Attachment 4

Attachment 4 to Initial Comments of the Clean Energy Organizations

Attachment 4:
Modeling Battery Storage in Integrated Resource Planning

Contents:

1. Excerpt from: U.S. DOE Lawrence Berkeley National Laboratory Training "State of the Art Practices for Modeling Storage in Integrated Resource Planning," October 12, 2021: Slides 1, 5, 8, 10-11, 25-28, 44, 50.

2. 5Lakes Energy, Technical Workshop Presentation: "Integrating Batteries into Resource Planning," April 13, 2022.

3. Excerpt from: Portland General Electric, 2016 Integrated Resource Plan, Chapter 8: Pages 227 and 231-237. See section "8.5.1.2 Operational Value" for discussion of PGE's sub-hourly modeling technique.

Attachment 4

State of the Art Practices for Modeling Storage in Integrated Resource Planning

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Innovations in Electricity Modeling
Training for National Council on Electricity Policy
October 12, 2021

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Lab research that informs this training

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- This training was informed by three research efforts by Berkeley Lab and Pacific Northwest National Laboratory (PNNL) that address energy storage practices in IRPs:
  - A 2019 PNNL study that examined how 21 U.S. utilities are treating energy storage in IRPs
  - A forthcoming PNNL study that builds on that work by identifying practices that utilities are developing to more accurately evaluate the costs and benefits of energy storage in the IRP process
  - Berkeley Lab research in response to a request from a state regulatory commission to identify best practices that utilities use to model utility-scale and distributed-scale energy storage in IRPs
    - See list of IRPs Extra Slides

Key IRP assumptions create barriers for storage

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- Preparing an IRP is a complex exercise.
  - Load and generation must be kept in constant balance.
  - There are dozens of generators, market interfaces, fuel costs, and changing load patterns (e.g., related to distributed generation, electric vehicles).
  - For each interval, solving the load/generation equation requires consideration of many complex variables.
  - A 15-year plan looking at hourly intervals must solve for 131,400 data points.
- As a result, resource plans make several simplifying planning assumptions.
  - Hourly planning resolution
  - Substitution of reserve margins for ancillary services
- These assumptions cause the flexibility and scalability benefits of energy storage to be undervalued.
  - Hourly planning resolution: Flexible, intra-hour benefits omitted
  - Reserve margins: Ancillary service benefits omitted
  - Generation focus: Transmission often not included; distribution benefits typically omitted

Guidance for reviewing storage modeling practices in IRPs (1)

- Look for storage assumptions, rationales, and references included within each component of the IRP.
  - **Near term action plan**: may include pilots, customer programs, or procurement solicitations in development
  - **Resource development plan**: outcomes of modeled scenarios, often with a portfolio identified, including capacity, technology type, and procurement year of resources
  - **Resource characteristics**: assumptions used for costs, technical parameters, and resources available for selection
  - **Load forecast/demand-side modeling**: assumptions for adoption of distributed storage, its impact on demand-side modeling, and how storage is integrated into bulk system analysis
  - **Future conditions**: may include sensitivities for technology maturity and environmental regulations that could influence storage costs and value
  - **Portfolio modeling**: a description of capacity expansion and production cost models used, how they interact within the analysis framework, sensitivities and assumptions for each scenario, resources selected for each portfolio, and a comparison of outcomes

Guidance for reviewing storage modeling practices in IRPs (2)

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- The same principles should apply to all assumptions or methodologies for modeling storage.
  - Based on the best information or methods available
  - Supported by traceable references to external sources
  - Acknowledges uncertainty and identifies possible alternatives
  - Consistent with treatment of other potential resources
  - Considers non-conventional behavior of storage resource
- Determine if potential stages of storage modeling are present and performed either within the IRP or calculated externally and supported by references.
  - Technology maturity forecast (i.e., cost and technical parameters)
  - Behind-the-meter storage adoption
  - Distribution system analysis of potential storage capacity and locational value
  - Loss-of-load-expectation studies
  - Capacity expansion modeling
  - Production cost modeling
  - Side calculations of additional value streams (e.g., flexibility, sub-hourly modeling)

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Opportunities for Improvements

Enhanced models and methods

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- Use additional tools (e.g., sub-hourly production cost models, effective load carrying capacity studies, and resource adequacy models) to more accurately capture benefits from storage (e.g., flexibility, ancillary services, and ELCC) and other electricity resources, rather than simply use assumed values in capacity expansion models or omit values entirely
  - These additional tools could more accurately assess value streams and dispatch for storage, improving its relative cost-effectiveness compared to other resources.
  - These tools also could improve resource adequacy assessment and representation of renewable energy sources.

Integrating Batteries into Resource Planning: A Day in the Life of a Battery

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5lakes energy
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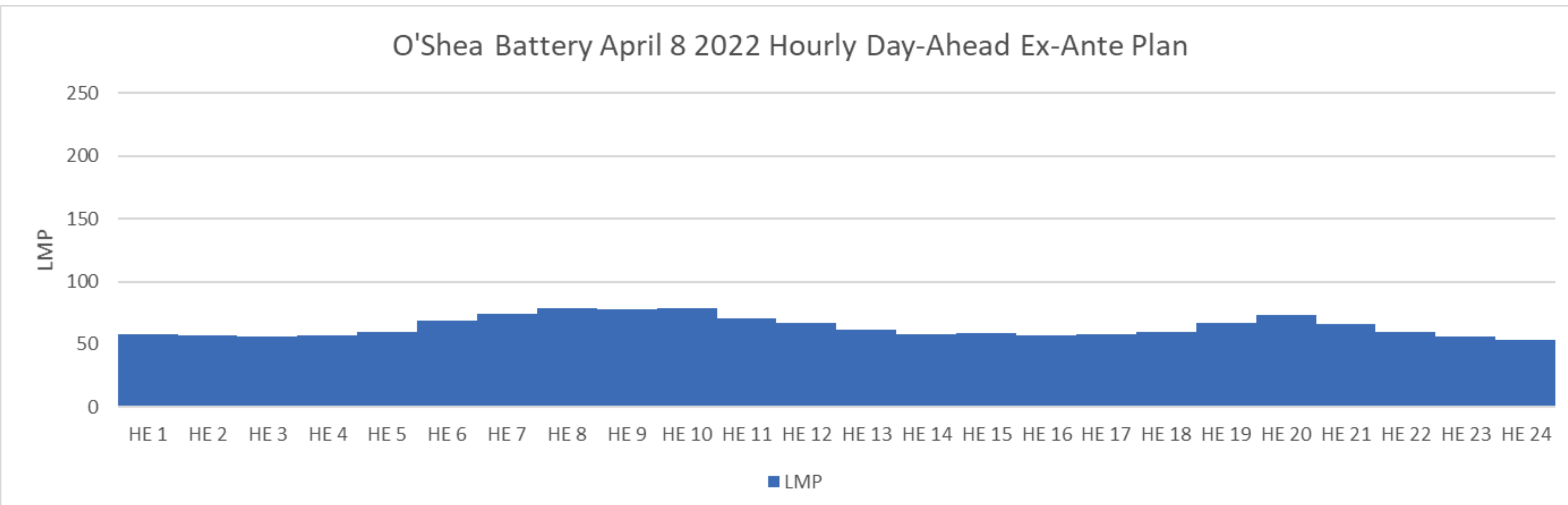
Energy Arbitrage

