Batteries in PJM: Facts and Issues

MIC

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IMM



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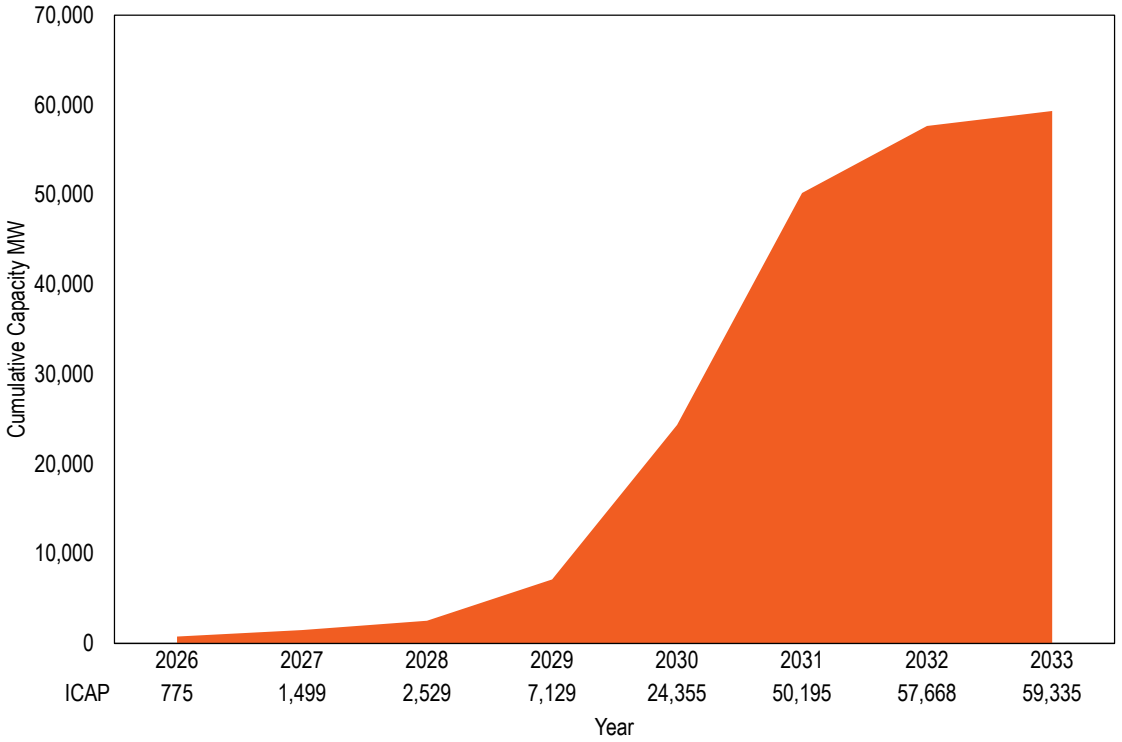
Current and Queue Battery Capacity



Completion Rates for Queue Projects

- Battery project completion rates based on data through September 30, 2026, are 4.2 percent
- Battery completion rates could increase as the technology matures
- Solar completion rates were 2.3 percent based on data through December 31, 2019, and 16.4 percent based on data through September 30, 2026
- A completion rate of 4.2 percent translates to 2,492 MW of storage by 2033
- A completion rate of 16.4 percent translates to 9,731 MW of storage by 2033

Completion Rates

- **Queue MW significantly overstate the likely level of expected actual completed and operating battery projects.**
- **Historical completion rates provide a guide to a range of likely completion rates.**
- **Actual completion rates will be a function, in part, of market incentives and market uncertainty.**
- **Real battery MW are likely to be closer to 2,500 to 10,000 MW than the 60,000 MW in the queue for 2033.**

Completion Rates for Queue Projects

Unit Type	Completion Rate (1997 through Dec 2019)	Completion Rate (1997 through Sept 2026)
Battery	1.3%	4.2%
Solar	2.3%	16.4%

Battery Participation

- Batteries and hybrids have cleared in recent capacity auctions:
  - 205 MW in 2027/2028 BRA
  - 478.3 MW in 2028/2029 BRA
- Almost 200 MW of batteries are currently participating in energy markets
- About 310 MW of batteries are currently participating in the regulation market

