MARKET SURVEILLANCE COMMITTEE

Storage offer formats and the value of stored energy

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Summary

- **Terminal value functions are likely to provide benefits over traditional price–quantity pairs**
  - **Approaches are equivalent under single-period dispatch with no gate closure**
  - **Gate closure gives advantage to terminal value functions**
- **With multiperiod dispatch, can construct examples where either approach is superior**
- **Gate closure, market parameterization, and constant offers through the hour are issues under either approach**
- **Terminal value functions could enable a more flexible approach to Default Energy Bids**

Example 1

Input	Value
Demand in both (hour-long) periods	10 MW
Gas capacity and marginal cost	9 MW at $100/MWh
Battery power and energy capacity	5 MW / 5 MWh, lossless, starts full
Wind in periods 1 and 2	8 MW, then $U[0,20]$ MW
Value of lost load	$10,000/MWh

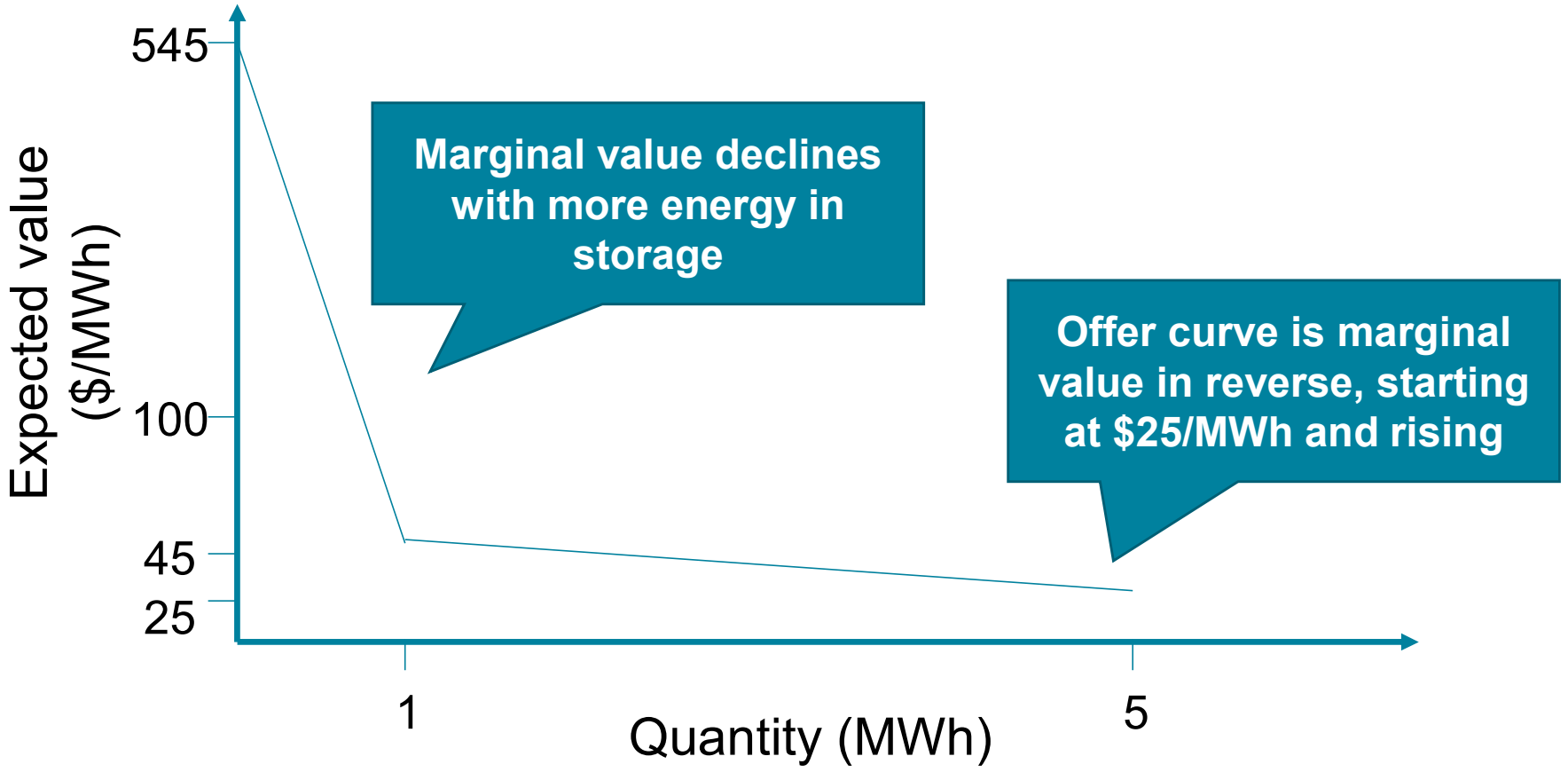
- **Period 1 decision trades current discharge against uncertain future scarcity**

