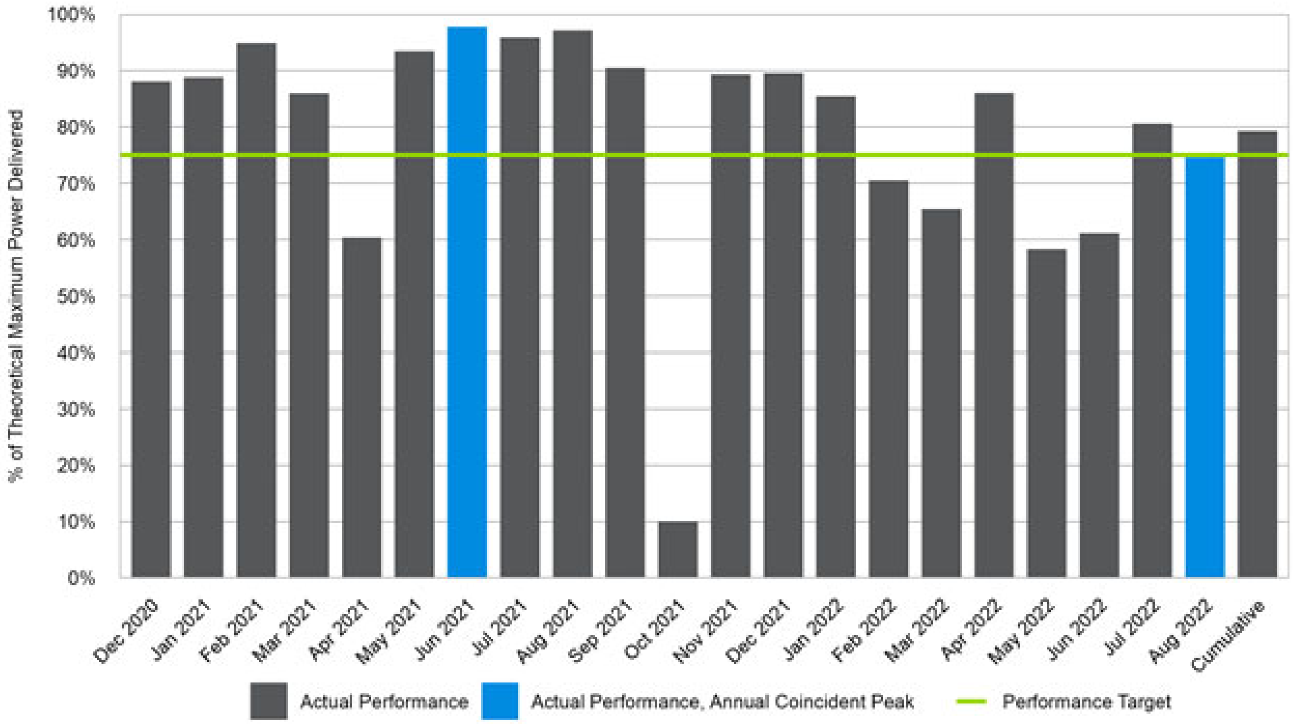
During Phase 1, the average monthly coincident peak performance was 79%, and annual coincident peak performance was 81%, both exceeding the target of 75% (see Section 2.1.1). Avoided Capacity costs, when adjusted for actual capacity prices and number of batteries, exceed original projections in the Settlement Agreement (see Section 2.1.2). Nonetheless, there is room for continued improvements in performance, which would further increase the benefits delivered by the Pilot program.

### 2.1.1 Peak Demand Impacts

This section summarizes the impact of battery dispatch at the times of annual ISO-NE coincident system peak demand and at the time of the Liberty Utilities monthly peak demand. Figure 2 represents the peak reduction performance during the coincident peak hour of each month in Phase 1 (December 2020 through August 2022). Peak reduction performance is defined as the actual peak reduction (average kW dispatched during coincident peak hour) relative to the maximum power rating of the batteries (5 kW per battery, 10 kW per customer). As set forth in the Pilot Settlement Agreement, the performance target is 75%. The weighted average monthly performance[4] throughout Phase 1 (as represented by the Cumulative bar in Figure 2) was approximately 79%, which exceeds the performance target. The weighted average performance during the annual coincident peaks in June 2021 and August 2022 (as represented by the blue colored bars in Figure 2) was 81%, which also exceeds the performance target of 75%.

[4] The weighted average performance weights monthly performance proportionally to the number of active, installed batteries in each month.

**Figure 2. Coincident Peak Reduction Performance for Phase 1**



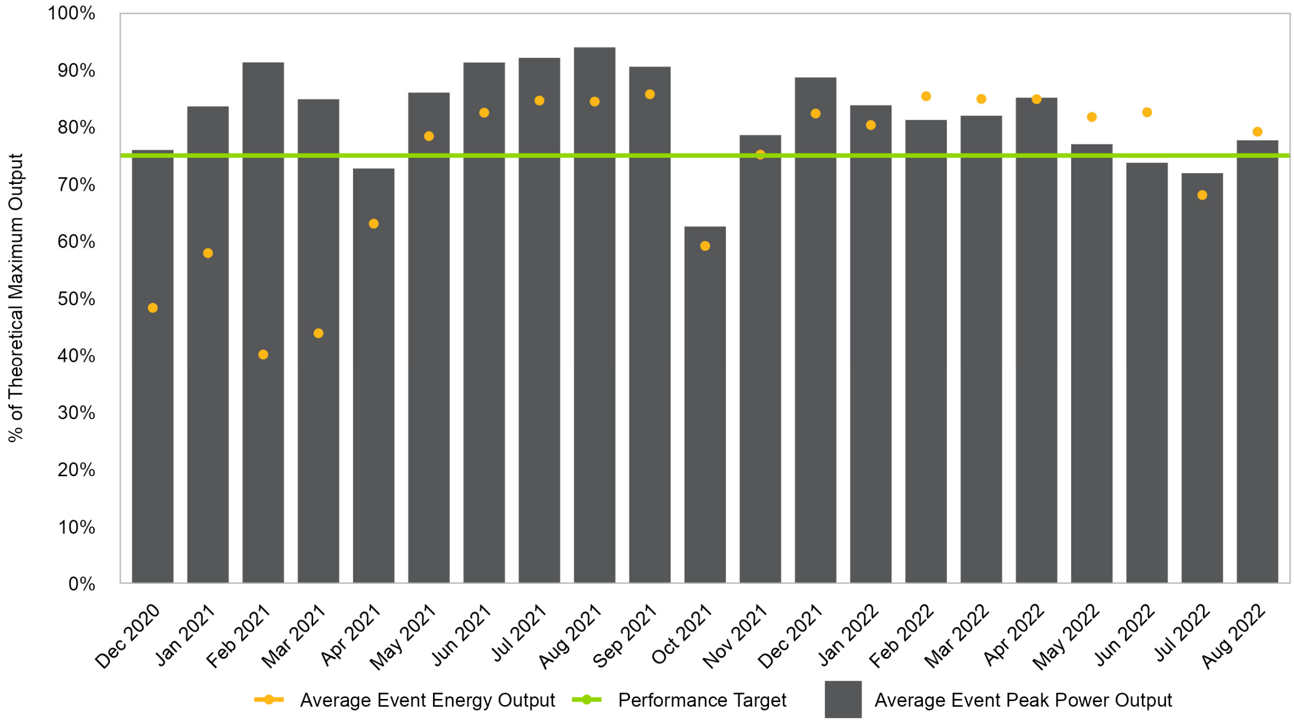

*Source: Guidehouse*

As shown in Figure 2, the coincident peak performance was the lowest (10%) in October 2021. Tesla reported that there was an unexpected issue with many Powerwall configurations in the Liberty fleet that erroneously limited the net battery exports to the grid during events between 12th October and 4th November, resulting in lower coincident peak performance on 14th October. The coincident peak performance (60%) was also comparatively low during the peak of 16th April. This was due to a National Weather Service Storm warning that triggered the batteries to start charging. Liberty was able to override this command, but the temporary charging from the storm warning during the peak lowered the overall performance of the batteries.

Additionally, the coincident peak performance in 2022 was comparatively lower than the average performance in 2021. This appears to be primarily a result of the change in event dispatch strategy. On coincident peak days in February (2/14), March (3/01), May (5/22) and Jun (6/26), it appears that forecast certainty for the coincident peak hour was low, and consequently the power output of the batteries was spread relatively evenly over three event hours. This resulted in lower power output throughout the event. See Section 3.1.2 for further discussion on the change in event dispatch strategy for 3-hour events.

To achieve the targeted coincident peak reduction, Liberty called 132 events during Phase 1 (Dec 2020 to Aug 2022). Of those, 73 events were 3 hours in duration, and 59 events were 2 hours long. Figure 3 shows the average peak hourly output (relative to total rated power output) across all in events each month in the Phase 1 period. This is calculated as an using peak hourly output of the batteries during any hour of the event, which is then averaged across all the events in a month. Additionally, Figure 3 shows the relative energy output during each individual event (relative to the maximum available energy during the course of the event).[5]

**Figure 3. Average Event Performance for Phase 1**




*Source: Guidehouse*

On an average, the peak power output during an event was greater than 75% in 16 of 20 months during Phase 1. The reduced performance in April and October were due to the storm warning and battery programming issues, as discussed earlier. Further, the relatively low performance in June 2022 is partly due to the change in event dispatch strategy for 3-hour events, as mentioned earlier. Because the battery output was distributed evenly across the three hours of the event, the maximum power output in any hour of the event never exceeded 65%, but the average energy output across all the June 2022 events was 82.6%, well above the performance target.

Additionally, the average event peak performance in July 2022 was lower than 75% because of low battery discharge specifically during the 12th July event. During the 2-hour event on July 12, most of the batteries failed to discharge which resulted in an average event peak performance of 16.4%.

[5] The maximum available energy is based upon the minimum of (a) the rated power multiplied by the duration of the event and (b) the total usable energy in the batteries (10.8 kWh per battery, which is based upon 13.5 kWh rated energy capacity less 20% energy held in reserve).

See Section 3.1.1 for additional analysis and discussion regarding variations in performance between different participants.

### 2.1.2 Avoided Cost of Capacity

Guidehouse calculated the overall avoided capacity cost benefits using avoided Regional Network System Charges (RNS), Local Network System Charges (LNS) and Forward Capacity Market charges (FCM). The benefits from RNS and LNS charges were calculated by multiplying the peak reduction impacts during the monthly coincident peaks by the monthly RNS and LNS rates provided by Liberty. To calculate the FCM charges, Guidehouse multiplied the annual coincident peak impacts at the time of ISO-NE's annual peak demand with the annual FCM rate.

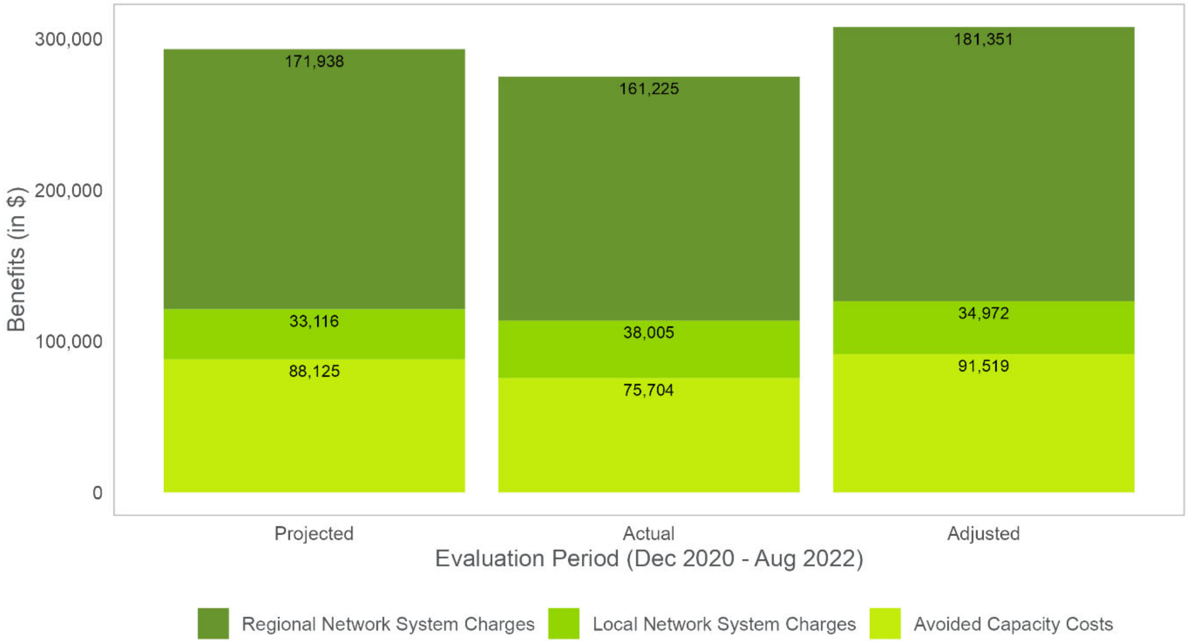
Figure 4 shows the comparison of savings from Regional Network System (RNS) charges, Local Network System (LNS) charges and Avoided Capacity Costs for the Phase 1 period calculated in three different ways:

a) **Projected Savings**: These savings are directly derived from the benefit-cost analysis included in the Settlement Agreement (page 26). The savings were based on estimated peak demand impact, number of batteries expected to be installed in Phase 1, RNS rates, LNS rates and Avoided Capacity cost rates. The projected savings were adjusted to reflect the period of actual data available for evaluation in this report, December 2020 through August 2022.

b) **Actual Savings:** Guidehouse updated the benefit cost analysis included in the settlement agreement using actual battery performance data and number of batteries installed during the Phase 1 evaluation period. We also updated the RNS rates, LNS rates and Avoided Capacity cost rates to reflect the actual rates.

c) **Adjusted Savings:** The actual and projected savings are not directly comparable, because there are differences in both the number of batteries and the rates for LNS, RNS, and Avoided Capacity. To enable a direct comparison on the basis of battery performance, Guidehouse also calculated the savings using actual performance data while keeping the estimated number of batteries installed and system charges the same as in the Settlement Agreement. This was done to understand what the savings would have been had the number of batteries and rates been the same as filed in the Settlement Agreement. As shown in Figure 4, the adjusted savings are higher than projected savings, which is expected given the higher-than-projected performance (above 75%) during both monthly and annual coincident peaks.