Battery Revenue Metrics

- **Top-Bottom 4, or TB4, is a measure of energy arbitrage potential at a pricing node for a four hour battery.**
- **TB4 is equal to the revenue from the four highest LMPs less the revenue from the four lowest LMPs per day, including an adjustment for round trip efficiency.**
- **TB4 does not account for all operational constraints of a battery.**
- **TB4 values will overstate potential revenues for a battery**
- **TB4 can be calculated for day-ahead or real-time LMPs**

TB4 Definition

Day-Ahead LMPs for one day

Hour of Day	LMP ($/MWh)
1	$23.62
2	$20.70
3	$18.24
4	$17.70
5	$18.49
6	$23.15
7	$24.08
8	$28.65
9	$25.74
10	$21.81
11	$22.39
12	$24.06
13	$22.52
14	$22.18
15	$27.67
16	$29.59
17	$39.10
18	$47.45
19	$50.15
20	$67.06
21	$67.21
22	$45.01
23	$32.86
24	$23.48

Sort by LMP Highest to Lowest

Hour of Day	LMP Sorted ($/MWh)
21	$67.21
20	$67.06
19	$50.15
18	$47.45
22	$45.01
17	$39.10
23	$32.86
16	$29.59
8	$28.65
15	$27.67
9	$25.74
7	$24.08
12	$24.06
1	$23.62
24	$23.48
6	$23.15
13	$22.52
11	$22.39
14	$22.18
10	$21.81
2	$20.70
5	$18.49
3	$18.24
4	$17.70

Multiply by 1 MW to get Dollars

LMP Sorted ($)
$67.21
$67.06
$50.15
$47.45
$45.01
$39.10
$32.86
$29.59
$28.65
$27.67
$25.74
$24.08
$24.06
$23.62
$23.48
$23.15
$22.52
$22.39
$22.18
$21.81
$20.70
$18.49
$18.24
$17.70

Sum Highest Hours Less Lowest Hours divided by RTE

Component	Value ($/MW-Day)
Top Hours	$231.87
Bottom Hours	$75.12
Bottom Hours Adj by RTE	$88.38
TB4	$143.49

RTE is round trip efficiency. Batteries experience efficiency losses which makes charging costs higher