Storage marginal value

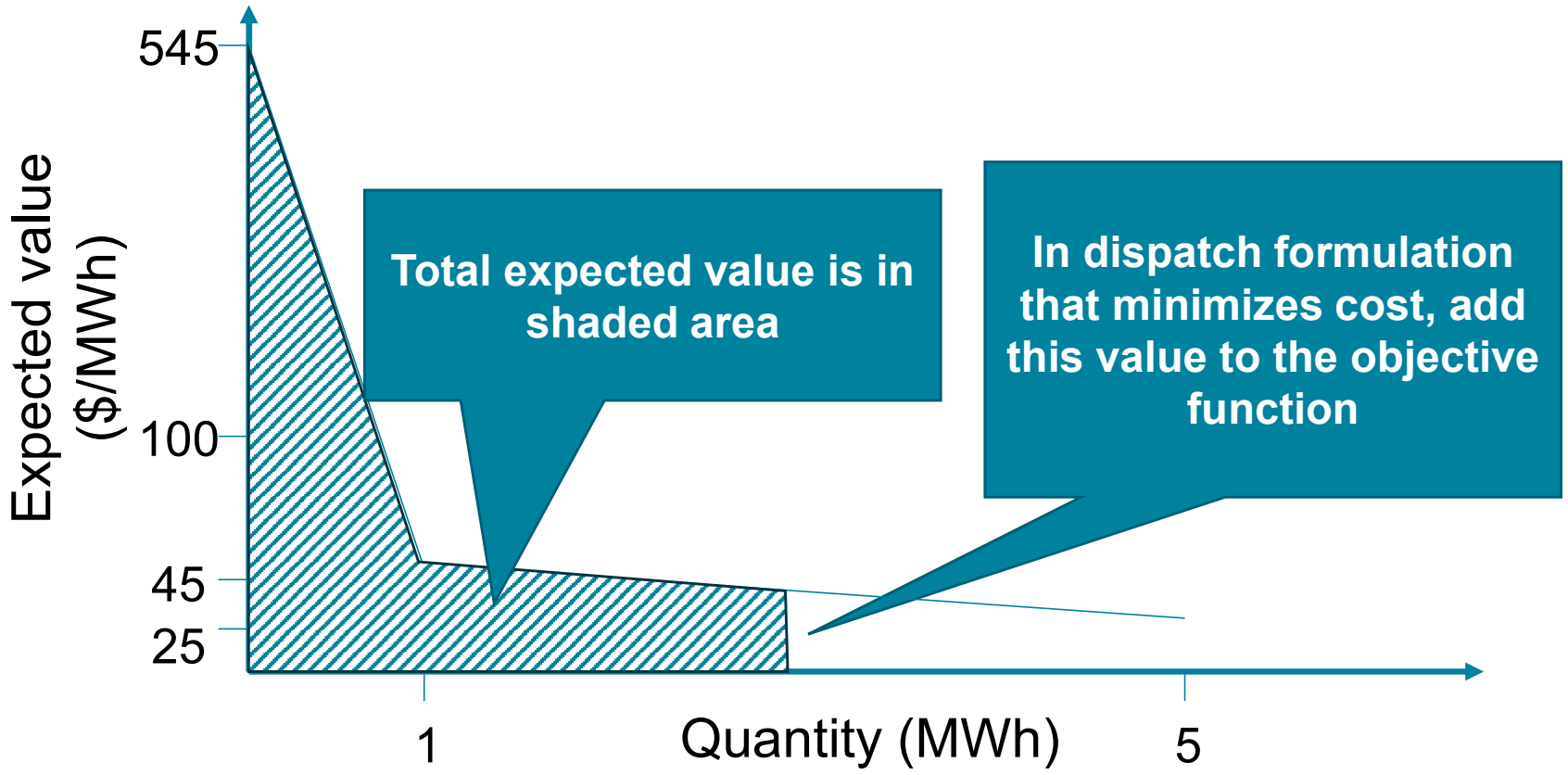
SOC entering period 2	Prob. of gas on margin in period 2	Prob. of lost load in period 2	Marginal value
5 MWh	25%	0%	$25/MWh
3 MWh	35%	0%	$35/MWh
1 MWh	45%	0%	$45/MWh
0 MWh	45%	5%	$545/MWh

- **Optimal dispatch at 2 MW with a price of $35/MWh if we solve this with a dynamic program**