MISO makes the day-ahead market by merit order dispatch of the available generators at an hourly scale, subject to transmission constraints. This is very similar to standard IRP modeling. The graph below is the resulting day-ahead locational marginal prices (LMPs) at MISO generation node DECO.OSHEA.BAT, DTE's O'Shea Park on April 8 2022.



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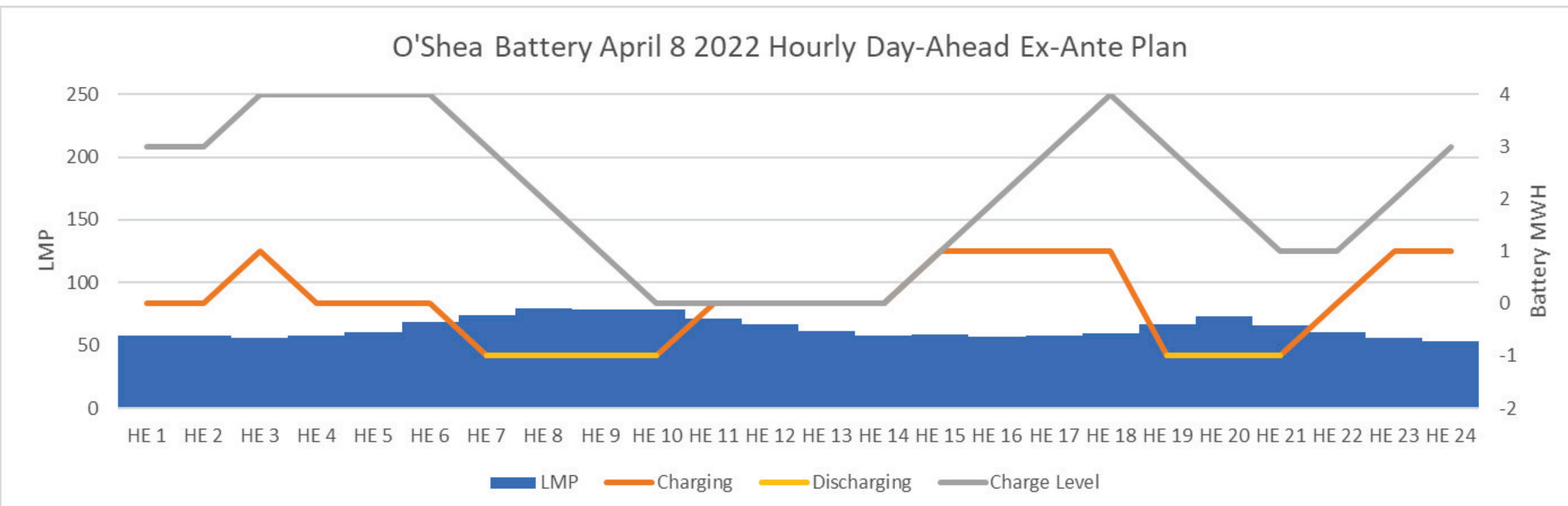
Energy Arbitrage

This graph depicts revenue-maximizing operating plan of a 1 MW throughput, 4 MWH storage battery at MISO generation node DECO.OSHEA.BAT, DTE's O'Shea Park on April 8 2022, assuming MISO's day-ahead hourly LMPs. Net revenue is $117.35.



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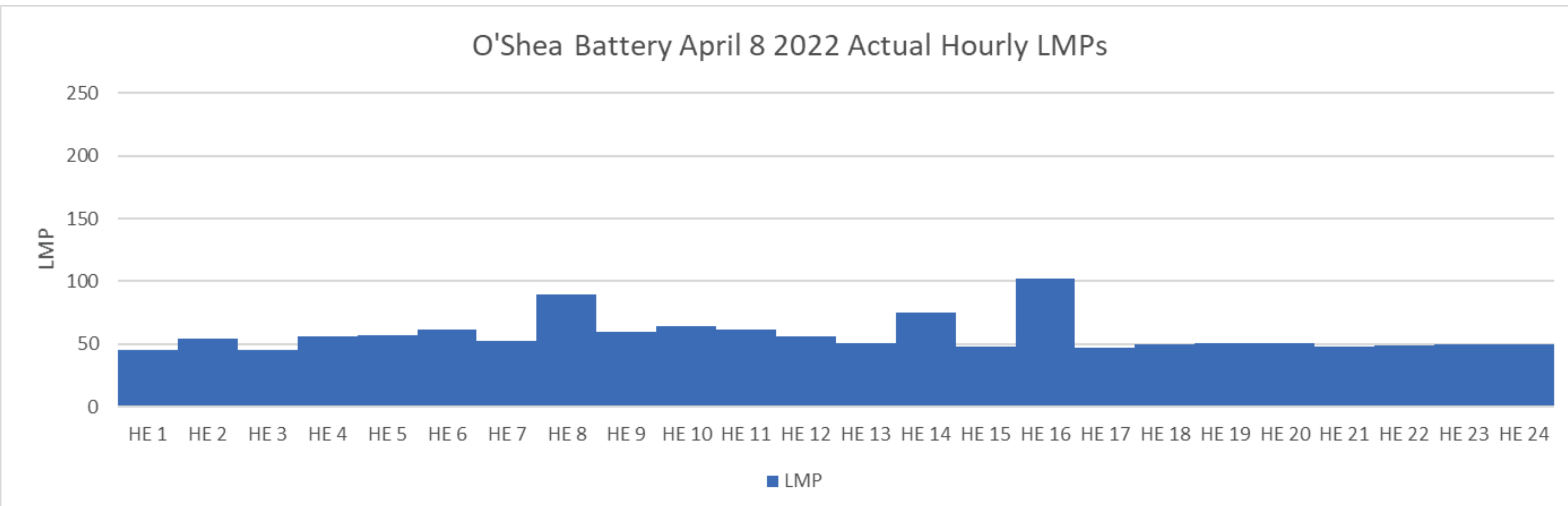
Energy Arbitrage

Actual Hourly LMPs are more variable than projected LMPs. Stuff happens.