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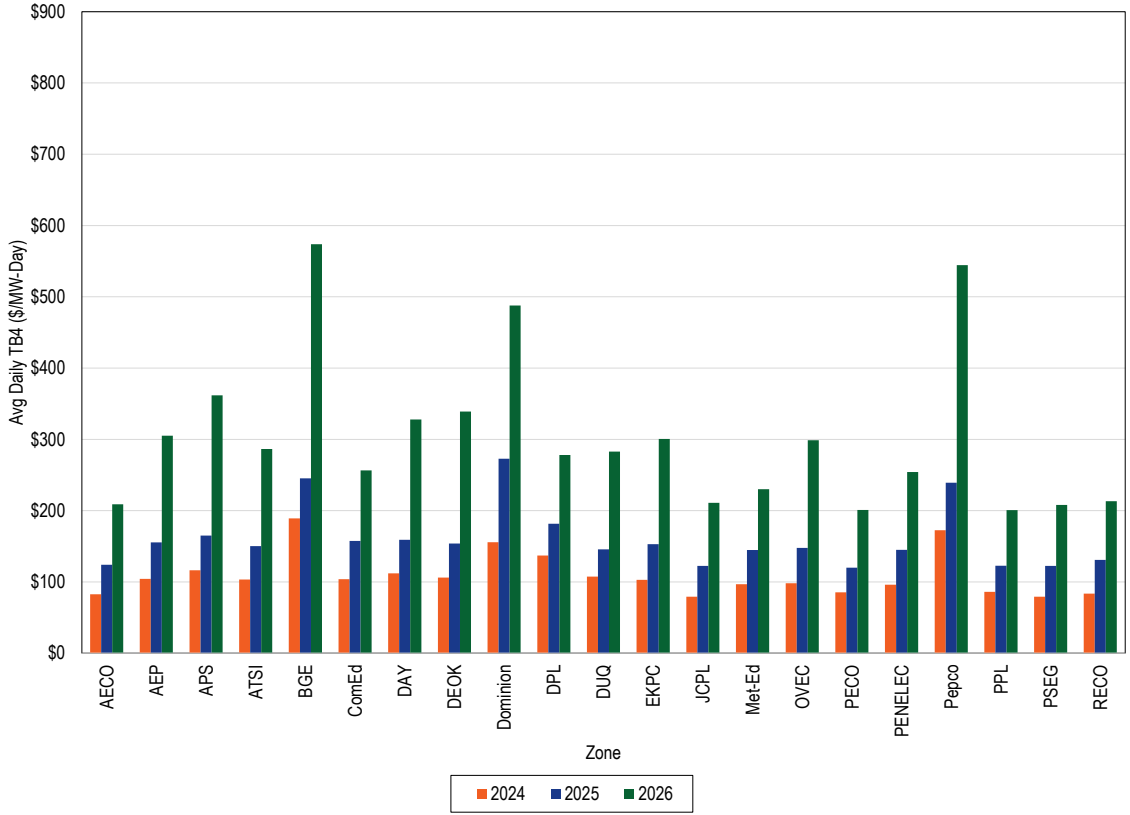
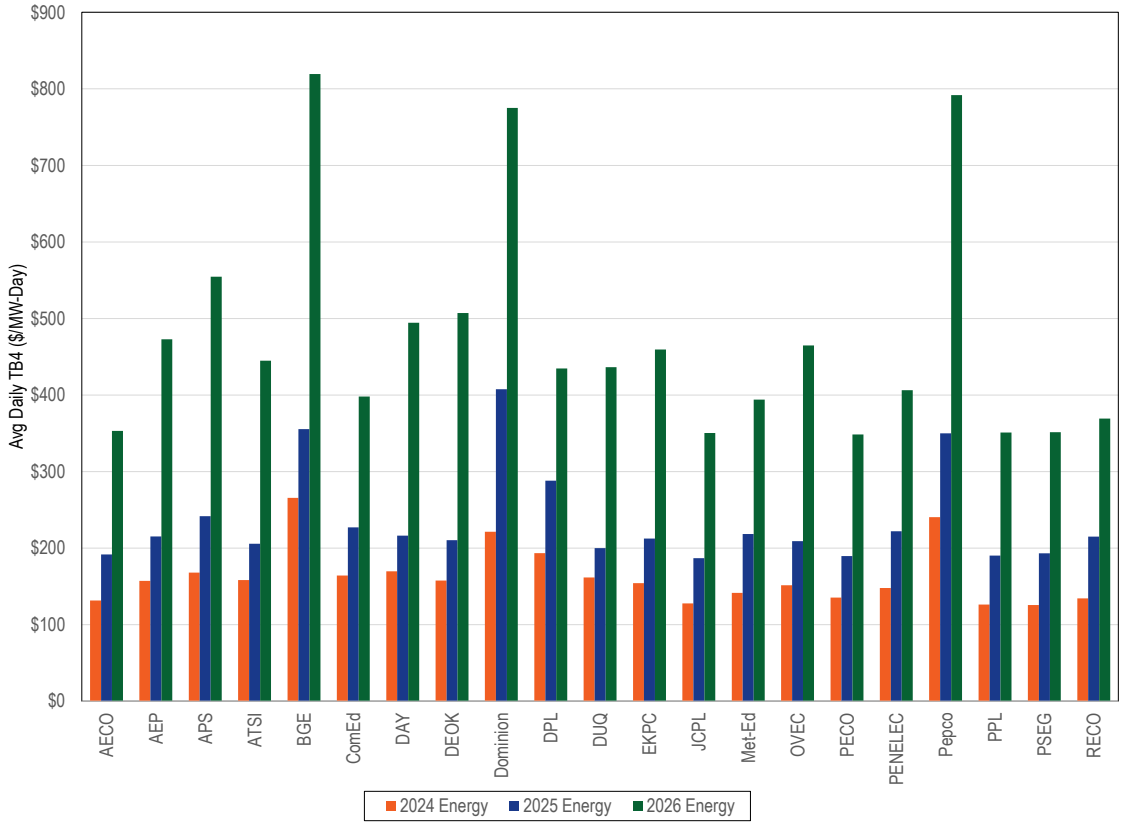
Day-Ahead TB4*