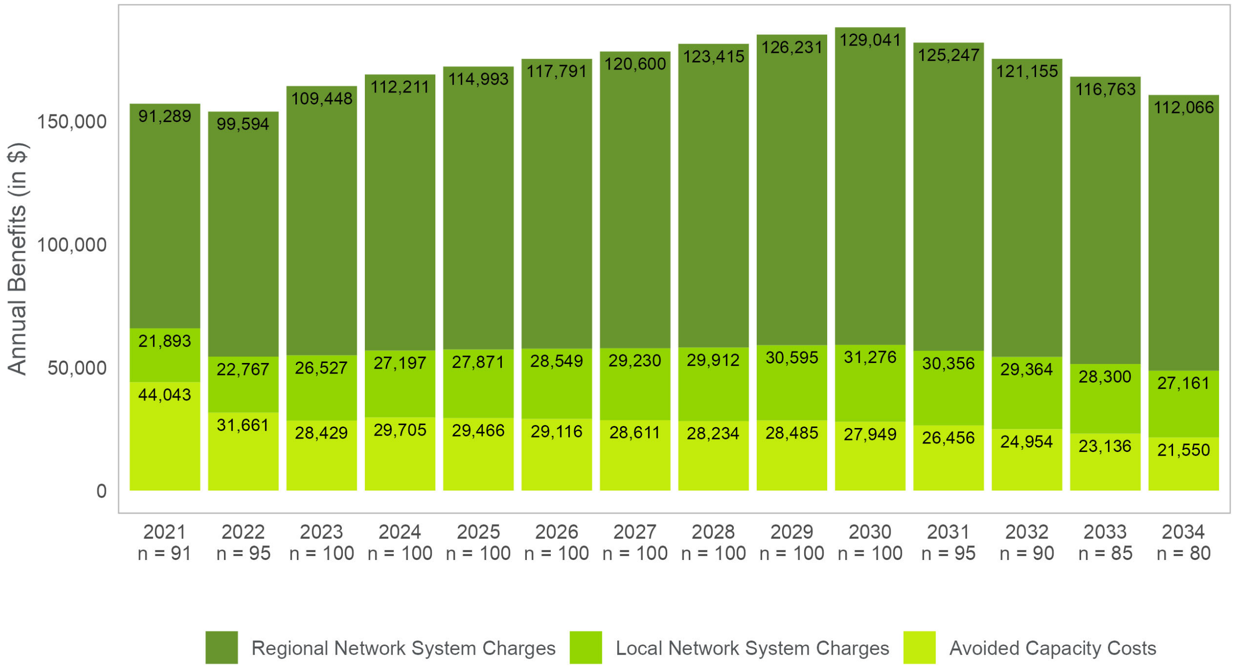
**Figure 4. Comparison of Projected, Annual and Adjusted Benefits in Phase 1**




*Source: Guidehouse*

Guidehouse also calculated the lifetime benefits of avoided capacity costs from battery dispatch for all batteries deployed in Phase 1, as shown in Figure 5. To calculate the lifetime avoided capacity cost benefit Guidehouse assumed a battery lifetime of 15 years with 5% of batteries being removed every year after the 10$^{th}$ year (consistent with assumptions used in the benefit cost analysis presented in the settlement agreement), achievement of peak demand impacts (79%) as observed on average during the Phase 1 period (December 2020 to August 2022) and an annual battery capacity degradation rate of 2% (as calculated in Section 3.3.4). The projected RNS, LNS and FCM rates were based on data received from Liberty. As shown in the figure, the benefits start to taper off starting 2031 as 10 batteries (5 participants) are removed every year till 2034.The x-axis of the figure also shows the average number of participants in that year contributing to the avoided capacity cost benefits.

**Figure 5. Overall Lifetime Benefits from Avoided Cost of Capacity (Phase 1 Batteries)**




*Source: Guidehouse*

## 2.2 *Energy Impacts*

As expected, participants shifted energy consumption from critical peak and on-peak hours to off-peak hours during both the winter and summer seasons. Approximately 39% of the energy reduction during on-peak and critical peak hours occurred during event hours (see Section 2.2.1).

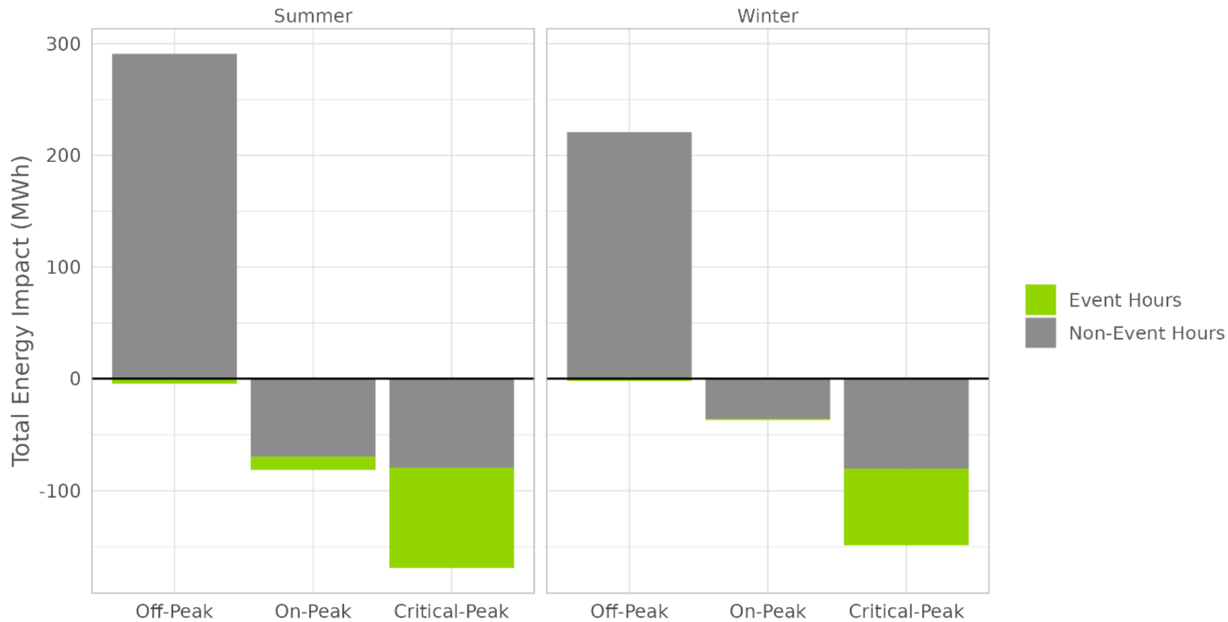
Average battery efficiency was 87%, slightly below the nameplate roundtrip efficiency of 90%. Total efficiency is expected to be lower than roundtrip efficiency due to auxiliary and other losses (see Section 2.2.2), so this outcome is consistent with expectations.

### 2.2.1 Impact by TOU Period

Figure 6 below summarizes the amount of battery energy imported (charging) and exported (discharging) during the three Liberty time-of-use (TOU) periods for both winter and summer seasons throughout Phase 1. The y-axis values (total energy impact) were calculated in a few steps. First, the data was split between summer (May-October) and winter (November-April). Then, average interval power was converted to energy and used to determine how much a battery was importing or exporting per 15-minute interval. These battery energy values were summed across each of the 6 TOU Period-Season categories, separately for event and non-event hours.

As shown in Figure 6, most event hours were during critical peak hours, while some occurred during on-peak and off-peak hours, resulting in battery discharge during these periods. Batteries discharged a total of 89 MWh during critical-peak event hours in the summer. Batteries also exported more energy during critical-peak non-event hours than during on-peak non-event hours. In the summer, batteries exported 80 MWh across 80,979 critical-peak non-event participant-hours, while batteries exported 69 MWh across 225,361 on-peak non-event participant-hours.

**Figure 6. Total TOU Period Impact by Season**



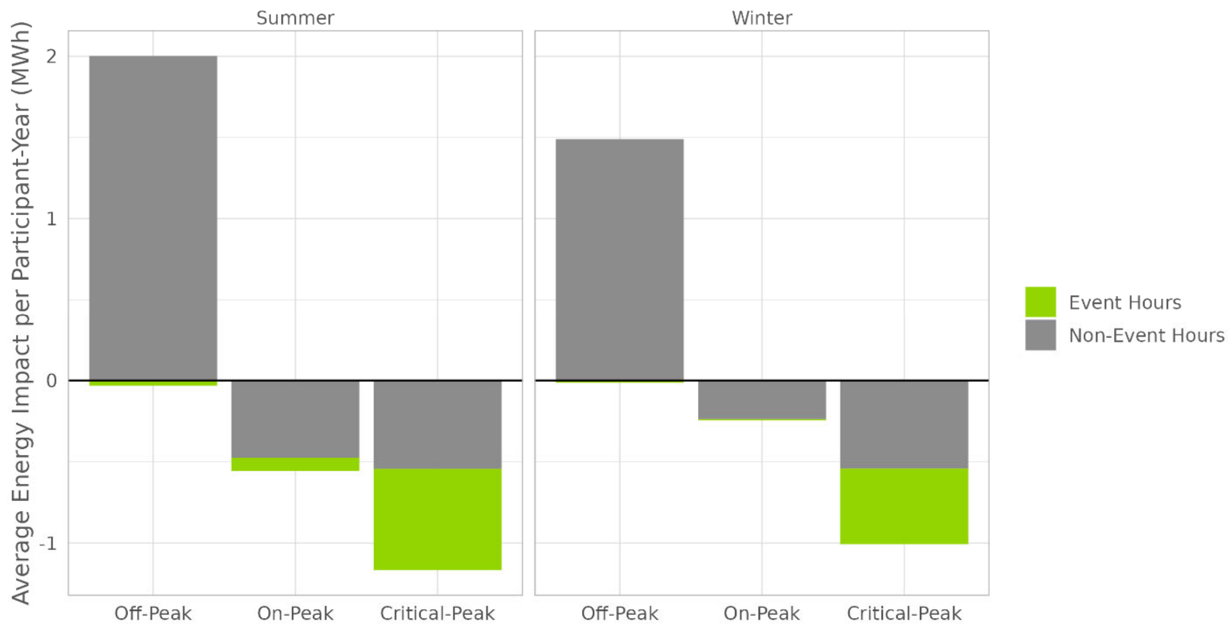

*Source: Guidehouse*

Figure 7 also summarizes the amount of battery energy imported and exported during the three Liberty time-of-use (TOU) periods throughout Phase 1, but normalizes the values based upon average annual usage per participant. Average interval power was again converted to energy and used to determine how much a battery was importing or exporting per 15-minute interval. These battery energy values were summed for each Site ID across each of the 6 TOU Period-Season categories, separately for event and non-event hours, so that each of the 96 Site-IDs had 12 values of total energy for each combination of Period, Season, and Event hours. Then, average energy impact per participant-year was calculated in a few additional steps. Average energy impact per participant for each combination of Period, Season, and Event hours was calculated using a weighted mean where batteries with more days of data were weighted more heavily than the newer batteries. These average totals were normalized to a participant-year by assuming 184 days in the summer period and 181 days in the winter period and comparing these numbers to the average number of days with data per participant.[6]

Figure 7 shows that the average participant exported 1.17 MWh during critical-peak hours per summer, including both event and non-event hours. See Section 3.2 for additional analyses and discussion regarding variations in TOU performance between participants.

[6] For example, the average total energy exported during the summer period non-event on-peak hours was 0.76 MWh per participant across an average of 294 days. Normalizing to one year's summer involves multiplying 0.76 MWh by (184/294) to get a value of 0.48 MWh (or dividing by 294/184). This means we can expect an average battery to export 0.48 MWh across one summer during on-peak non-event hours, given the same number of event-hours.

**Figure 7. Average Annual TOU Period Impact per Participant by Season**




*Source: Guidehouse*

### 2.2.2 Efficiency Losses

Guidehouse calculates battery efficiency as the sum of all energy discharged divided by the sum of all energy charged. Table 1 shows a summary of the calculated battery efficiency for all 96 participants during Phase 1. Battery efficiency ranged from 11.4% to 95.4%, with most batteries showing efficiency above 85%.

The median (88.6%) and mean (87.0%) roundtrip efficiencies are similar to the nameplate roundtrip efficiency (90%). Total efficiency is expected to be lower than roundtrip efficiency, as roundtrip efficiency accounts only for cycling losses, while total efficiency includes standby losses from factors such as auxiliary power consumption and self-discharge. Variations in total efficiency are likely driven primarily by variations in energy throughput – participants with low energy throughput have greater standby losses relative to cycling losses, resulting in lower apparent efficiencies.

See Section 3.3.3 for further analysis and discussion regarding variation in efficiency between participants.

**Table 1. Participant Battery Efficiency**

| Minimum | Median | Mean | Maximum |
|---|---|---|---|
| 11.4% | 88.6% | 87.0% | 95.4% |

*Source: Guidehouse*

## 2.3 Bill Savings

Guidehouse calculated the net-energy metering (NEM) credits resulting from battery dispatch during event hours (see Section 2.3.1) to determine the actual values from the Pilot for use in the cost-effectiveness analysis (see Section 2.4). Overall, the calculated actual credits are higher than originally projected, but the adjusted calculations match within 1% of original projections.

Participants reduced their monthly bills by an average 33%, or $60. Overall, customers generated net bill savings in 5 of 6 TOU season-periods, with only the winter off-peak period resulting in an increase in customer bills relative to baseline (see Section 2.3.2).

### 2.3.1 NEM Credits

Guidehouse calculated the total net-energy metering (NEM) credits using actual net battery energy exported to and imported from the grid and the net energy metering rates[7] provided by Liberty. The hourly net export of the batteries to the grid was calculated by subtracting the hourly customer demand from the total power exported from the batteries during the event hours. Similarly, the hourly net import from the grid to the batteries was calculated by subtracting the hourly solar generation from the total power imported by the batteries during the off-peak hours leading to an event. Guidehouse then multiplied the net hourly exported energy from the batteries to the prevailing net energy metering rates to get the monetary value of the energy exported to the grid and the net hourly imported energy by the batteries to the prevailing TOU rates to get the monetary value of the energy imported from the grid. The difference between the monetary value of the energy exported to the grid and energy imported from the grid resulted in the total NEM credits earned by participants.

Figure 8 shows the comparison of total NEM credits from Jan 2021 to August 2022[8] calculated in three different ways:

a) **Projected Credits**: These savings are directly derived from the benefit-cost analysis included in the Settlement Agreement (page 26). The savings were based on estimated energy exported to the grid, number of batteries expected to be installed in Phase 1, and NEM rates. The projected savings were adjusted to reflect the period of actual data available for evaluation in this report, January 2021 through August 2022.

b) **Actual Credits:** Guidehouse updated the NEM credit calculations included in the settlement agreement using actual energy exported to and imported from the grid and number of batteries installed based on Phase 1 data. We also updated the NEM rates to reflect the actual rates to which the customers were subjected.