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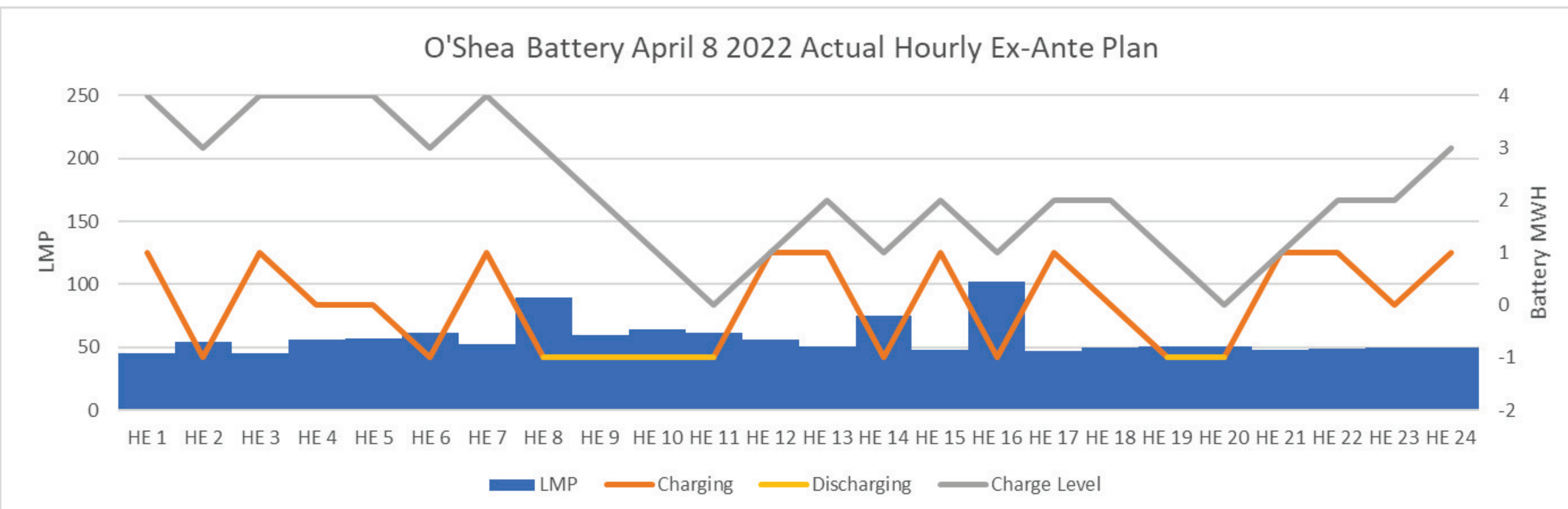
Energy Arbitrage

This graph depicts revenue-maximizing operating plan of a 1 MW throughput, 4 MWH storage battery at MISO generation node DECO.OSHEA.BAT, DTE's O'Shea Park on April 8 2022, assuming the actual hourly LMPs. Net revenue is $177.65.



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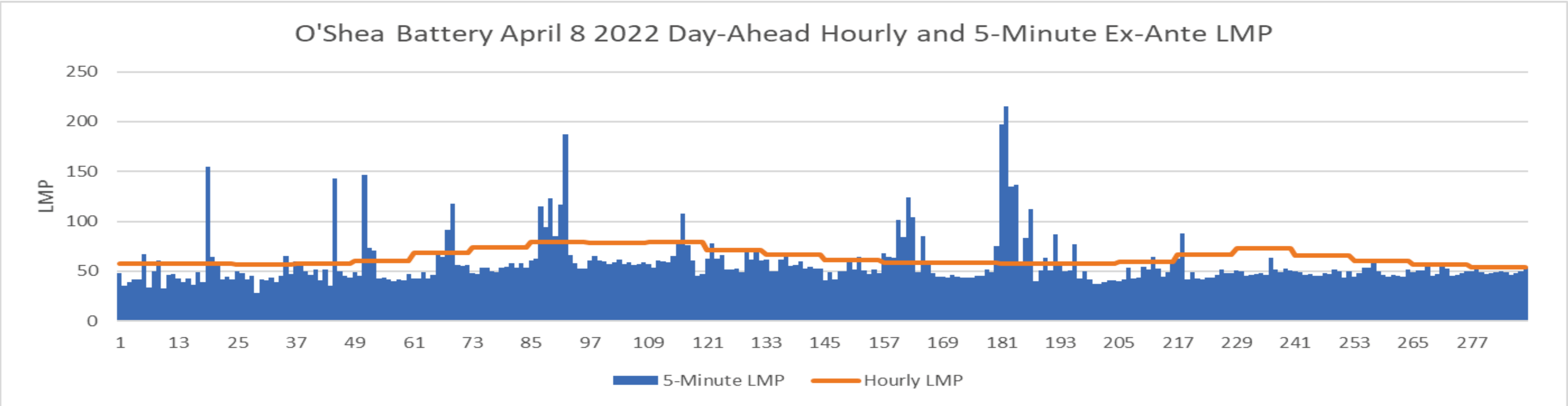
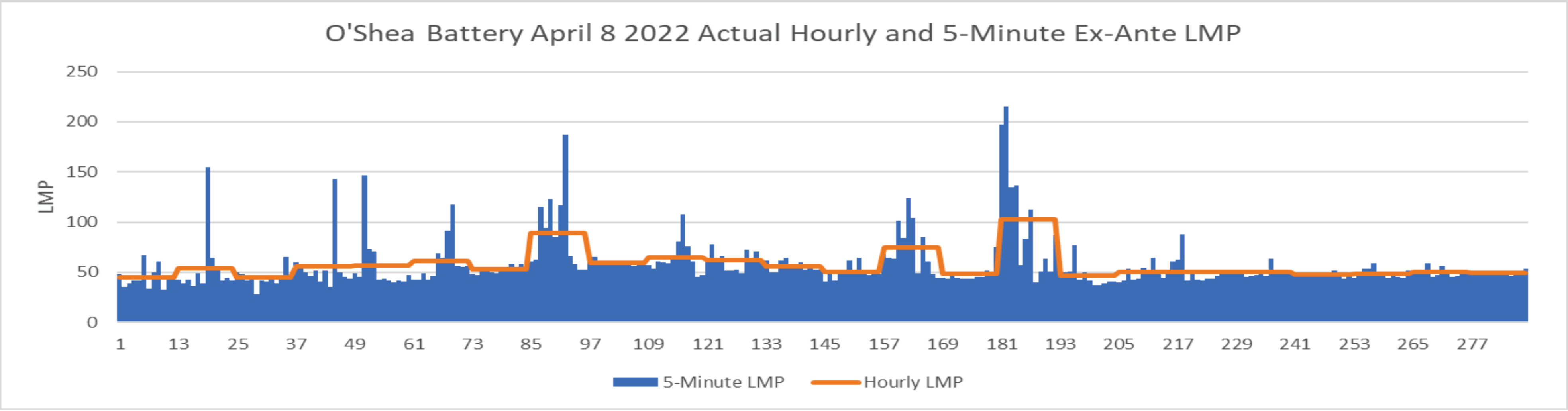
Energy Arbitrage