*** TB4 assumes a round-trip efficiency of 0.85, January through October 2026**

Real-Time TB4*



*** TB4 assumes a round-trip efficiency of 0.85, January through October 2026**

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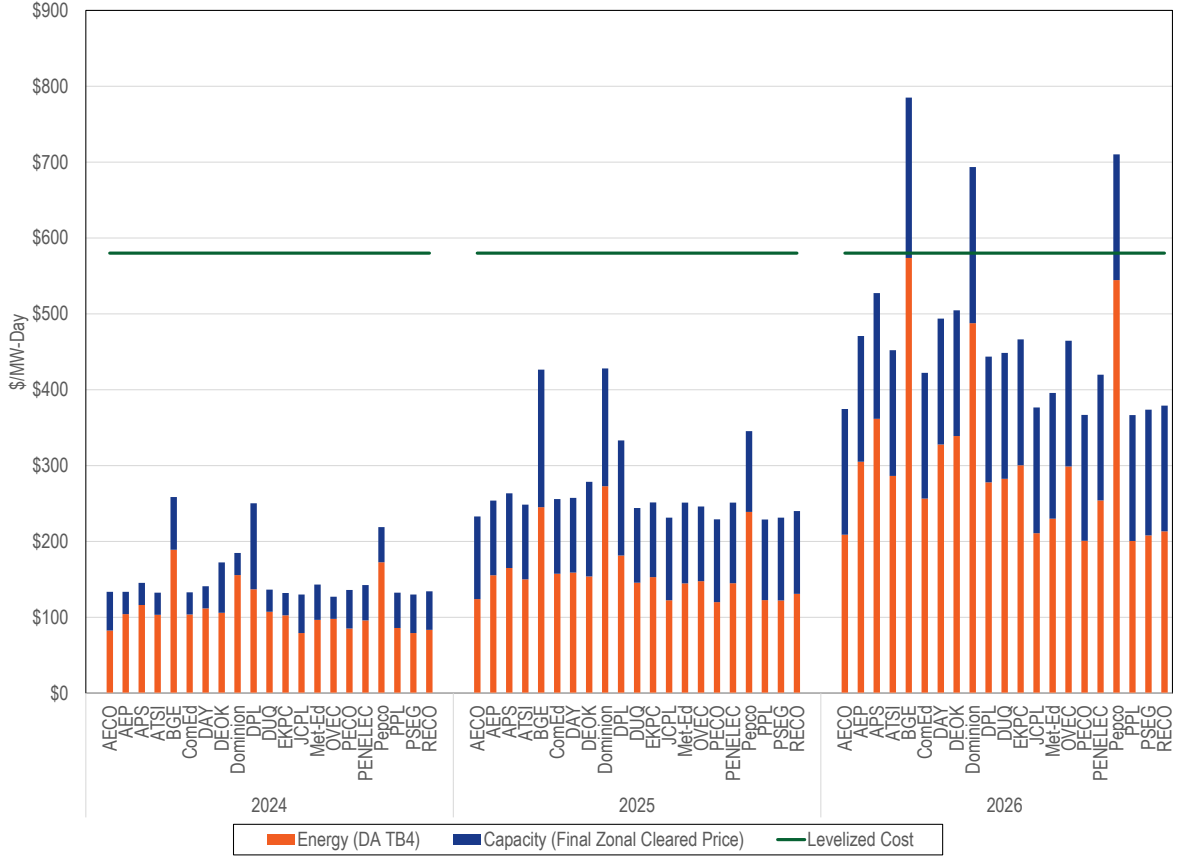
Basic Battery Economics

- **Estimated annual levelized costs for a 200 MW, 4 hour battery are $580/MW-Day***
- **Estimated energy arbitrage revenue equal to DA TB4** values.**
- **Estimated capacity market revenues based on capacity market clearing prices and ELCC values.**
- **Compare levelized costs to revenue from the energy and capacity markets.**

- * 2025 State of the Market Report (Provided by Pasteris Energy, Inc. based on 20-year project life, 50/50 debt to equity capital structure with target IRR of 12% and debt rate of 7%.)
- ** Day-Ahead TB4 values for 2026 based on January through October