Table 2 summarizes the difference between the assumptions used in the Settlement Agreement to calculate projected NEM credits and the actual values as observed in the Pilot.

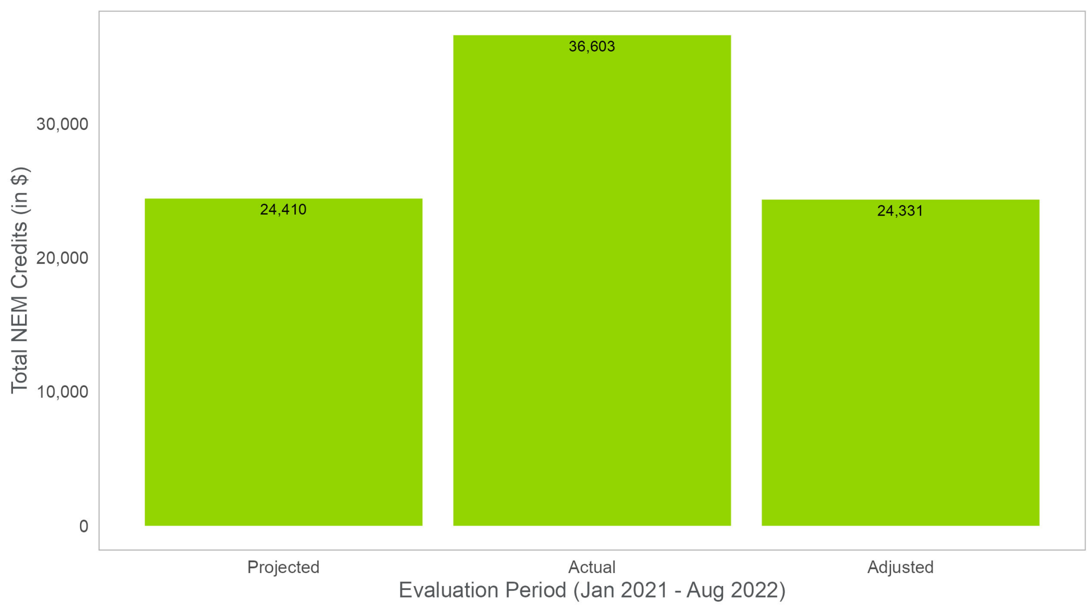
[7] The Net Energy Metering Rates comprise of 25% of Distribution Charges, 100% of Transmission Charges and 100% of Energy Service rates.
[8] The data used for this evaluation excludes December 2020 due to some data issues leading to intermittent data available for solar energy generation.

**Table 2. Summary of Assumptions and Observed Values Used in the Projected and Actual NEM Credits Calculations**

| Metric | Filing Assumptions (used in calculation of projected NEM credits) | Actuals based on Guidehouse analysis (used in calculation of actual NEM credits) |
|---|---|---|
| Average NEM Rate | $0.181/kWh | $0.278/kWh |
| Number of Events in a Month | 6 | 6.3 |
| Battery Energy Exported to the Grid | 48% | 43% |

c) **Adjusted Credits:** The actual and projected credits are not directly comparable, because there are differences in both the number of batteries and the NEM rates. To enable a direct comparison on the basis of battery performance, Guidehouse also calculated the credits using actual battery data while keeping the estimated number of batteries installed and NEM charges same as in the Settlement Agreement. This was done to understand what the credits would have been had the number of batteries and rates been the same as filed in the Settlement Agreement. As shown in Figure 8, the adjusted credits are very similar to the projected credits suggesting the actual battery exports and imports were very similar to assumptions made in the Settlement Agreement.

**Figure 8. Comparison of Projected, Actual and Adjusted NEM Credits**




*Source: Guidehouse*

### 2.3.2 Bill Savings

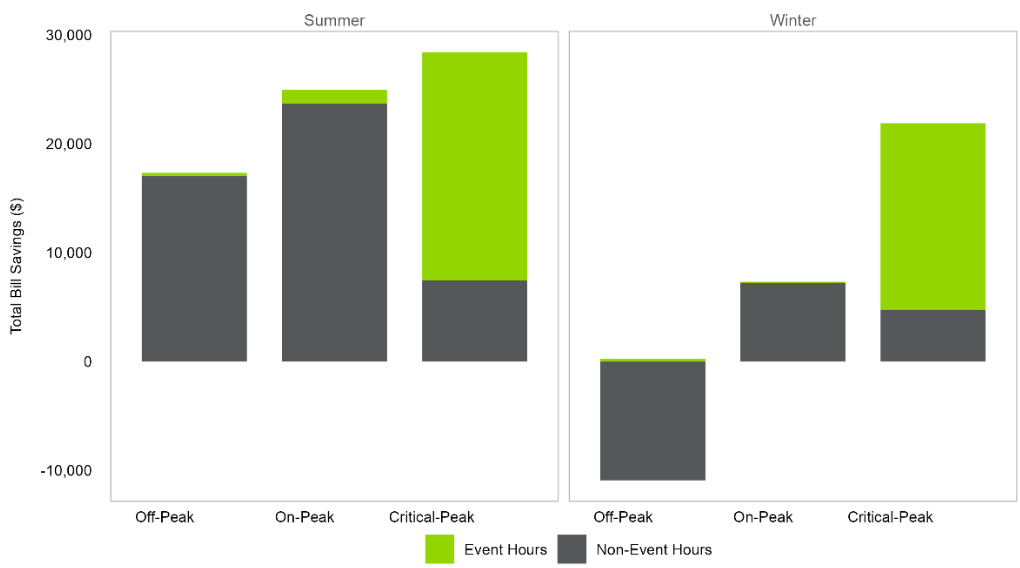
Figure 9 summarizes the average bill savings for a participant during different time-of-use (TOU) periods in the summer and winter season. Guidehouse calculated the actual participant variable cost by multiplying the participant interval demand during a TOU period with the corresponding TOU rate (Rate D-11) in the pilot. The counterfactual participant variable cost was used to determine the participant's bill if the customer had not been enrolled in the program. This was calculated by applying the energy shifting impacts to participant's internal metering load data to deliver an estimate of counter-factual consumption (i.e., what the participant would have consumed absent the program). This was then multiplied by the participant's pre-participation rate (Rate D) to calculate what their bill would have been. The difference between the actual participant variable cost and counterfactual participant variable cost determined the average bill savings for a participant enrolled in the program.

As expected, the highest bill savings were achieved during critical peak hours when the batteries were either dispatched to maximize coincident peak demand reduction (during event hours) or offset household electricity consumption (during non-event hours).

The off-peak and on-peak periods during the summer season also had high bill savings. The average off-peak period consumption during the pilot program also increased during the summer season but the change in bill was offset by the decrease in off-peak TOU prices as compared to the flat rates participants would have experienced had they not enrolled in the pilot.

The bill savings in the winter off peak period were negative, i.e., the average participant bill during the winter off-peak period increased under the pilot. The increase in participant bill is mainly due to the increase in consumption during the off-peak hours from charging of the batteries. The average off-peak period consumption during the pilot program also increased during the summer season but the change in bill was offset by the decrease in off-peak TOU prices as compared to the flat rates participants would have experienced had they not enrolled in the pilot. The off-peak TOU prices were on, on average, 60% lower than the flat rate in the summer season, which was almost double the corresponding price differential in the winter season (32%).

**Figure 9. Total Bill Savings by TOU Period and Season**

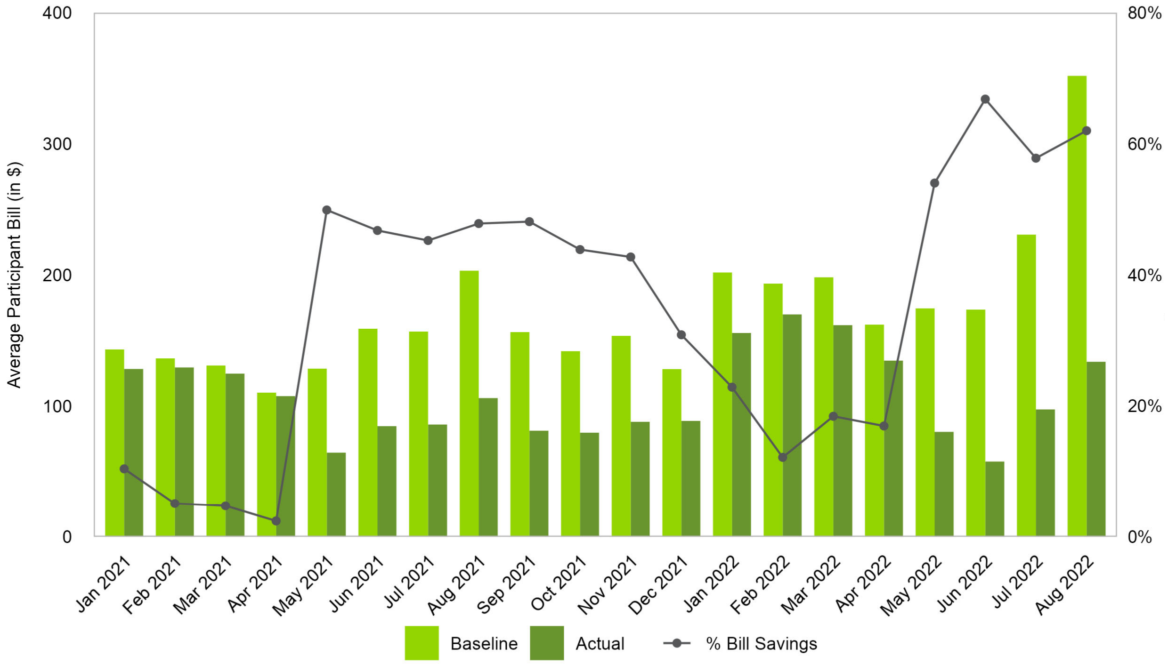



*Source: Guidehouse*

The Figure 10 shows a comparison between actual and baseline (counterfactual) variable component of a participant's monthly bill. As shown in the Figure 10 the average summer (May-October) monthly bill savings (51%) were higher as compared to the average savings (16%) during the winter months (November-April). One of the reasons contributing to the seasonal difference in savings is the difference between time-of-use and counterfactual flat rates. This difference was higher during the summer season as compared to the winter season.

See Section 3.2 for additional analysis of TOU bill savings, including differences in savings between participants.

**Figure 10. Comparison of Average Baseline and Actual Participant Monthly Bill**




*Source: Guidehouse*

## *2.4 Cost-Effectiveness*

Guidehouse updated the cost-effectiveness analysis utilized in the Settlement Agreement to provide revised projections of Pilot cost-effectiveness based upon actual results from Phase 1. Applying a similar methodology to the original filing, referred to as the Filing Cost Test (FCT), the updated results continue to suggest that the Pilot will deliver benefits approximately equivalent to costs, with a benefit-cost ratio of 0.99 for Phase 1 and Phase 2 combined.

### 2.4.1 Cost and Benefit Streams

Guidehouse used the Filing Cost Test (FCT) to assess the cost-effectiveness of the program. The FCT was used to align the cost-effectiveness estimates with the methodology used by Liberty Utilities in Attachment 2 of the Settlement Agreement. This allowed for a comparison of the retrospective estimate of cost-effectiveness with the prospective estimate developed for Liberty's original filing. The value streams that are considered for the FCT are identified in Table 3, below.

**Table 3. Summary of Benefit and Cost Analysis Categories considered in FCT**

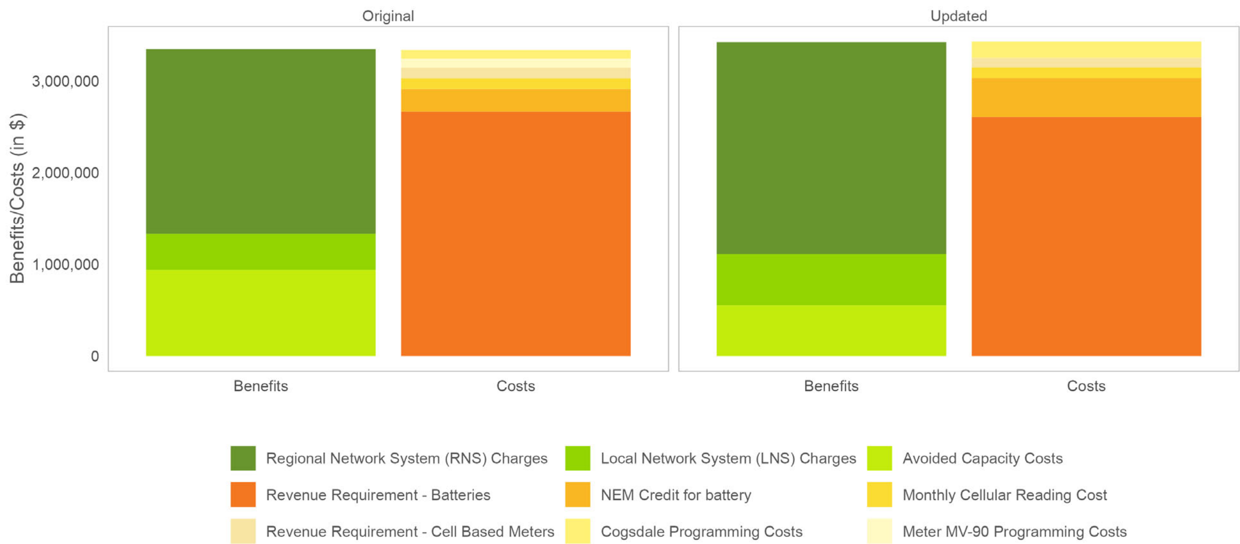
| BCA Category | FCT | Description | Approach |
|---|---|---|---|
| **Battery Costs** | Cost | Costs associated with battery hardware, installation, and control. | Provided by Liberty |
| **Metering Costs** | Cost | Costs associated with metering upgrades to support TOU rates. | Provided by Liberty |
| **Avoided Regional Network System Monthly Charges** | Benefit | Avoided RNS charges due to reduction of monthly coincident peak demand. | Guidehouse used actual battery performance data and rate forecasts provided by Liberty to calculate RNS Charges (Refer Section 2.1.2 for details). |
| **Avoided Local Network System Monthly Charges** | Benefit | Avoided LNS charges due to reduction of monthly coincident peak demand. | Guidehouse used actual battery performance data and rate forecasts provided by Liberty to calculate LNS Charges (Refer Section 2.1.2 for details). |
| **Avoided Annual Generation Capacity Costs** | Benefit | Avoided generation capacity charges due to reduction of annual coincident peak demand. | Guidehouse used actual battery performance data and rate forecasts provided by Liberty to calculate Avoided Capacity Charges (Refer Section 2.1.2 for details). |
| **Net Energy Metering Credits** | Cost | Credits on participants' bills for NEM compensation for net exports during dispatched peak events. | Guidehouse used actual battery net energy exported to and imported from the grid to calculate NEM credits (Please refer Section 2.3.1 for details). |

### 2.4.2 Phase 1 + 2 Cost-Effectiveness

Figure 11 shows a comparison between original and updated benefit and cost value streams for both Phase 1 and 2 of the Pilot. The "Original" value streams represent the estimated net present value of costs and benefits as included in the Settlement Agreement without any adjustments (page 31). The "Actual" value streams represent the net present value of the updated costs and benefits using the actual data from January 2021 to August 2022 and an updated forecast of rates for 2023 and onwards. In these calculations, Guidehouse assumed that the average battery performance moving forward (Sep 2022 and onwards) would remain same as the average historical performance in Phase 1 (79%).