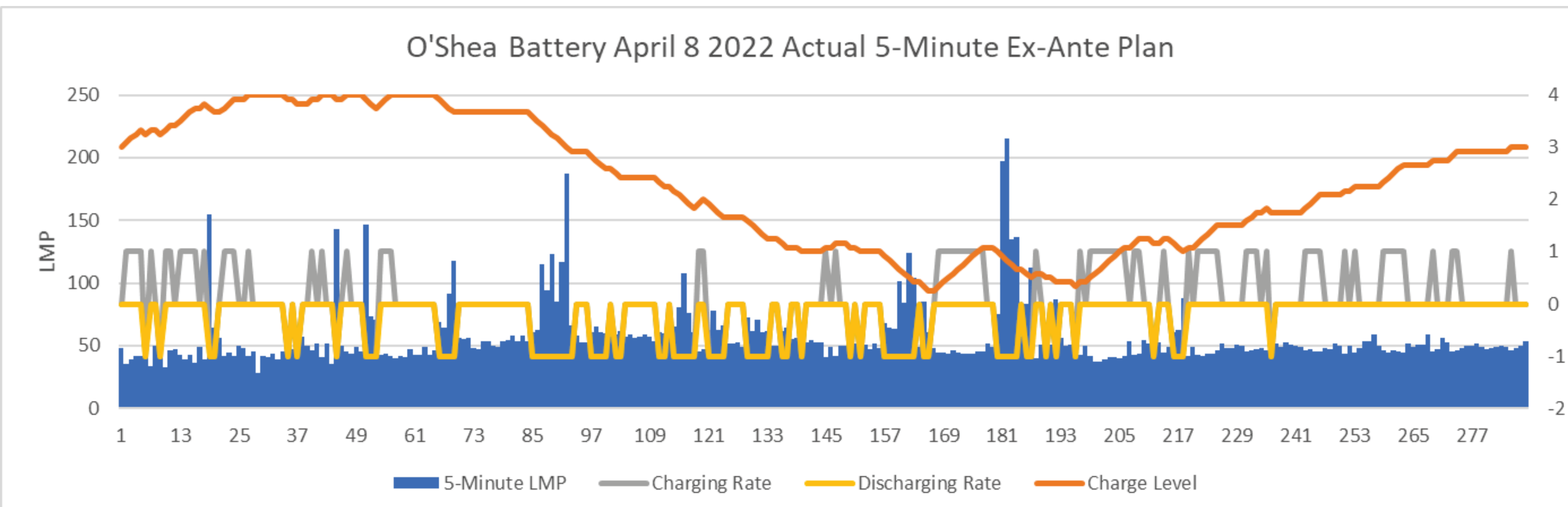
5 Minute Ex-ante LMPs at DECO.OSHEA.BAT show much greater volatility than the hourly day-ahead LMPs or the actual hourly average LMPs.





Energy Arbitrage

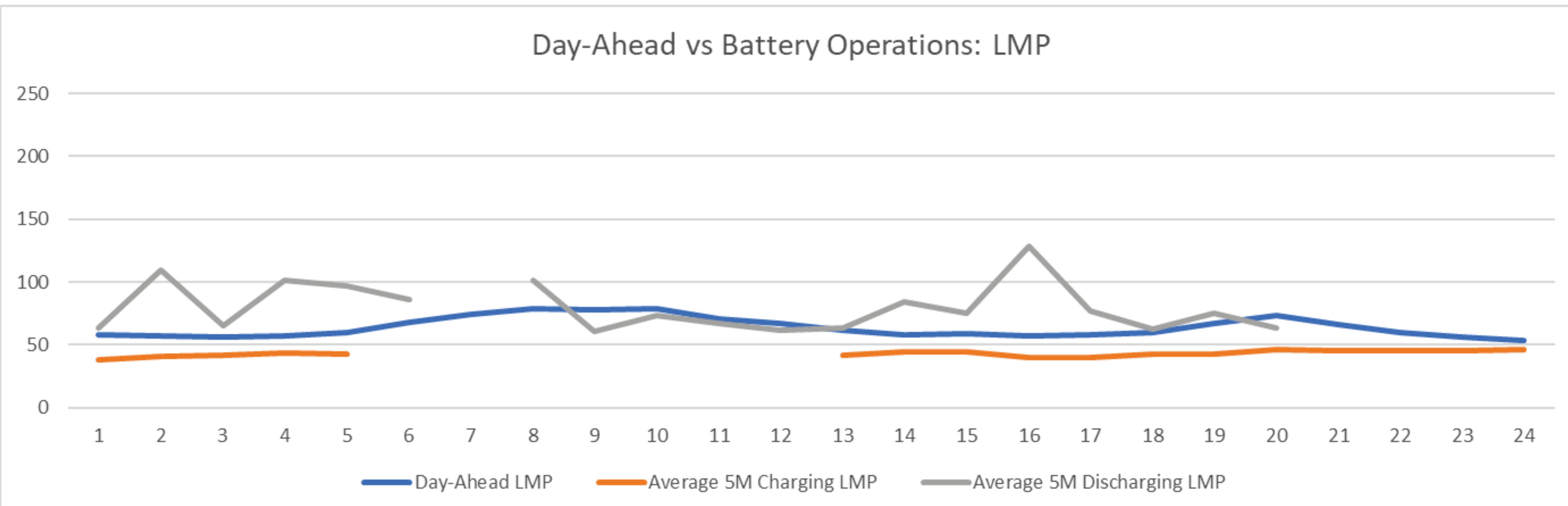
This graph depicts revenue-maximizing operation of a 1 MW throughput, 4 MWH storage battery at MISO generation node DECO.OSHEA.BAT, DTE's O'Shea Park on April 8 2022, if the battery operator responded to the ex-ante 5-minute LMPs with a simple optimized cost-triggered control band. Net revenue is $253.43 due to the opportunity to exploit volatility in the 5-minute market. A model-predictive controller or approximate dynamic programming solution would do even better.