Battery Levelized Costs vs DA TB4 and Capacity



Basic Battery Economics by Zone: 2026

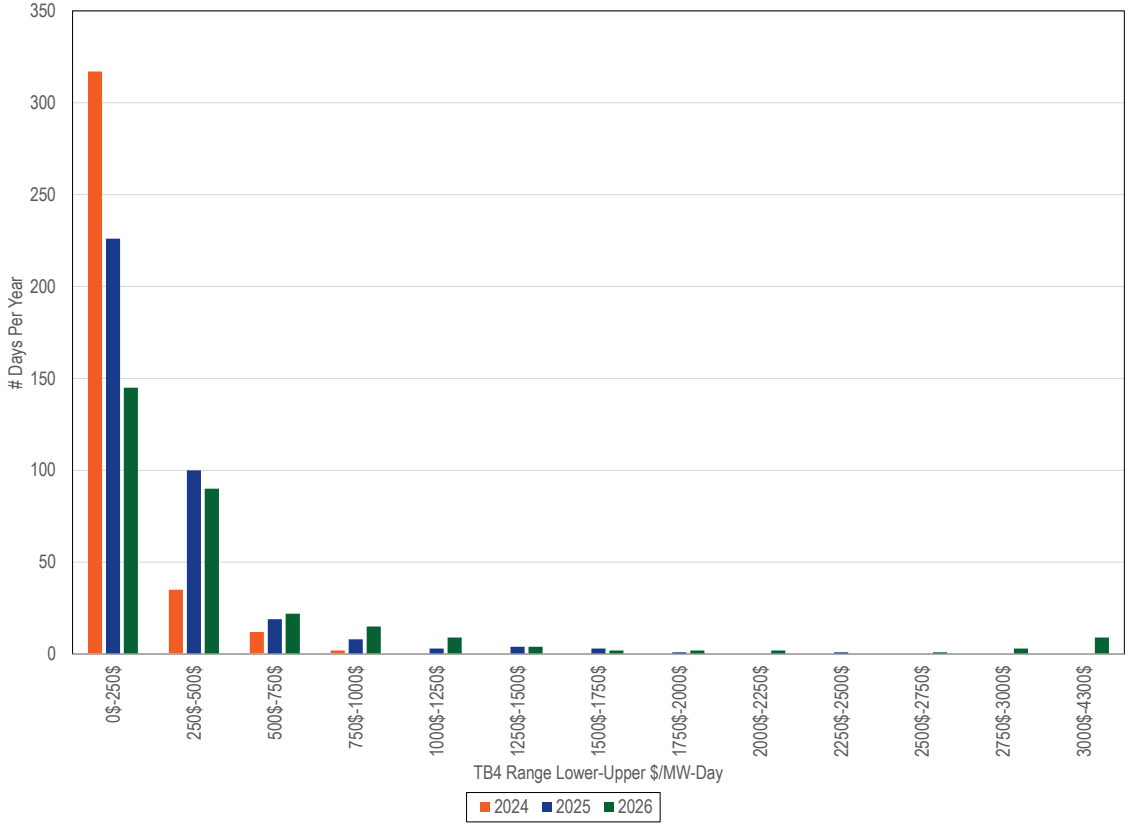
- **TB4 revenues plus capacity market revenues minus annual levelized costs for net positive zones**
  - **200 MW, 4 hour battery.**

Zone Name	TB4+Capacity-Levelized Cost
BGE	$205.12
Dominion	$113.55
Pepco	$130.24

Battery Economics and Risk

- **TB4 values in PJM over the last several years resulted from a small number of high TB4 days**
- **The daily TB4 values for Dominion illustrate this.**
- **There is risk in reliance on a small number of hours for investment signal.**