As shown in Figure 11, the updated net present value of both benefits and costs are very similar to the original benefits and costs. Consequently, the updated benefit-cost ratio (1.00) is approximately equal to the benefit-cost ratio projected in the settlement agreement.

**Figure 11. Comparison of Benefit and Cost Value Streams (Phase 1 and 2)** [9]




*Source: Guidehouse*

# 3.0 Technical Evaluation

This section provides additional analysis to understand variations in performance between customers, assess compliance of battery operation with program design, and to inform considerations for the design of Phase 2. Key findings include the following:

- While the performance in Phase 1 exceeded the target performance (75%), there is reasonable potential for even greater performance moving forward through improvements to battery programming and dispatch strategy (see Section 3.1).
- Summer bill savings for participants without solar PV were of a similar magnitude to maximum expected savings based upon the specified arbitrage methodology in summer. Bill savings were less than maximum expected savings in winter and for participants with solar PV (see Section 3.2.1).
- Battery dispatch generally complied with requirements for net export avoidance (see Section 3.2.2) and backup power reserve (see Section **Error! Reference source not found.**), with some exceptions.
- Battery performance generally aligned with nameplate specifications for charge and discharge rates (see Section 0), efficiency (see Section 3.3.3), and energy capacity degradation (see Section 3.3.4).

[9] The date ranges considered in the original and updated benefit cost analysis are different due to a delay in the actual Phase 1 start date. The original analysis values are based on 2018 dollars while the updated analysis is based on 2020 dollars.

## *3.1 Event Performance*

While the performance in Phase 1 exceeded the target performance (75%), there is reasonable potential for even greater performance, as Guidehouse identified issues with variations in participant performance that suggest that approximately one quarter of participants could perform significantly better after issues with battery programming are addressed (see Section 3.1.1). Additionally, improvements in event dispatch strategy associated with improved confidence in forecasting coincident peak hours could further increase peak reduction benefits (see Section 3.1.2).

### 3.1.1 Participant Performance Variability

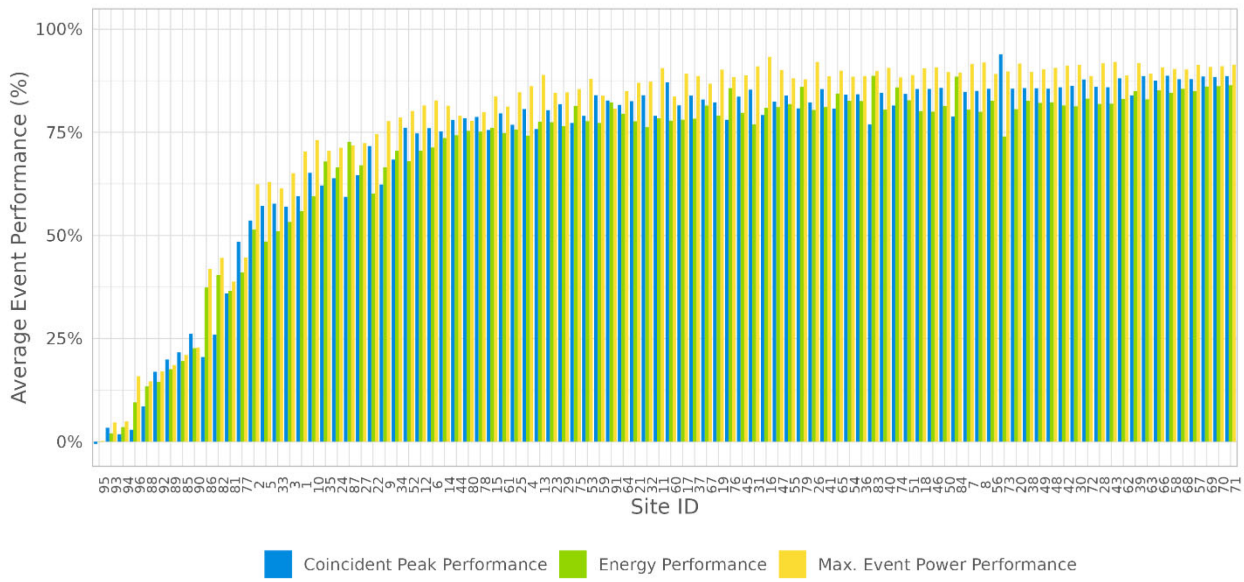
Guidehouse used a variety of metrics to measure battery event performance. Figure 12 displays three of the primary performance metrics calculated, coincident peak performance, energy performance, and maximum event power performance. These parameters are calculated as follows:

- **Coincident peak performance** for each participant is the average hourly power output during monthly coincident peaks divided by 10 kW (the maximum theoretical power output). This average is across the individual peak hours of each month. For a participant with 80% coincident peak performance, the battery exported 8 kW on average across coincident peak hours.
- **Maximum event power performance** is based upon the highest hourly power output during events. First, the maximum hourly event power output is calculated for each event for all participants. Then, the performance is calculated for each event and participant by dividing the maximum event power by 10 kW. Lastly, the average maximum event power performance metric is calculated by averaging performance across all events for each participant.
- **Energy performance** is the amount of energy exported during an event divided by the theoretical maximum energy exported. The theoretical maximum energy exported is 20 kWh during a 2-hour event (due to the maximum power output of 10 kW), and 21.6 kWh during a 3-hour event (as participant batteries cannot drop below 20% of the 27 kWh capacity). As with the other metrics, energy performance is averaged across all events for each participant.

Figure 12 shows that there is a strong correlation between coincident peak performance, maximum power performance, and energy performance. Each participant is labeled by a Site ID, which corresponds to the order in which the system was installed (i.e., lower Site IDs were installed earlier in Phase 1, and higher Site IDs were installed later in Phase 1).

Most participants (72%) had average coincident peak performance greater than 75%. Nonetheless, there is a steep drop-off in performance for the lowest quartile of participants. Most of the lowest performers are the newest participants that were deployed in 2022 (indicated by the higher Site-IDs), which may suggest that Tesla may have introduced programming changes in newer batteries which resulted in lower performance. However, some of the below average participants were enrolled from the beginning of Phase 1.

**Figure 12. Average Event Performance Metric Comparison**



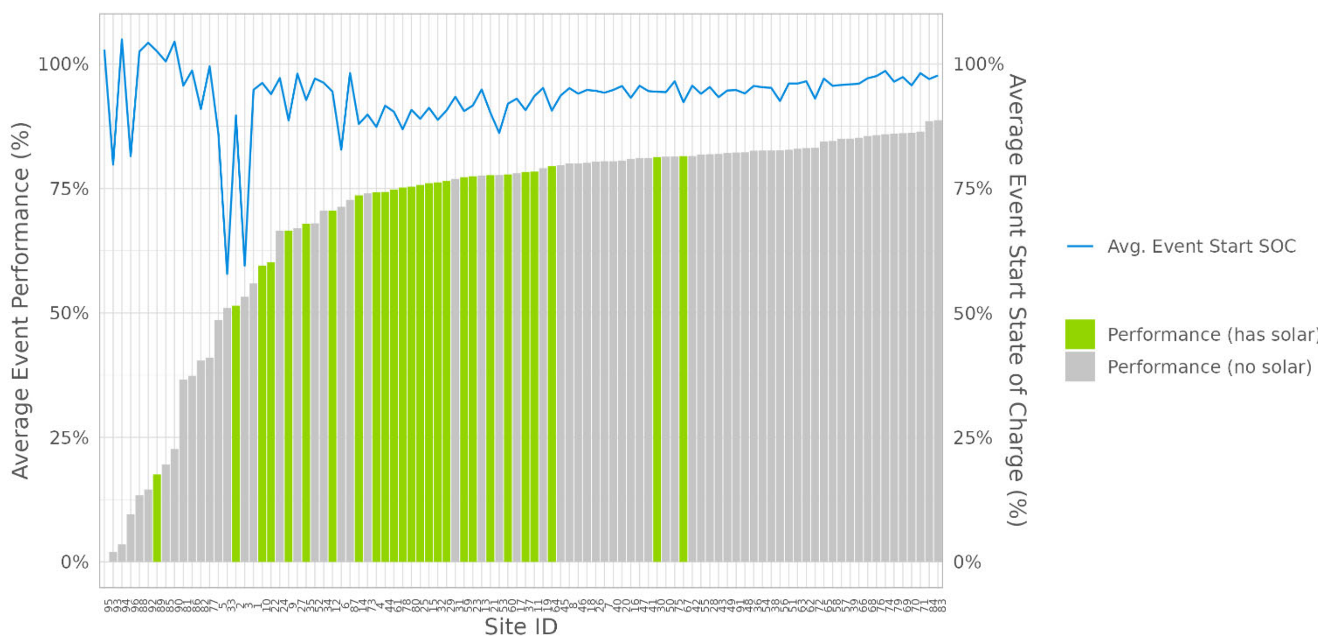

*Source: Guidehouse*

Figure 13 summarizes two key metrics for each participant: average event start state-of-charge (SOC) and event energy performance. Guidehouse calculates event start SOC from the battery interval data based upon the battery energy remaining at the beginning of each event period. The bars in Figure 13, representing energy performance, are colored by whether the participant has a battery only (gray) or has solar PV (green). The blue line represents average event start SOC.

The figure shows a correlation between event start SOC and energy performance for the participants with average performance above 75%. The highest performers are nearly all Site-IDs without solar PV that have a high average event start SOC. It is possible customers with solar PV may have lower event start SOCs due to requirements for charging directly from PV (rather than the grid). However, exceptions are made to allow charging from the grid on event days. The lower energy performance may be associated with having some solar output during events, which may limit battery output (if the inverter is shared).

For the lowest quartile of performers, there does not appear to be a correlation between event start SOC and performance for the lowest quartile of performers. There does, however, appear to be a correlation between Site ID and performance, as all of the batteries with average energy performance below 40% have Site IDs in the top quartile, meaning they were deployed later in Phase 1. This suggests that changes in battery programming may have been introduced partway through Phase 1 which resulted in lower performance.

**Figure 13. Average Event Energy Performance and Event Start SOC by Battery**




*Source: Guidehouse*

### 3.1.2 Forecast Accuracy

Every monthly (Liberty system peak) and annual (ISO-NE peak) coincident peak occurred during an event, so batteries effectively reduced peak demand charges for 100% of months during Phase 1. Table 4 shows the number of events called to hit the coincident peaks. The average number of events called per month in 2021 was 6.17 and 6.5 in 2022. Each event lasted for either 2 or 3 hours. The average number of hours per event was 2.76 in 2021 and 2.23 in 2022, indicating there were more 3-hour events in 2021 as compared to 2022.

**Table 4. Summary of all Events by Months during Phase 1**

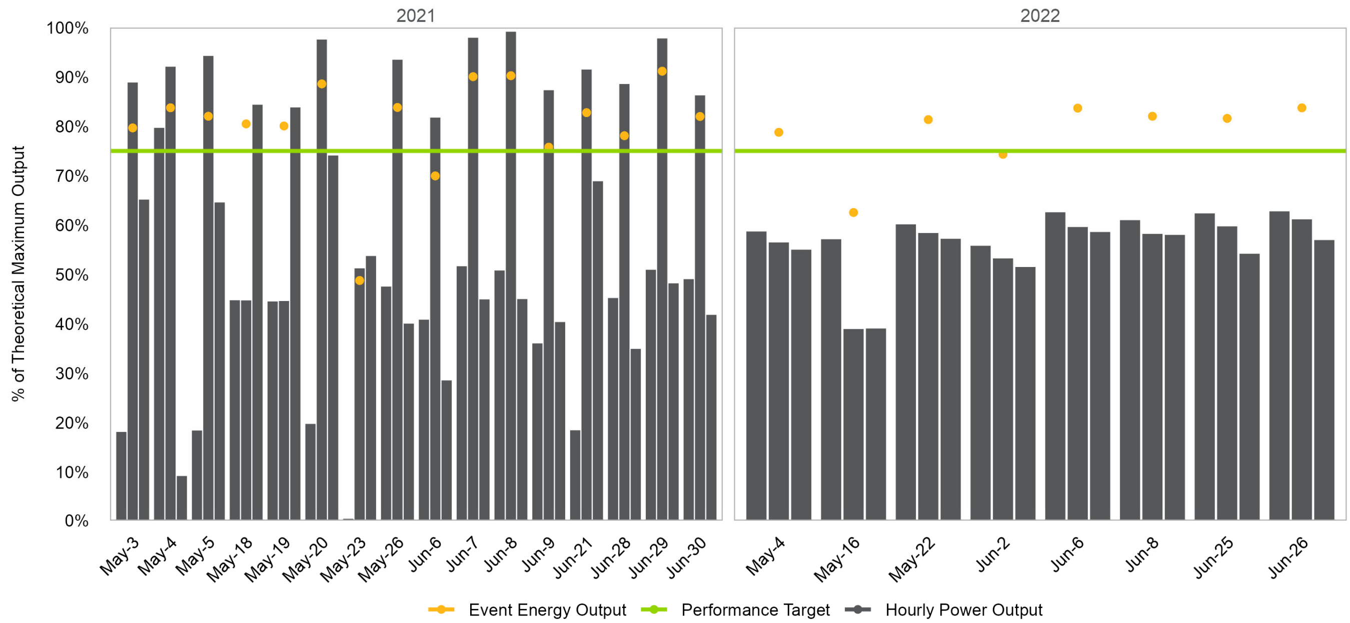
| Month-Year | Number of Events | Average hours per Event | Average Event Energy Performance |
|---|---|---|---|
| Dec-2020 | 5 | 3 | 48% |
| Jan-2021 | 7 | 3 | 58% |
| Feb-2021 | 3 | 2.25 | 40% |
| Mar-2021 | 1 | 3 | 44% |
| Apr-2021 | 3 | 3 | 63% |
| May-2021 | 8 | 3 | 78% |
| Jun-2021 | 8 | 3 | 82% |
| Jul-2021 | 5 | 3 | 85% |

| Month-Year | Number of Events | Average hours per Event | Average Event Energy Performance |
|---|---|---|---|
| Aug-2021 | 7 | 2.86 | 84% |
| Sep-2021 | 3 | 3 | 86% |
| Oct-2021 | 7 | 3 | 60% |
| Nov-2021 | 16 | 2.44 | 75% |
| Dec-2021 | 6 | 2 | 82% |
| Jan-2022 | 4 | 2 | 80% |
| Feb-2022 | 3 | 2.33 | 85% |
| Mar-2022 | 5 | 2.4 | 85% |
| Apr-2022 | 4 | 2 | 85% |
| May-2022 | 9 | 2.33 | 82% |
| Jun-2022 | 11 | 2.45 | 83% |
| Jul-2022 | 10 | 2 | 68% |
| Aug-2022 | 6 | 2.17 | 79% |

*Source: Guidehouse*

As noted in Section 2.1.1, due to an apparent change in event dispatch startegy for 3-hour events, it appears that there may have been less confidence in forecasting the coincident peak hour in 2022 as compared to 2021. Figure 14 shows hourly event performance during 3-hour events in the months of May and June during 2021 and 2022. As shown in the Figure 14, the average hourly event output in 2022 was spread relatively evenly across all the 3 hours of an event. Due to limitations in battery energy capacity, this strategy resulted in relatively low hourly power performance (less than 75%) event across all event hours, even though the average event energy output was 75% or greater during most of the events. The event dispatch strategy for 3-hour events was very different from 2021, where peak event output typically exceeded 75% in one interval (presumably the one most expected to be the coincident peak).