Attachment 4

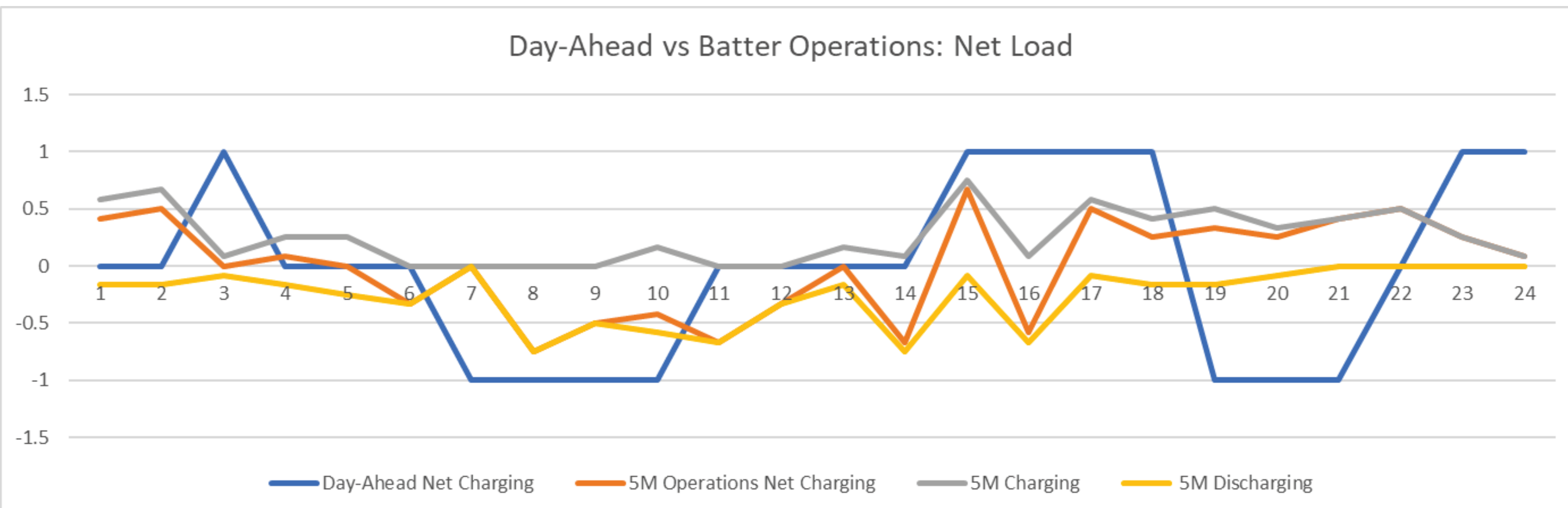
Energy Arbitrage

This graph contrasts LMP as seen in an IRP model with LMP as seen in a battery operator's ability to buy low and sell high to generate revenue. This mismatch drives erroneous battery economic analysis in the IRP. On April 8 2022 an IRP modeler would have made $117.35 on battery operations while a market arbitrager would have made $253.43.



Energy Arbitrage

This graph contrasts battery charging and discharging as seen in an IRP model with charging and discharging as seen by a battery operator. If batteries are deployed at scale, this drives erroneous hourly battery contributions to load balance. An IRP modeler sees larger load shifts than a market arbitraging battery operator.



Energy Arbitrage

- Deterministic dispatch models understate price variation and battery revenue from energy arbitrage.
- Hourly dispatch models, deterministic or stochastic, understate price variation and battery revenue from energy arbitrage.
- Standard models understate energy arbitrage value of a battery and therefore overstate net capacity cost of batteries under current grid conditions.

Energy Arbitrage

- Energy Arbitrage is not the only value of a battery
  - Operating value for ancillary services, including reserve capacity
  - Contribution to resource adequacy
  - Locational transmission and distribution considerations
- These can also be addressed through similar modeling *for current grid conditions*
  - Co-optimize battery operations for energy arbitrage and ancillary services including capacity availability using current grid conditions
  - Calculate Effective Load-Carrying Capacity (ELCC) of a battery using the usual methods
  - Substation and circuit analyses

Analyzing Near-Term Resource Additions

- What can we do about this in IRP modeling?
  - Model battery operations outside IRP software to determine net cost of capacity and buy batteries if justified as a pure capacity resource priced at net cost of capacity.
  - Issue an RFP for battery capacity credits and let a battery operator determine net cost of capacity, competing on operating algorithms as well as overnight capital cost, round trip efficiency, and cost of capital.

Analyzing Long-Term Resource Portfolios

- Preceding methods do not work for analysis of resource portfolios that are very different from the current grid
  - LMP stochastic process will be different so battery operations will be different
  - If economics indicate battery additions, the preceding methods do not help to determine the right quantities of batteries in the portfolio because they do not characterize how battery and other resource values change with portfolio changes

Analyzing Long-Term Resource Portfolios

- Until we have new planning methods and tools that incorporate stochastic optimization,
  - Climate and cost considerations suggest high future use of renewables
  - With high renewables penetration, all resources including batteries are valued primarily as reliability resources rather than net energy margin
  - My 15 minutes today does not allow deep exploration of storage in reliability modeling
  - Suggestion: model hourly energy sufficiency with limited or no fossil generation to determine renewables and storage quantities and begin building that in steady increments

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CHAPTER 8. Energy Storage

Energy storage resources are receiving increased attention as higher penetrations of renewables put new demands on the grid and battery technology costs continue to decline. This chapter presents an overview of PGE's actions to date regarding energy storage, including ongoing energy storage demonstration projects like the Salem Smart Power Center (SSPC), preparations for compliance with Oregon's energy storage legislative mandate (HB 2193), and progress toward developing an evaluation framework for future energy storage procurement decisions.