Dominion Zone Day-Ahead TB4 Frequency



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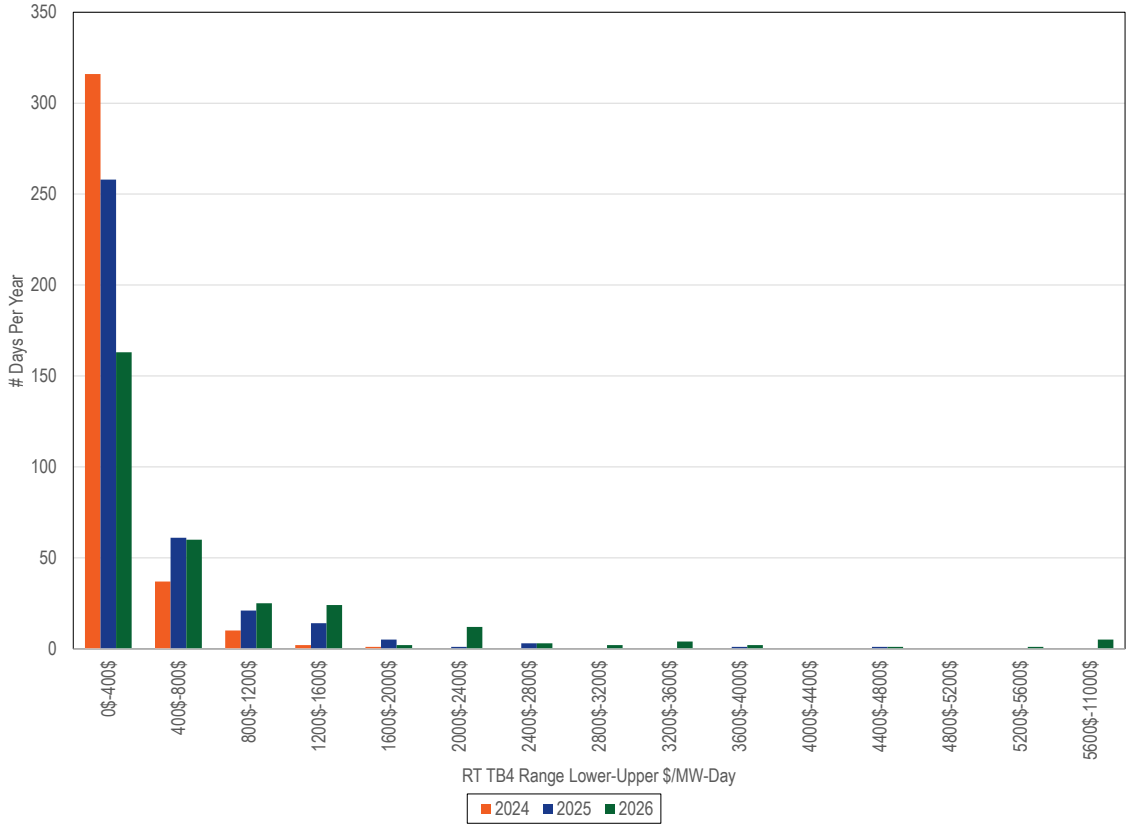
Dominion Zone Real-Time TB4 Frequency



*** TB4 assumes a round-trip efficiency of 0.85, January through October 2026**

Market Power Mitigation

- Market power mitigation measures are an essential component of the PJM market design
  - Batteries are no exception
- Batteries can exercise market power in the day-ahead market and in the real-time market
- Batteries likely to have market power in the aggregate market. Probability increases with growth of batteries.
- Batteries can be marginal and can set prices in the energy market
- Brattle's approach does not demonstrate that market power mitigation prevents efficient outcomes

Cost Offer Options

- Opportunity costs are conceptually relevant.
- It is not possible to calculate opportunity cost accurately. Except on a very short term basis
- Incorrect opportunity cost calculations create risk:
  - If too low, the risk is early deployment of the battery
  - If too high, the risk is that the high offer sets a price that does not accurately reflect system conditions

Cost Offer Options

- **The use of arbitrary and high (e.g. $1,000/MWh or $2,000/MWh) opportunity costs is circular.**
- **The use of arbitrary and high (e.g. $1,000/MWh or $2,000/MWh) opportunity costs creates and facilitates market power.**
- **The use of arbitrary and high (e.g. $1,000/MWh or $2,000/MWh) opportunity costs makes market power mitigation impossible.**

Cost Offer Options

- The use of complex opportunity costs calculations based on history is a waste of time.
- Day-ahead LMPs are not a good proxy for real-time LMPs.
  - No modifications or adjustments based on history make DA LMPs a good measure of opportunity costs.
- Actual opportunity costs depend on perfect forecast of nodal prices.
  - Such forecasts are impossible.

Next Steps

- The use of opportunity costs is based on the idea that batteries, like thermal units, can and should be dispatched based on offers, either cost or price based.
- Batteries are not generators.
- Batteries are net load.
- Batteries shift load from high price hours to low price hours.
- The goal is to optimize the use of batteries.

Next Steps

- The goal is to optimize the use of batteries.
- Optimization can be managed by batteries:
  - Shift MW to maximize profits.
  - Follow algorithmic rules to shift MW.
- Optimization can be managed by PJM:
  - DA optimization in the 24 hour clearing process.
  - RT optimization based on objective function.
- Reliance on market participants or on PJM decisions?
- Best approach requires detailed analysis.
- Best approach will approach optimization goal while preventing the exercise of market power.

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