**Figure 14. Hourly Event Performance during Events in May-June of 2021 and 2022**




*Source: Guidehouse*

## *3.2 TOU Performance*

For customers without solar, bill savings during summer months was similar to the maximum expected savings, while winter bill savings were somewhat lower than the maximum, possibly due to greater difficulty in forecasting lower customer loads with less weather dependence. For customers with solar, limitations for battery charging and discharging resulted in somewhat lower bill savings (see Section 3.2.1).

The batteries generated the bill savings while generally complying with net export restrictions, with some exceptions (see Section 3.2.2).

### 3.2.1 Savings vs. Maximum

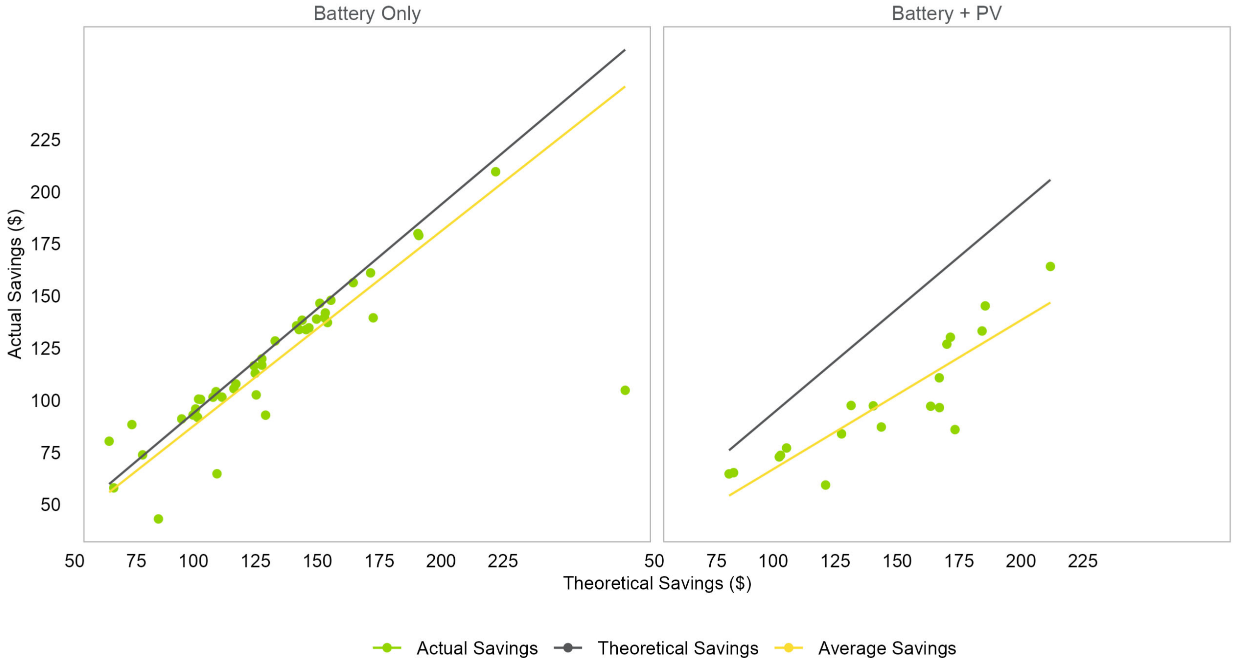
Figure 15 shows a comparison of actual achieved bill savings and maximum theoretical savings assuming perfect foresight[10] during a typical month in both summer and winter season. To calculate theoretical savings, Guidehouse assumed that the batteries were dispatched to maximize peak load reduction during critical peak hours on event days. On non-event days, Guidehouse assumed that the batteries were dispatched to offset customer load during critical peak hours on weekdays and on-peak hours on weekends. The batteries were assumed to

[10] Perfect foresight assumes that a customer's load consumption – excluding the battery – is known in advance. This allows battery-driven TOU savings to be maximized within constraints (e.g., no net export during non-event hours). The assumption of perfect foresight and calculation of theoretical savings does not include impacts from PV, which places additional constraints on charging and discharging.

charge to their maximum capacity only during the off-peak hours. The batteries were not assumed to reduce on-peak consumption on non-event weekdays.

As shown in Figure 15, the actual savings (95%) during a representative summer month (June 2022) were very close to the maximum expected bill savings possible for customers with stand-alone batteries. For customers with both battery and solar PV systems, the actual savings were on an average 72% of the maximum expected bill savings. This is expected since solar PV places additional limitations on charging and discharging,[11] which weren't considered while calculating the theoretical savings.

**Figure 15. Comparison of Actual and Theoretical Savings in Summer (June 2022)**



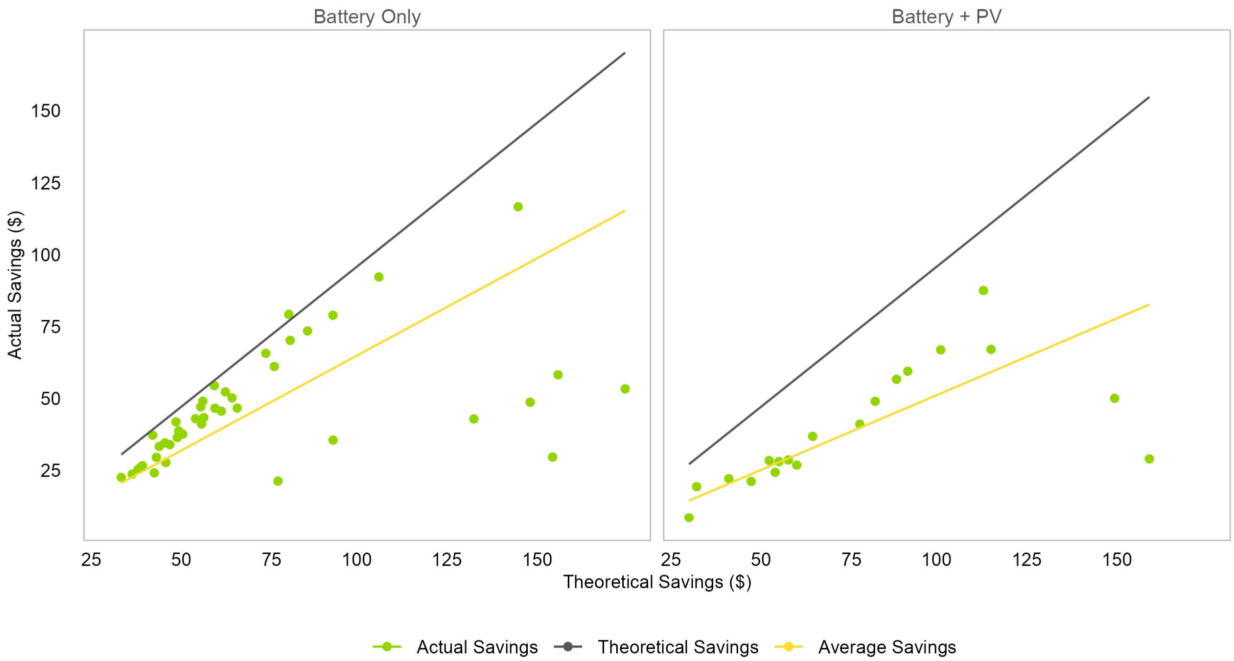

*Source: Guidehouse*

On average, the actual savings achieved during a representative winter month (January 2022) were lower than the summer month for customers both with and without a solar PV system. As shown in Figure 16, the actual savings were 74% of the theoretical maximum bill savings possible for customers with stand-alone batteries. For customers with solar PV system, the actual savings were on an average 55% of the theoretical maximum bill savings. Again, this is expected due to charging and discharging limitations for customer with solar PV.

It is not clear why TOU performance, relative to maximum, would be relatively low in the winter as compared to summer. Notably, winter performance for most participants without solar was near the theoretical savings, while several (7) outliers generally related low TOU savings.

[11] For batteries paired with solar PV, the charge rate was limited by PV generation power so that batteries were charged directly by PV, rather than the grid. Additionally, the discharge rate during non-event hours is limited to avoid net export, and solar PV generation reduces effective load, thereby limiting the maximum discharge rate.

**Figure 16. Comparison of Actual and Theoretical Savings in Winter (January 2022)**



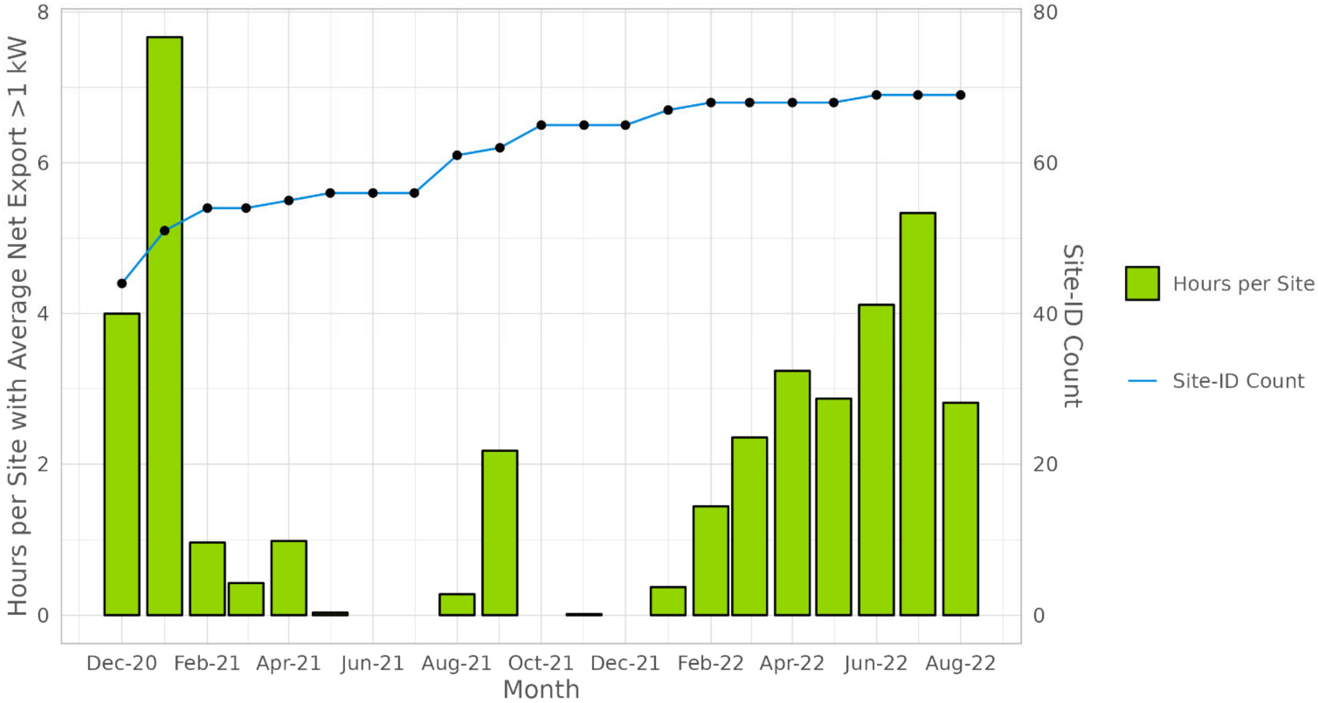

*Source: Guidehouse*

### 3.2.2 Net Export Avoidance

Guidehouse analyzed the battery data to assess compliance with limitations on net exports during non-event hours. Figure 17 shows – for each month during Phase 1 – the average number of hours per participant during which a battery is net-exporting over 1 kW on average during the hour. Since non-solar batteries should not be exporting to the grid during non-event hours, Guidehouse filtered the interval battery data to non-event hours and calculated the average hourly site power for each non-solar participant for all hours of Phase 1. Guidehouse then calculated the total number of hours per month where average site power was greater than 1 kW exported, as well as the number of participants with data in that month. The total number of participant-hours with greater than 1 kW exported was divided by the number of participants with data to determine how often the batteries were net-exporting, on average, throughout Phase 1.

Figure 17 illustrates that battery-only customers were net exporting with higher frequency in the first couple of months, then less frequently or not at all through 2021, then with higher frequency again in 2022. It is not clear why net export frequency varied in this way over time. Overall, 87% of battery-only participants net-exported for at least one non-event hour during Phase 1. Nonetheless, across all non-event hours of Phase 1, battery-only participants net-exported only 0.27% of participant-hours.