Chapter Highlights

- ★ **Energy storage resources have the potential to provide valuable services to the PGE system over a wide range of timescales.**
- ★ **PGE has begun evaluation of procurement options to comply with HB 2193, which requires 5 MWh of energy storage by 2020.**
- ★ **PGE is also developing an evaluation framework that the Company can apply to future energy storage procurement decisions. An initial energy storage analysis in this IRP aims to incorporate the key benefits that energy storage provides to the PGE system and to identify critical analytical capabilities that PGE will need for future IRPs and resource decisions.**

including: mitigating peak demand, integrating grid connected distributed standby generators, balancing renewables and responding to a transactive price signal.

Following PGE's commitment to the US DOE, PGE began exploring additional ways to exploit energy storage to address a wide set of use cases. One of the first use cases tested was the development of an algorithm that would allow SSPC to respond to frequency events. In early 2015, during such an event, PGE's batteries immediately responded, discharging 5 MW onto the grid to help recover grid frequency. The integration of a customer's solar array with the SSPC enabled PGE to demonstrate the value of energy storage in the integration of renewables on to the grid.

In collaboration with Portland State University, PGE is also exploring the use of an aqueous Na-Ion battery that seeks to provide a low-cost, 6-to-8 hour storage solution. In June 2016, PGE demonstrated the use of this battery at a customer's home to provide backup power during a grid outage. When not used for backup power, the battery will serve as a demand response resource.

HB 2193 provides an opportunity for PGE to extend its learnings beyond the SSPC project and these research activities. In the first three OPUC workshops, PGE, PacifiCorp, and other industry experts shared their respective views on energy storage, use cases, including value streams and a plan for how the utilities are likely to value energy storage beyond the legislative mandate. By January 1, 2017, PGE expects the OPUC to finalize project proposal guidelines, and then the Company will have 12 months to bring forth a project proposal.

In parallel with the OPUC's development of guidelines, PGE is working with outside consultants to analyze the various value streams of energy storage systems. PGE also issued a request for information (RFI) to solicit further insight from a wide array of vendors, manufacturers, and developers of energy storage. The Company is conducting face-to-face meetings with respondents throughout 2016 to aid in the development of PGE project proposals for HB 2193 or other energy storage resource acquisitions.

The Company is also actively engaged in developing methodologies for evaluating a range of storage technologies in response to both HB 2193 and the anticipated challenges in integrating renewable resources to comply with SB 1547. The following sections describe these efforts.

8.4.1 Quantifying Potential Benefits

PGE is developing an economic evaluation framework for energy storage resources that consists of five key classes of value streams:

- Energy shifting and arbitrage;
- Ancillary services;
- Avoided renewable curtailment;
- System peaking or capacity value; and
- Locational value.

While PGE describes each value stream individually, it is important to note that the capability to simultaneously provide multiple benefits is limited. The ability of an energy storage system to provide each benefit will depend on how PGE operates the system and prioritizes the benefit relative to the others in terms of value to the system. In this way, PGE's framework considers energy storage benefits to be "staggered," rather than "stacked."

8.4.1.1 Energy Shifting and Arbitrage

Energy storage resources in other jurisdictions have enabled utilities to time shift energy purchases (or to arbitrage) between peak and off-peak hours to reduce the cost of meeting the load as it fluctuates over time. With increasing renewable resources on the system, PGE anticipates price volatility to increase as the net load (load minus renewables) becomes more variable. In other parts of the West, analysts anticipate rapid solar development will depress daytime prices and drive increased prices in shoulder hours, leading to new opportunities for diurnal storage devices that charge during the day and discharge to help meet the evening peak as the sun sets. For the PGE system, price volatility between high and low renewable output events may be less predictable because of the region's higher reliance on wind resources.

Storage also has the potential to shift dispatch from more expensive peaking plants to lower cost thermal plants to realize reductions in fuel use and variable operations and maintenance (O&M) costs, avoid thermal unit starts, and reduce cycling burden. The balance of priority between these internally realized cost reductions and the net revenues associated with a storage resource interacting with a market are highly dependent on the utility and the specific controls utilized for the storage device.

8.4.1.2 Ancillary Services

Energy storage systems can also provide regulation (both up and down), frequency response, and contingency reserves to the system. Using energy storage devices to provide ancillary services reduces the burden placed on thermal generators to provide ancillary services, allowing them to operate at more efficient set points. While PGE is investigating the impact of additional renewable resources on the need for regulation, frequency response, and contingency reserve requirements, it is widely accepted that higher renewable penetrations will drive increased variability over very short time-scales, which may increase the need for reserve products, specifically regulation reserves.[184] In addition to this increased need for ancillary services, renewables introduce the additional challenge of meeting ancillary service requirements with fewer conventional generators online during hours with high renewable output. Both of these factors contribute to potential cost increases associated with relying on thermal resources to integrate higher levels of renewables on to the system. Providing a portion of these ancillary services with energy storage resources has the potential to reduce power costs.

In addition to regulation, frequency response, and contingency reserves, renewable integration analyses have identified an increased need for load following reserves under higher renewable penetrations. These reserves may be held in anticipation of forecast errors and sub-hourly fluctuations in net load on timescales down to five minutes. Similar to regulation reserves, providing load following reserves with thermal generation requires plants to operate at less efficient set points, which increases power costs. Energy storage resources may contribute to reducing these renewable

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[184] Renewable integration analyses typically incorporate larger regulation requirements to account for 1-min renewable output fluctuations, but maintain the frequency response and contingency reserve constraints applicable to today's systems.

integration costs by reducing the reliance on thermal plants to accommodate forecast errors and sub-hourly fluctuations.

8.4.1.3 Avoided Renewable Curtailment

At higher renewable penetrations, PGE has also identified the potential for events in which the system cannot fully accommodate high renewable output due to a combination of low load conditions, high hydro conditions, flexibility constraints on conventional generators, and the need to maintain minimum levels of conventional generation on the system to provide the ancillary services described above. Section 5.3, Flexible Capacity, further discusses these operational considerations. Energy storage systems have the potential to absorb excess generation during curtailment events, reducing the cost of meeting the Company's renewable energy targets.

8.4.1.4 System Peaking Value

The **state of charge (SOC)** of an energy storage system is the amount of energy stored in the system at a given point in time. This terminology can be used across technologies, but typically refers to a battery system.

Long duration energy storage systems can provide value to a system by dispatching during peak load conditions, reducing the amount of conventional capacity required to meet resource adequacy obligations. Since the ability of a storage resource to provide capacity during a potential shortage will depend on its state-of-charge (SOC) prior to the event, some have proposed an ELCC methodology similar to that applied to renewable resources to approximate the capacity contribution of storage devices.[185] In lieu of a standard methodology, some jurisdictions have simply applied a minimum duration constraint for counting energy storage resources toward capacity adequacy. For example, in California, resources must be capable of running for four hours over three consecutive days to qualify for resource adequacy payments. As a result, Southern California Edison used a four-hour duration as a proxy for this capability in its recent Local Capacity Requirements (LCR) RFO.