**Figure 17. Net Exports during Non-Event Hours (Battery-only Participants)**

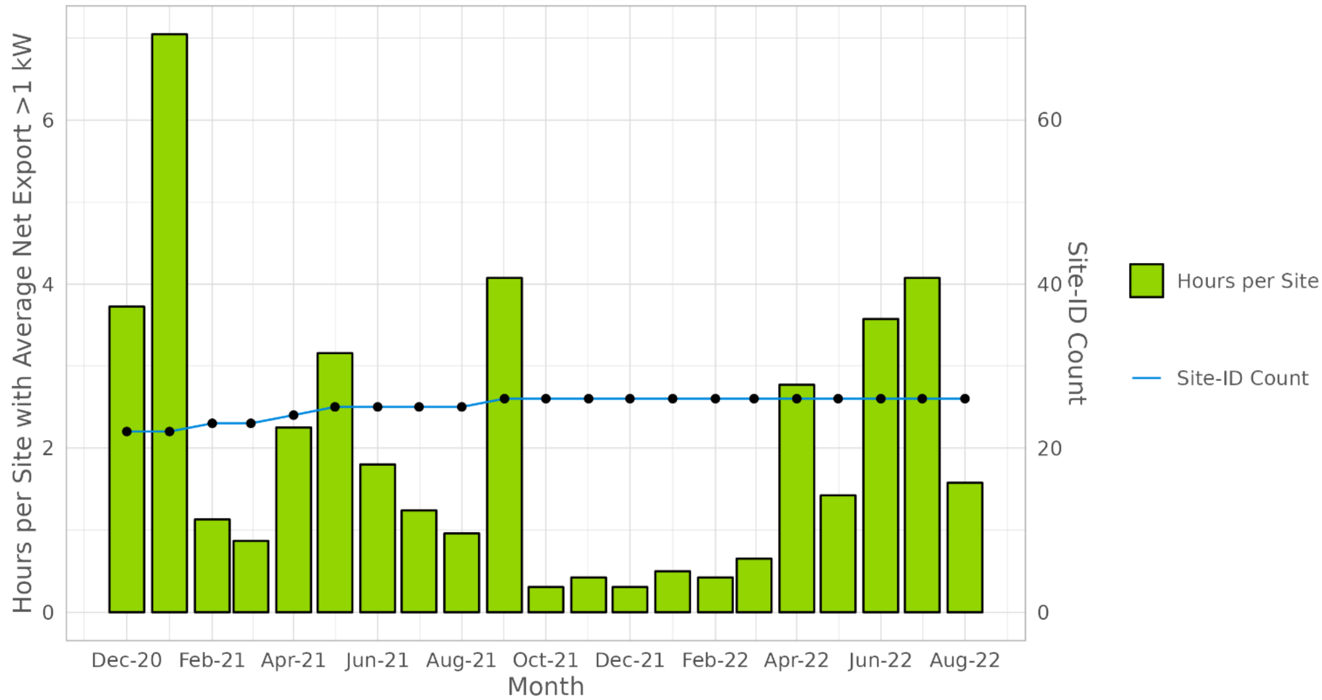



*Source: Guidehouse*

Figure 18 illustrates the net exports for participants with solar PV and follows a slightly different methodology than that for battery-only participants. Participants with solar can export solar energy to the grid during non-event hours but should not be exporting battery energy to the grid during non-event hours. Therefore, Guidehouse filtered the interval battery data to non-event hours and calculated the average hourly site power and average hourly battery power for each participant with solar PV for all hours of Phase 1. Guidehouse then calculated the total number of non-event hours per month where the average site power was greater than 1 kW exported and the average battery power was greater than 1 kW exported, along with the number of participants with data in that month. The total number of hours meeting these criteria were divided by the number of participants with data to determine how often the participants with solar were net-exporting on average throughout Phase 1.

Figure 18 shows more consistent exporting for the participants with solar PV, relative to battery-only customers, throughout Phase 1, and batteries for every participant with solar PV net-exported for at least one non-event hour during Phase 1. Additionally, the two types of participants (solar/non-solar) seem to have net-exported most frequently during similar months, such as January 2021, September 2021, and July 2022. Nonetheless, across all hours of Phase 1, participants with solar PV net-exported only 0.28% of participant-hours.

**Figure 18. Net-Export during Non-Event Hours (Participants with Solar PV)**




*Source: Guidehouse*

## *3.3 Battery Performance*

The batteries performed generally in line with energy reserve requirements and nameplate specifications. The average hourly state of charge dropped below 20% (minimum reserve requirement) in less than one percent of all non-outage hours (see Section 3.3.1). Maximum observed charge rates were within 5% of nameplate (10 kW per participant) for 94% of customers, and maximum observed discharge rates were within 5% of nameplate for 96% of customers (see Section 3.3.2). Average battery efficiency (87%) was slightly below the nameplate roundtrip efficiency (90%), consistent with expectations (see Section 3.3.3), and degradation was approximately 2% per year, consistent with a nameplate lifetime of 10 years (see Section 3.3.4). Backup Power Reserve

### 3.3.1 Energy Reserve Compliance

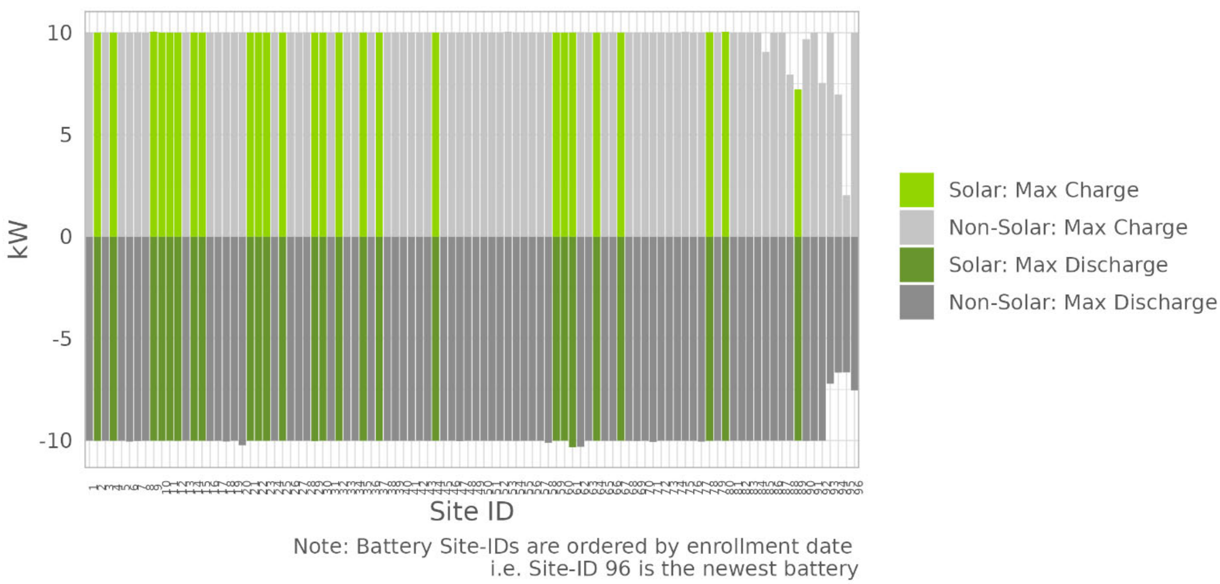
Guidehouse analyzed battery data to assess compliance with energy reserve requirements, which guarantee participants that the 20% of battery energy will be reserved for use only in the case of system outages. Guidehouse calculated the percentage of participant-hours with state-of-charge (SOC) below 20% by filtering the battery data to intervals in which the battery was grid-connected (i.e., not in backup mode), then calculated the SOC based upon the battery energy remaining data and the nameplate energy capacity. The batteries generally complied with the requirement, with some exceptions. Of the 96 participants, 49 (51.6%) had at least one hour with an average SOC under 20%, but less than one percent (0.55%) of non-outage participant-hours had an average SOC under 20%. There is no apparent correlation between events and low SOC, as average SOC fell below 20% for 0.69% of participant-hours during events, compared to 0.54% of participant-hours during all other non-outage hours.

### 3.3.2 Maximum Charge & Discharge Rates

Figure 19 shows the maximum charge and discharge power for each Site ID. Guidehouse created this figure by calculating the maximum and minimum battery instant power for each Site across all intervals in the Tesla data. The bars are also colored by whether there is solar PV present at the Site, and the sites on the x-axis are ordered by the date they first appeared in the data. The figure shows that nearly all batteries reported a maximum charge and discharge rate near 10 kW, the maximum nameplate specification power output.

The few batteries that have lower maximum output are all relatively new batteries (deployed between January 2022 and February 2022). While this may suggest that batteries have not needed to charge at a faster rate during the shorter period, all have participated in events during which maximum discharge is desired. Thus, this provides further indications, in addition to lower relative event performance, that there may have been programming issues with batteries that were more recently installed.

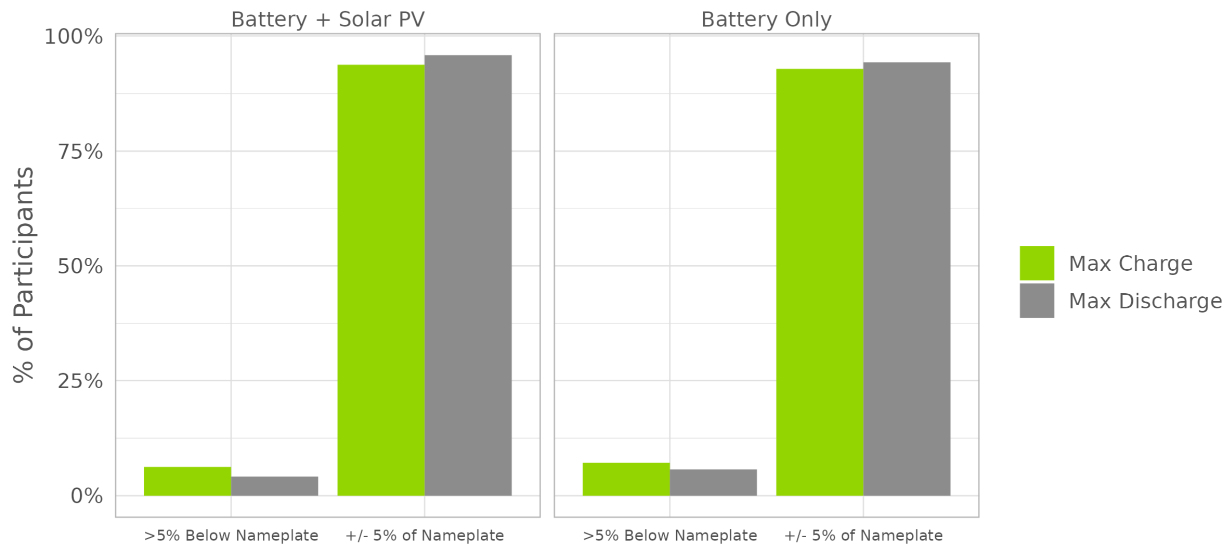
**Figure 19. Maximum Battery Charge and Discharge Rate by Site-ID**




*Source: Guidehouse*

Figure 20 summarizes the findings above in Figure 19. The figure shows that 96% of all batteries have discharged at a rate within 5% of 10-kW, while 94% of all batteries have charged within 5% of 10-kW. Results are similar for battery-only customers and those with solar PV. There is a slightly higher percentage of batteries with a maximum discharge rate within 5% of the 10-kW expectation than there is with a maximum charge rate in that range. This is intuitive as we expect batteries to need to discharge at a high rate during events but may not necessarily need to charge near the maximum possible rate.

**Figure 20. Maximum Charge and Discharge Summary**




*Source: Guidehouse*

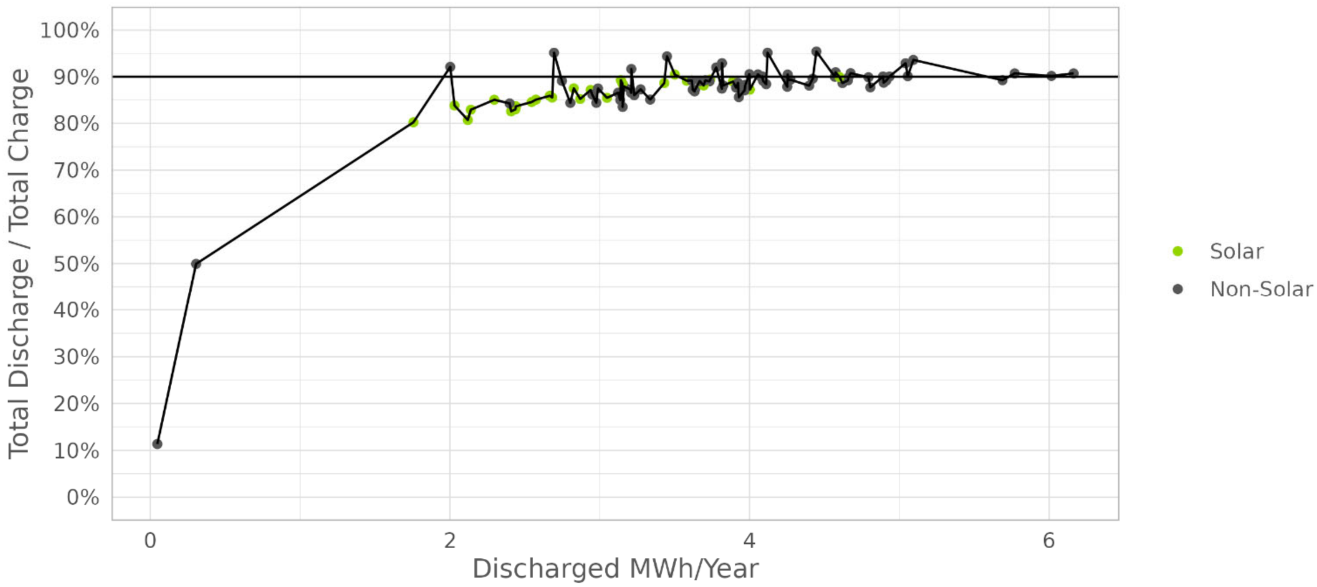
### 3.3.3 Efficiency

Figure 21 combines and compares two battery metrics – efficiency and total energy dispatched – to calculate total energy efficiency. Guidehouse calculates efficiency as the sum of all energy discharged divided by the sum of all energy charged.[12] Total efficiency is expected to be lower than nameplate roundtrip efficiency, as roundtrip efficiency accounts only for cycling losses, while total efficiency includes standby losses from factors such as auxiliary power consumption and self-discharge. Therefore, we expect participants with relative low energy throughput may have lower apparent efficiencies due to relatively high standby losses in comparison to cycling losses.

Figure 21 illustrates that batteries with a higher total discharge sum do in fact have a higher efficiency. Most batteries in Phase 1 show an actual efficiency near the targeted nameplate efficiency of 90%. Many of the batteries with efficiencies below the 90% nameplate rating are customers with relative low energy throughput. Furthermore, customers with solar PV tend to have lower energy throughput, resulting in relatively low efficiencies.