8.4.1.5 Locational Value

If sited and operated to specifically defer investment in transmission or distribution upgrades, energy storage may also provide locational value to the system. Similarly, the incorporation of energy storage into a Remedial Action Scheme (RAS) could support transmission reliability. These locational benefits require assessment on a site-by-site basis and may impact the ability of storage systems to provide other operational benefits.

8.4.1.6 Other Use Cases and Business Models

Use cases beyond those described above may provide opportunity to otherwise increase value to customers. For example, the ability to provide backup power during outages represents an important

[185] See Chapter 5, Resource Adequacy, for more information about PGE's ELCC methodology.

customer value stream, especially if the device can also provide the system-level benefits described above during normal operations.

8.4.2 Operationalizing Potential Benefits

To provide the greatest value to the system, the operation of each energy storage system (or aggregation of energy storage systems) must occur in a way that optimizes across all value streams with consideration of how the battery dispatch interacts with the dispatch of the full PGE resource portfolio. Such optimization must take into consideration the operating constraints of the storage system and clearly respect the staggered versus stacked nature of energy storage use cases. In many hours, this will result in a storage device providing some combination of energy and ancillary services. In evaluating energy storage resource benefits, PGE assumes centralized control of the devices in coordination with the commitment and dispatch of other resources in the PGE fleet in order to maximize the value to the system across all of the benefit streams. The resulting dispatch and identified operational value may therefore vary from studies in other jurisdictions in which battery systems are modeled as price takers within organized energy and ancillary service markets.

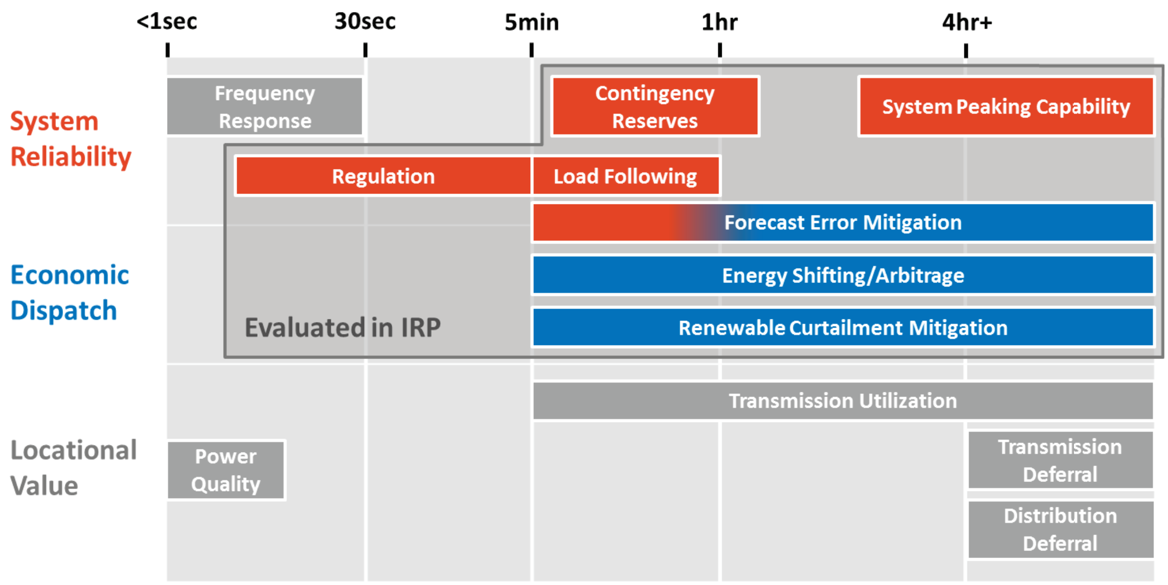
Finally, the cost-effectiveness of energy storage systems will depend not only on the value of the benefits described here, but also the costs associated with building, integrating, and operating the systems. As both renewable integration challenges grow and technology costs drop, PGE anticipates that energy storage systems will eventually be part of a cost-effective strategy for meeting the Company's renewable, flexibility, and capacity needs. However, considerable uncertainty surrounds both the cost and value trajectories into the future as technological advancement is difficult to predict and renewable development and market evolution across the West promises to shift operational paradigms. For these reasons, evaluation of energy storage resources will be ongoing and will incorporate the latest information regarding operational needs, technological advancement, and technology cost reductions.

8.5 Treatment in IRP

In Order No. 14-415, the OPUC directed PGE to consider storage in its portfolio analysis in this IRP[186] . The economic evaluation of energy storage remains a rich area of research and full evaluation of storage devices within the IRP portfolio analysis framework remains challenging. In developing an initial evaluation methodology, PGE sought to capture the value streams most critical to a generic (i.e., location non-specific) storage device on the PGE system, including operational benefits (e.g., energy shifting and arbitrage, ancillary services, and avoided curtailment) and system peaking or capacity value. Figure 8-3 highlights the values captured within the IRP analysis and the subsequent section discusses the methodology.

[186] OPUC Order No. 14-415, at 6.

FIGURE 8-3: Energy storage value streams evaluated in the IRP



8.5.1 Methodology

The primary challenge in accounting for storage systems in the IRP is that much of the value of energy storage resources is associated with very short timescale behavior that is not resolved by models that seek to characterize electricity system behavior and economics over several years and across a range of potential futures. Full consideration of an energy storage device and the value it brings to a system requires detailed modeling of complex operational constraints, representation of reserve requirements, and high resolution characterization of renewable integration challenges, all of which dramatically increases computation time and limits the scope of the analysis in time and across futures. The methodology described below focuses on battery storage behavior and value in a single test year (2021). The storage analysis specifically focuses on answering the following questions:

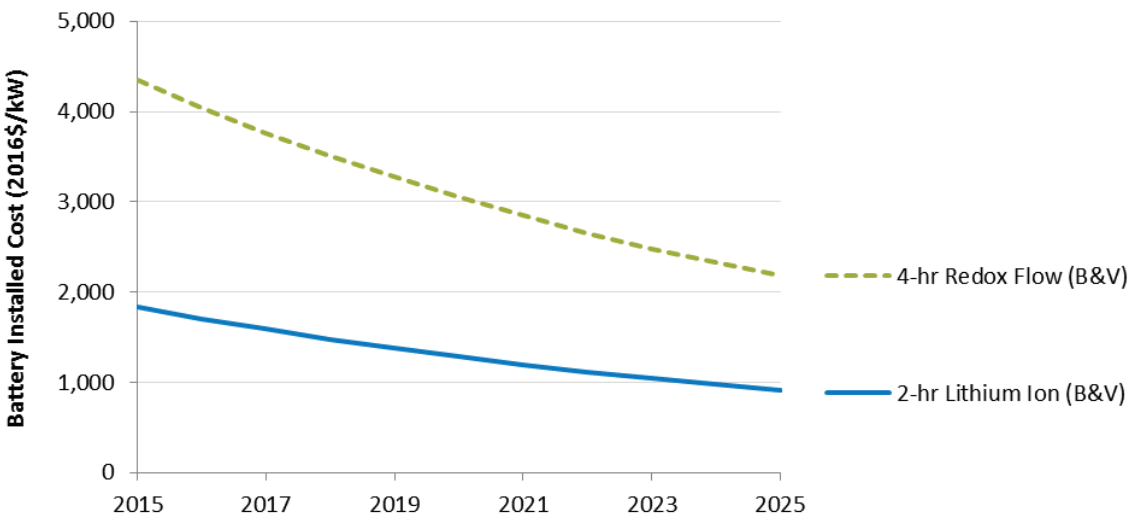
- How is a battery system anticipated to behave in the PGE fleet if operated to maximize value to the system?
- What are the primary use cases provided by a battery system, if operated in this manner?
- What is the total operational value provided by a battery system?
- Does the identified operational and capacity value of a battery system in 2021 relative to its cost warrant full incorporation into the IRP portfolio analysis at this time?

While the 2021 analysis provides preliminary insights into these questions, PGE acknowledges that findings may vary over time and across renewable portfolios, conventional resource portfolios, battery configurations, and market conditions. Therefore, this analysis is preliminary and investigative. PGE will continue to evaluate the economics of battery systems and other storage resources as additional data becomes available.

8.5.1.1 Resource Cost

PGE obtained resource cost estimates for a 2-hour lithium ion battery system and a 4-hour redox flow battery system from Black & Veatch as part of the independent analysis described in Chapter 7, Supply Options, and summarized in Appendix K, Characterization of Supply-Side Options (Black & Veatch) (see also Figure 8-4). PGE used an Excel-based revenue requirement model to determine the $/kW-yr fixed cost impact of each battery system with an assumed commercial online date of 2021.

FIGURE 8-4: Battery installed costs by COD year from Black & Veatch



8.5.1.2 Operational Value

To capture operational value streams, PGE relied on the Resource Optimization Model (ROM), which the Company originally designed to quantify operational challenges and costs associated with renewable integration. Because of this history, ROM already incorporates the key features required for energy storage evaluation: optimal unit commitment and dispatch of the PGE resource fleet over multiple time horizons with forecast errors (e.g., day-ahead to real-time), ancillary service requirements, and sub-hourly dispatch. More information about ROM is available in the discussion of the Variable Renewable Integration Cost in Chapter 7, Supply Options.

In each ROM simulation, the battery system was dispatched with PGE's full resource portfolio in order to minimize the net cost of meeting demand in each time step while also meeting several ancillary service requirements across the system. In addition to shifting energy through charging and discharging cycles, the simulated battery systems were able to provide: contingency reserves (spinning and non-spinning); upward and downward regulation reserves, which are held to accommodate fluctuations on timescales shorter than five minutes; and upward and downward load following reserves to meet flexibility requirements on timescales between five minutes and one hour.[187] Operation of the battery system was subject to constraints on maximum charging and

[187] While reserve requirements approximate the need for flexibility on very short time scales, ROM does not currently explicitly resolve time scales shorter than 15 minutes.

discharging levels as well as a maximum SOC constraint to reflect the duration of the battery. Losses were incurred upon both charging and discharging. The operational value was determined by comparing PGE's total annual simulated operating costs in the test year with and without the battery system. This approach ensures that identified operational value is net of any variable costs associated with operating the battery. Importantly, this operational value assumes that PGE operates the battery system (or fleet) specifically to avoid operational costs across the PGE fleet and to maximize revenues in the market – alternative operational strategies would necessarily yield lower operational benefits.

8.5.1.3 Locational Value

While PGE acknowledges that specific energy storage resources may provide additional benefits to the grid through transmission or distribution investment deferral, the IRP considers a generic energy storage device without specific locational information. Each storage resource therefore receives zero locational value for the purposes of this analysis.

8.5.1.4 System Peaking or Capacity Value

PGE used two preliminary methodologies to quantify the capacity contribution of each battery system: a duration-based methodology and an ELCC-based methodology. The duration-based methodology draws inspiration from practices in other jurisdictions, in which battery systems that meet a minimum duration requirement can count toward resource adequacy requirements. In CAISO, for example, battery systems must be capable of discharging for four hours to provide reliable capacity to the system. PGE's duration-based methodology assumes that a battery system that PGE controls can provide peaking capability at the maximum discharge level that the battery system can sustain for a four-hour period. For example, a 50 MW 4-hr battery system has a capacity contribution of 50 MW or 100% while a 50 MW 2-hr battery system has a capacity contribution of 25 MW or 50%. This approach assumes that the operator is precisely aware of the time periods in which the battery system will be required to provide reliable capacity and is always able to charge the system in advance of the need. While it is likely that the operator will be able to anticipate the high load conditions that drive the system's capacity need to a large extent, events driven by forced outages or low wind levels are less predictable and may result in a lower capacity contribution than is determined by this methodology.

PGE's second approach attempts to capture in part the reliability impact of imperfect information. In the ELCC-based methodology, the assumption is that peak load conditions can be predicted on a day-ahead basis, but the exact timing of the event is uncertain. In this framework, the battery system follows a fixed monthly charging/discharging schedule on capacity-constrained days. PGE made use of the loss of load expectation (LOLE) calculated by month-hour in Chapter 5, Resource Adequacy, to establish this hourly schedule by month in which the battery discharges at its maximum four-hour capability for the four consecutive hours in each day with the largest probability of loss of load. The fixed schedule also incorporates adequate charging over the consecutive hours of the day with the lowest probability of loss of load to sustain the peak discharge level. Storage resources with durations exceeding four hours are scheduled to dispatch at their maximum capability over the longest period that can be sustained given charging requirements within the day. Given these schedules, PGE used the RECAP model to calculate the ELCC of a 50MW storage resource over a