[12] This calculation does not account for changes in the initial and final state of charge. However, the average impact from this factor is expected to be minimal. For batteries with 2.2 MWh dispatched, the maximum impact of state of charge on calculated efficiency is less than1%.

**Figure 21. Battery Efficiency vs. Total Energy Discharged**




*Source: Guidehouse*

### 3.3.4 Available Energy & Degradation

Figure 22 shows the average monthly battery energy capacity for the 66 Site-IDs that were enrolled for all of Phase 1.[13] Tesla nameplate specifications indicate a battery lifetime of 10 years. Given that battery end of life is commonly assumed to be the point at which batteries reach 20% degradation (or 80% of original energy capacity), we assume expected battery degradation is approximately 2% per year. The yellow line below represents that expected capacity, while the green line shows the average nominal battery energy capacity for the 66 participants enrolled all of Phase 1. The blue line represents a best fit linear regression for average nominal battery energy capacity. The figure shows that while capacity varies slightly by season,[14] the overall trend is very similar to the expected degradation rate. The linear regression estimates that average nominal capacity begins at higher percentage than expected and decreases at a rate of approximately 2.2% per year.

[13] Batteries deployed later in Phase 1 are excluded in order to isolate the impacts of degradation over time.
[14] Tesla has indicated this estimation of available energy is sensitive to a variety of factors, including ambient temperature.

**Figure 22. Average Monthly Battery Energy Capacity & Expected Degradation**


*Source: Guidehouse*

# 4.0 Process and Customer Experience Evaluation

Guidehouse engaged with participants via an online survey during two customer participation points of the pilot, the enrollment period as well as at the close of the pilot. Responses from survey questions provided insights into the participant's motivations, behaviors, comprehension of the pilot, as well as satisfaction, as outlined in Table 5.

**Table 5. Process Evaluation Research Questions for**

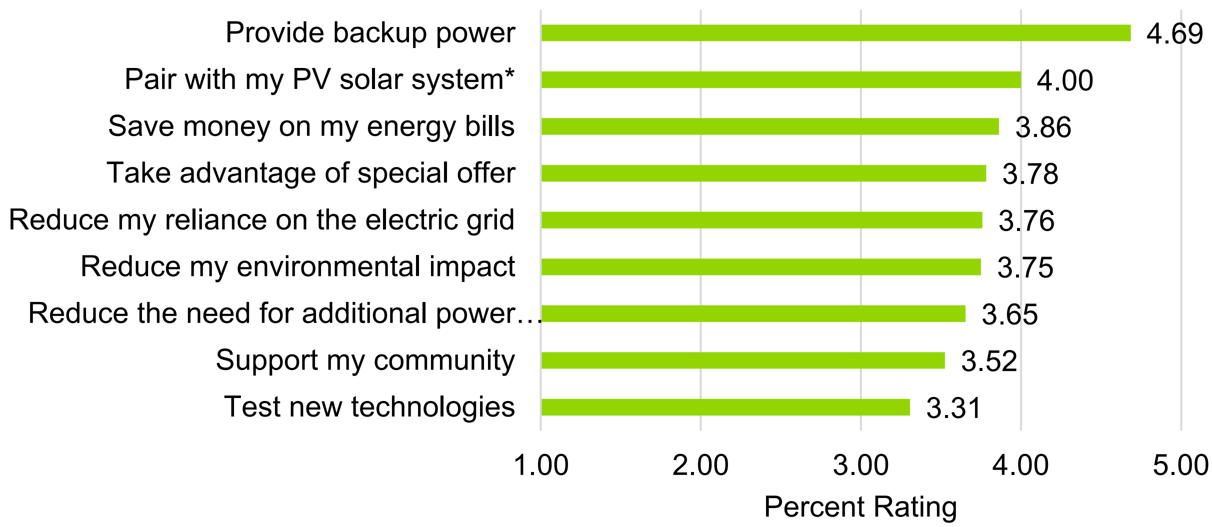
| Category | Research Questions |
|---|---|
| **Motivations** | What was the primary motivation for customers to obtain a battery and participate in the program? |
| **Outreach** | How did participants hear about the program?<br>Which of the marketing and outreach methods were most successful? |
| **Processes** | Were there any issues in the installation process?<br>What are these barriers, and how might Liberty address them? |
| **Behaviors** | What are customer usage patterns and end-uses prior to participation?<br>Are customers changing their consumption patterns due to TOU rates?<br>How have behaviors changed during the critical peak period?<br>How have behaviors changed during the on peak period? |
| **Comprehension** | How well do customers understand the TOU rate and Liberty's access to their battery? |
| **Demographics** | What are the demographics of the participant population? |
| **Distributed Generation** | How many participants have solar PV or other distributed generation? |
| **Satisfaction** | Were the customer's expectations met?<br>Would they participate in the program again or recommend it to a friend based on their experience? |

At the close of the enrollment survey, which was fielded from June 2020 through July 2022, Guidehouse received 71 survey responses equaling a response rate of 72%. The end of pilot survey was fielded from July 2022 through August 2022 and received a total of 68 responses, a response rate of 73%. Some customers that completed the enrollment survey chose not to respond to the end of pilot survey. For comparison purposes, Guidehouse has excluded customers that only completed one survey when discussing participation trends.

### 4.1.1 Motivation

Motivations for participating in the pilot varied as shown in Figure 23, however, the ability to provide backup power was rated the most important factor at 4.69 of respondents rating it as extremely important. The second highest rated factor for participation was the ability to pair the system with their solar PV (4.0) as seen in Figure 23.

**Figure 23. Motivations for Pilot Participation**




**Results only show respondents that identified as solar PV owners.*

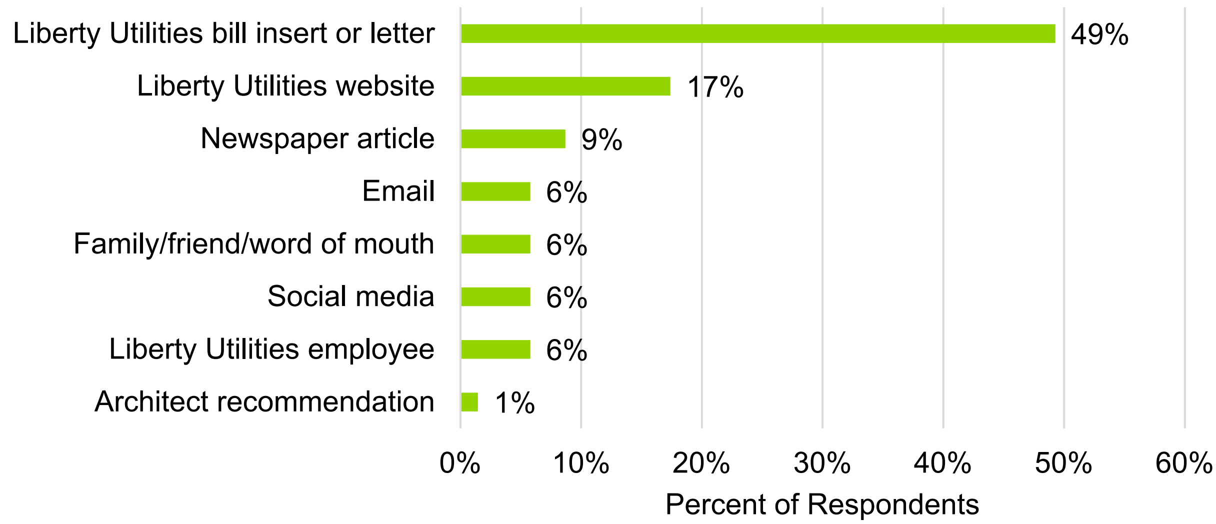
*Source: Guidehouse Analysis*

### 4.1.2 Outreach

Various marketing methods were deployed to promote the pilot program prior to the enrollment phase. When asked how participants learned of the program, half (49%) responded that they first heard about the pilot through a Liberty Utilities bill insert or letter. The second most successful method of outreach was the Liberty Utilities website (17%). Methods such as a Liberty Utilities employee (6%) and architect recommendations (1%) were the least common ways in which the participants learned about the pilot, as seen in Figure 24.

It should be noted that direct mail (bill inserts) had the most impact in program awareness, as well as the Liberty Utilities website. It could be hypothesized that these methods are integrated with bill payment methods, thus making them the most pronounced.

**Figure 24. Methods of Battery Storage Outreach**



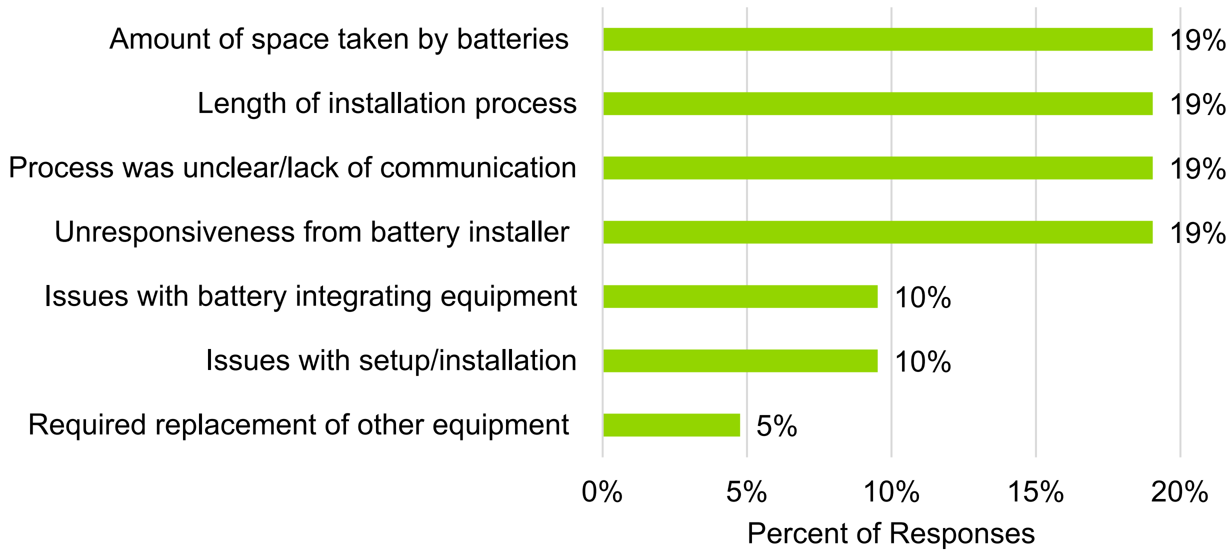

*Source: Guidehouse Analysis*

### 4.1.3 Processes

Participants noted some challenges and barriers during the enrollment and installation period. Of the customers that responded to the survey, 30% reported encountering a barrier during the installation process. The most frequent issues reported were the space the battery took in the home (19%), the length of the installation process (19%), the lack of communication around the process (19%), and the level of responsiveness from the battery installer (19%), as seen in Figure 25.

Respondents who expressed challenges cited increased communication from both the installer and from Liberty Utilities on timeline, changes to rates, and other programs as ways to help improve the program.

**Figure 25. Barriers Encountered During Installation Process**




*Source: Guidehouse Analysis*

Participants also had the opportunity to rate factors associated to the installation process. Using a scale of 1-5, where 1 is extremely dissatisfied and 5 is extremely satisfied, customers rated the ease of scheduling the installation with the technician an average of 4.45, the installation process an average of 4.59, and the professionalism of the technician that came to their home as an average of 4.93.

At the close of the pilot, participants once again had the opportunity to share barriers that they experience throughout the program. Customers who expressed challenges noted that most of their issues were associated with the installer (n=10). Additional issues include not optimizing for PV, delays in reactivation after a storm, difficulties with registering, lack of battery/PV system coordination, limits to the battery storage size, and limit to solar PV even after home load had increased, which all had an n value of one.

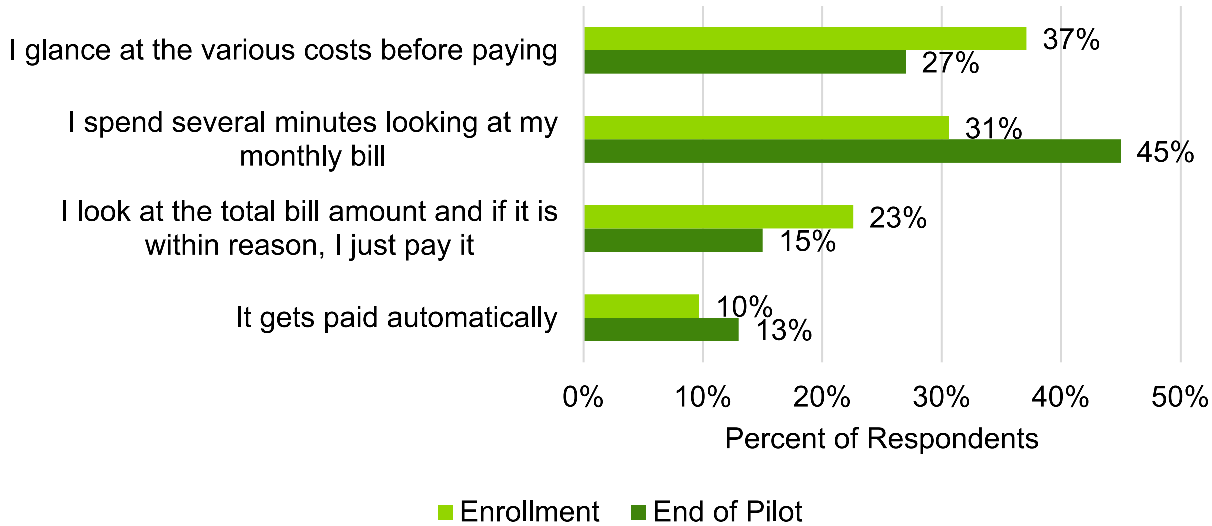
At the close of the pilot, participants noted that most of their issues were around their interaction with the installer, with some noting issues with the batteries itself. Customers cited the amount of battery down time after an outage, difficulty with battery registering, and coordination between the battery and some customer's PV systems. To rectify this, participants stated that they are looking to better understand the program and how they can improve their benefits. Some participants would like to understand how they could add more battery storage and potentially change their charging patterns. Additionally, participants would like more communication and education on the algorithm used for payment and how the program works. Despite some challenges, most customers (79%) are willing to recommend the program to a friend.

### 4.1.4 Behaviors

*Utility Bill*

Prior to participating in the pilot, respondents were split in how they engaged with their utility bill. Respondents reported glancing at the various costs and other information on the bill before paying (37%), spending several minutes looking at their bill to understand the costs and other information provided (31%), and looking at the total bill amount and if it is within reason, they just pay it (23%). Only 10% do not look at their bill at all since it is paid automatically, as seen in Figure 26.

**Figure 26. Customer Utility Bill Behavior**




*Source: Guidehouse Analysis*

Guidehouse saw most notably an increase (14%) in the number of respondents reporting spending several minutes looking at their monthly bill after participating in the pilot. This is an indication that participants overall are spending more time looking at their utility bill post pilot.

*Appliances/Equipment*

Overall, participants largely did not change the amount of equipment or appliances in their home throughout the pilot. The notable exceptions were the addition of 6 heat pumps (Table 7), the removal of 4 electric water heaters (Table 7), the addition of 6 computers (Table 9), and the addition of 5 televisions (Table 9). Based on the small sample size of participants in this analysis, it appears that there is a correlation between customers adopting heat pumps and customers adopting energy storage. While about 2-4% of New Hampshire customers are estimated to have air-source heat pumps,[15] the survey responses indicate that more than 20% of Pilot participants have adopted heat pumps.

[15] New Hampshire Potential Study: Statewide Assessment of Energy Efficiency and Active Demand Opportunities, 2021-2023, Volume III: Residential Market Baseline Study (2020)

**Table 6. Customer Cooling Equipment Pre and Post Pilot**

| | Evaporative or swamp cooler | Central air conditioning | Window unit air conditioner |
|---|---|---|---|
| Enrollment | 1 | 19 | 6 |
| End of Pilot | 0 | 21 | 8 |
| **Difference** | **-1** | **2** | **2** |

*Source: Guidehouse Analysis*

**Table 7. Customer Heating Equipment Pre and Post Pilot**

| | Electric baseboard heat | Electric furnace | Heat pump (ground or air source) | Space heaters | Electric water heaters |
|---|---|---|---|---|---|
| Enrollment | 4 | 6 | 8 | 8 | 17 |
| End of Pilot | 5 | 3 | 14 | 6 | 13 |
| **Difference** | **1** | **-3** | **6** | **-2** | **-4** |

*Source: Guidehouse Analysis*

**Table 8. Customer Kitchen Appliance and Equipment Pre and Post Pilot**

| | Refrigerator | Freezer (separate from refrigerator) | Electric stove / range | Dishwasher |
|---|---|---|---|---|
| Enrollment | 41 | 31 | 34 | 55 |
| End of Pilot | 39 | 31 | 35 | 56 |
| **Difference** | **-2** | **0** | **1** | **1** |

*Source: Guidehouse Analysis*

**Table 9. Customer Appliance and Electronics Pre and Post Pilot**

| | Clothes washer | Electric clothes dryer | Computer | Television | Gaming system | Swimming pool with filtration system |
|---|---|---|---|---|---|---|
| Enrollment | 54 | 50 | 6 | 14 | 12 | 5 |
| End of Pilot | 56 | 50 | 12 | 19 | 13 | 6 |
| **Difference** | 2 | 0 | 6 | 5 | 1 | 1 |

*Source: Guidehouse Analysis*

It was also reported that two participants added solar PV since participating in the program, two other customers removed their backup generator, and three customers purchased EVs. Overall, 12 customers self-reported having solar during the pilot program. This number does differ from tracking data values as not all participants responded to the survey.

*Electric Vehicles*

Of the respondents that reported owning EV's (n=12), all respondents reported charging their vehicles at home. Most customers (83%) reported charging their vehicles between 8pm-8am or during the off-peak time of use period.

*Thermostats*

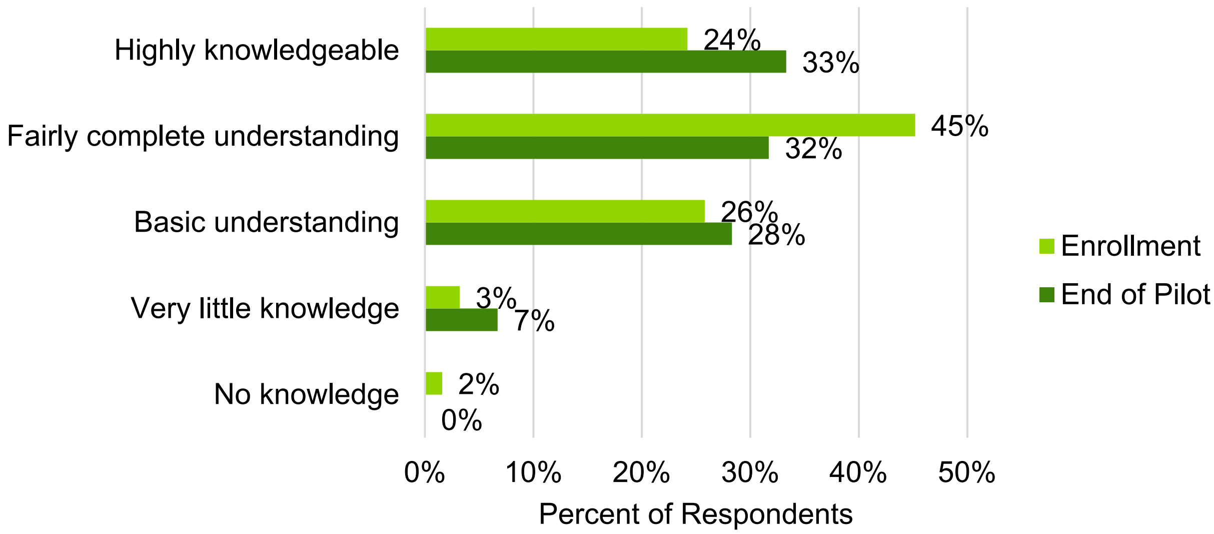
Throughout the pilot, participants largely did not change their winter heating behavior. The average temperature set during the day/evening when people were at home and awake was approximately 68 degrees. Similarly, during the day and evening when no one was home, customers are reporting setting their thermostat at 64 degrees, which is the same temperature reported at night when people were sleeping. When customers were away on vacation, the average temperature reported was 60 degrees.

In the summer months, respondents did report a slight change to their cooling behaviors. From the enrollment period to the end of the pilot, customers set their temperature approximately 4 degrees higher than previously reported, 69 to 73 degrees during the day and evening when people were home and awake. There was also an increase in the average temperature during the day and evening when no one was home, from 70 degrees to 75 degrees. The period at night when people were sleeping also saw a rise from 68 to 72 degrees. Lastly, during vacations or times when the home is unoccupied for a day or more, customers reported setting the temperature at an average of 76 degrees, an increase of five degrees from the enrollment period.

### 4.1.5 Comprehension

When enrolling in the pilot, 45% of participants expressed having a fairly complete understanding of how their battery storage system charged and discharged. However, this percent dropped to 32% at the end of the pilot. There was also a 9% increase in respondents who rated their understanding as highly knowledgeable (24% to 33%), and a slight increase in the basic understanding of charging and discharging (increase of 2%). Guidehouse also saw an increase (4%) of customers reporting very little knowledge (3% to 7%), signaling that some customers may be experiencing confusion post pilot, as seen in Figure 27.

**Figure 27. Customer Comprehension of Battery Charging and Discharging**

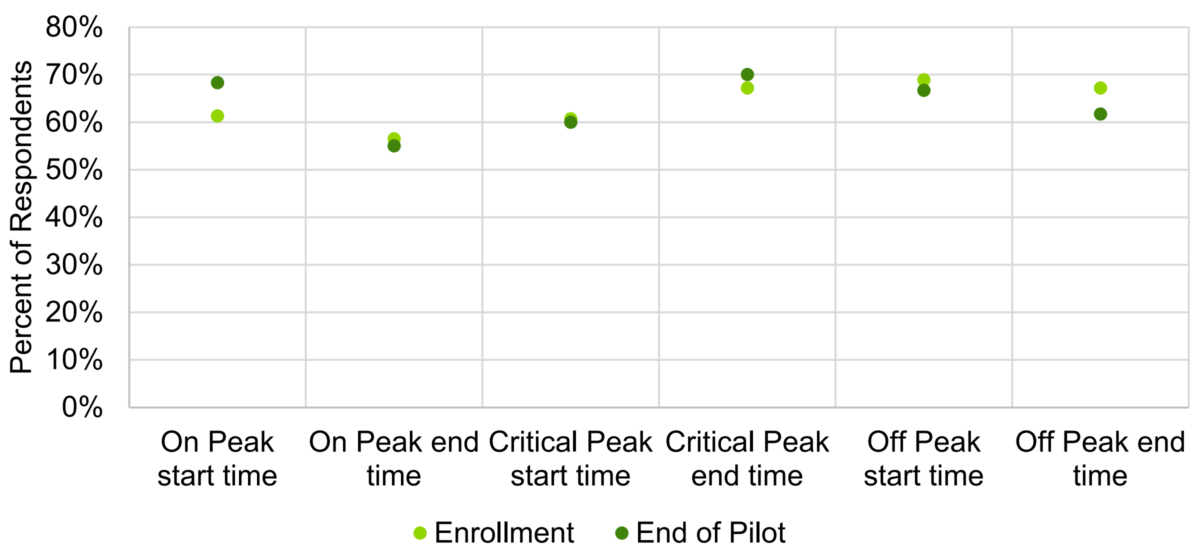



*Source: Guidehouse Analysis*

When probed on the definition of time-of-use rates, Guidehouse saw an increase from 94% to 97% of participants correctly identifying that time-of-use as rates are based on the time of day that the electricity is used. Participants also reported more awareness of the number of time-of-use rates there are on weekdays, an increase of nearly 14% in comprehension (63% to 77% correctly identified).

Respondents were also gauged on their understanding of what the start and end times were of several time of use periods, off peak, critical peak, and on peak. Overall, comprehension of these periods showed only slight changes. The period that showed an overall decline in comprehension was the off-peak time-of-use period as seen in Figure 28.

**Figure 28. Level of Comprehension of Time of Use Periods Over Time**




*Source: Guidehouse Analysis*

### 4.1.6 Demographics

Customers that responded to the enrollment survey overwhelmingly stated that they owned their own home (99%), with only one respondent noting that they rented. Ages of the homes ranged as early as 1807 and as recent as 2020, with an average build period of the early 1970's. Homes were largely single-family (93%) with some customers reporting living in duplexes (4%), or townhomes (3%).

When surveyed on annual household income in 2019, 31% of survey respondents opted not to respond to this question. Most of the respondents that did respond (55%) stated an annual income of $100,000 or higher, with 20% of that range noting an income of $200,000 or above. The remaining 13% of customers reported annual incomes at or below $100,000, with only 3% of this segment reporting their income in the range of $30,000 to $50,000.

On average, respondents reported one child in the home with 2 adults. The highest level of education reached by most respondents was a Graduate Professional degree (59%) followed by a college degree (35%). Only 4% of respondents reported having either a high school degree or some college or additional schooling. Two percent of respondents choose not to respond to this question.

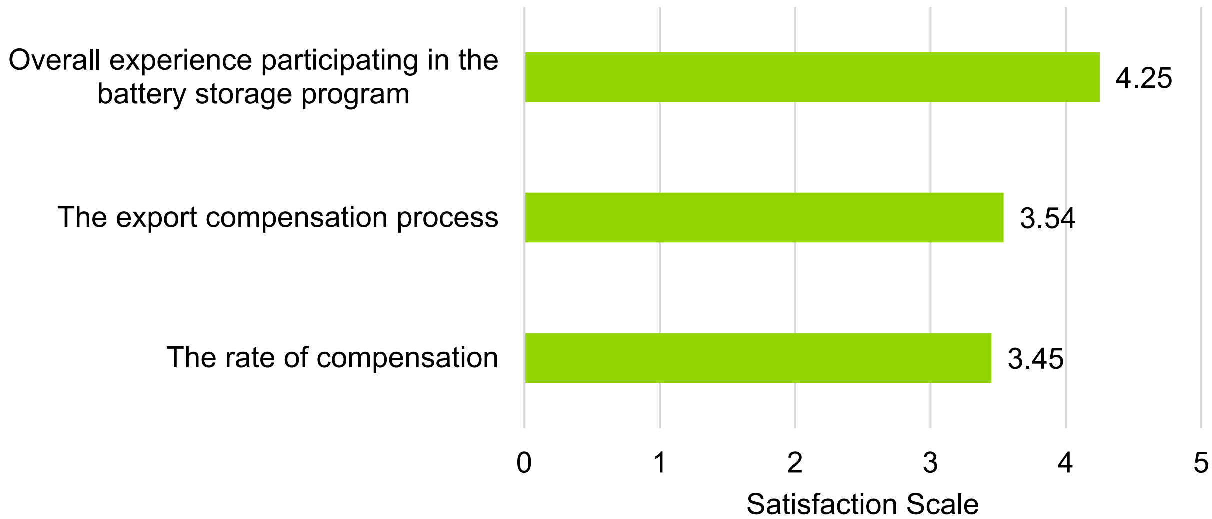
### 4.1.7 Satisfaction

Using a scale of 1 to 5, where 1 is extremely dissatisfied and 5 is extremely satisfied, customers on average rated their overall experience participating in the program as an average of 4.25, as shown in Figure 29. Drivers of dissatisfaction were issues with the system (n=4), lack of experienced savings (n=3), lack of control of the system (n=2), dissatisfaction with the discharge (n=2), and unclear billing practices (n=1).

Customers rated the export compensation process lower, an average of 3.54, with dissatisfaction primarily driven by an unclear billing process (n=10), lack of savings (n=5), and an unclear schedule (n=3).

The rate of compensation was rated the lowest at an average of 3.45. The primary factor driving this rating was the lack of realized savings (n=17), complicated billing (n=5), discharge or process issues (n=4), and issues with the battery (n=3).

**Figure 29. Average Satisfaction Rating of Program Factors**




*Source: Guidehouse Analysis*

Over half of surveyed customers (56%) stated that they were not concerned about Liberty Utilities discharging their battery, an increase of 13%. However, there was a reported 3% increase of customers not being aware that Liberty Utilities was discharging their battery. Additionally, only 59% of customers stated that they were aware when an event-day was initiated. It should be noted that Liberty Utilities did not inform customers when an event day would occur. Twenty percent of customers did however express that they did not want to be contacted or were neutral regarding being informed of an event day, while the remaining 80% of respondents would prefer to be notified in the future.

When surveyed about customer battery usage, most customers (80%) stated that their battery was available when needed. Other customers (13%) stated that due to the discharge period, they were not able to use their battery for backup during outages or storms. The remaining 6% of customers reported that they were not sure if their battery was available when they needed it.

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