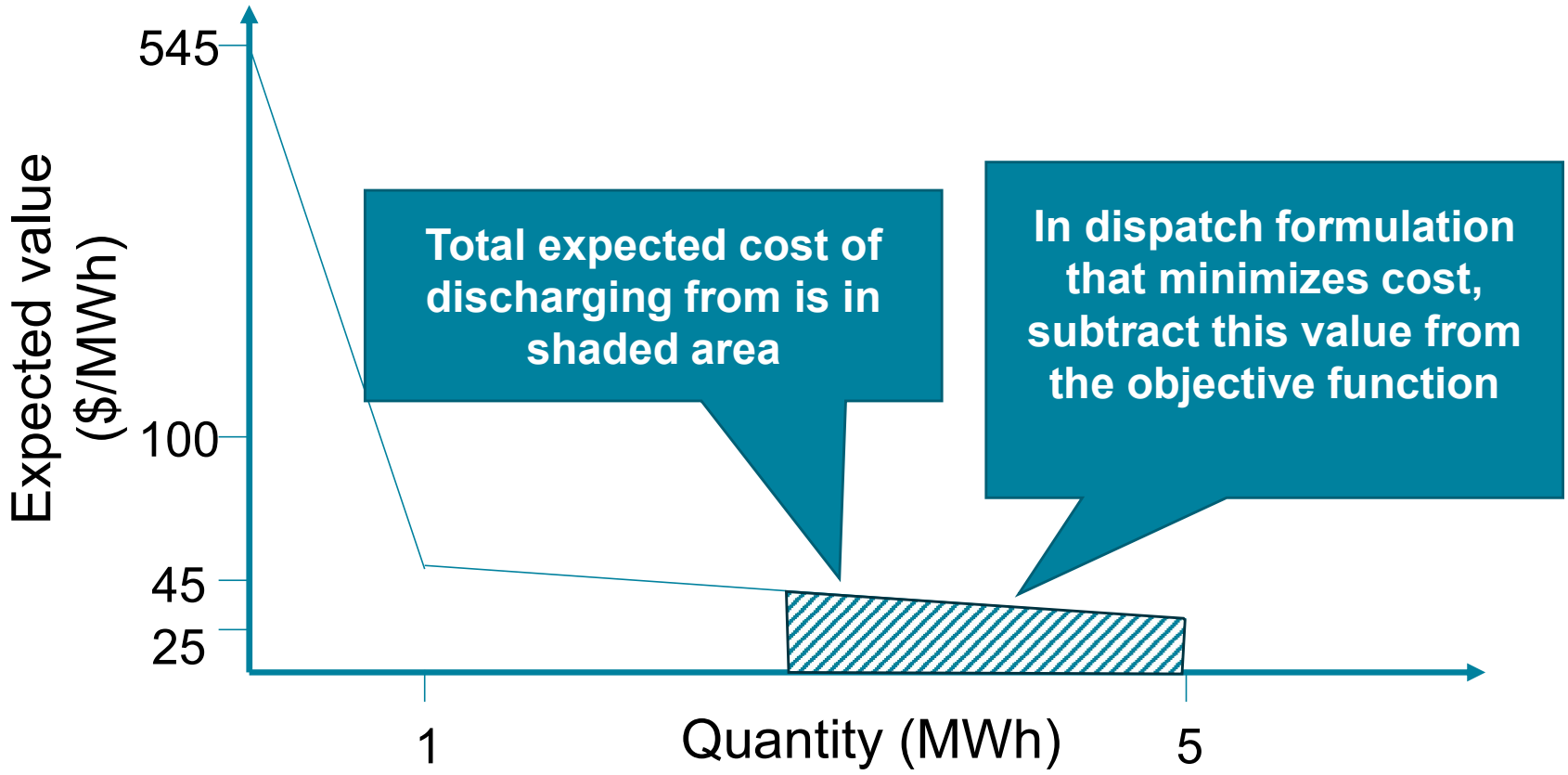
Expected marginal value and offer curve



Value function for state of charge



Total cost based on offer curve



- **Traditional offers and terminal value give the same answer, just with a slightly different formulation**

Observation 1: translation and single-period equivalence

- **In simplest setting there is a direct correspondence between price–quantity pairs and terminal value functions**
- **However, this equivalence relies on a known initial SOC**

State of Charge dependence

- **Suppose that the battery operator has to submit its offer 75 minutes in advance**
- **Terminal value function: does not change**
- **Traditional offer curve: starting value depends on battery knowing that it will enter period 1 with 5 MWh of charge**

Terminal value function implicitly allows a state-dependent offer without introducing non-convexity (cf. 2021-22 Energy Storage Enhancements discussion)

Observation 2: gate closure

- **The potential advantage of terminal value functions is clearer under gate closure**
- **With conventional price–quantity pairs, participant translates valuation into bids/offers implicitly using some assumed SOC**
- **With terminal value function, the ISO can find the right part of the curve, giving a marginal value consistent with actual SOC**
- **Should be noted that terminal value functions may still be using stale information under gate closure**

Consistency within operating hours

- **Suppose we split period 1 into 2 half-hour blocks, both with 8 MW of wind and 10 MW of demand**
- **Call these periods 1a and 1b**
- **Optimal terminal value is different between the two periods**
- **With optimal period-specific terminal values, get same dispatch and prices of $35/MWh in both 1a and 1b**
- **If we insist on the same terminal value function in both periods (e.g., the function appropriate for 1b), get price of $30/MWh in 1a and $35/MWh in 1b (assuming single-period dispatch)**

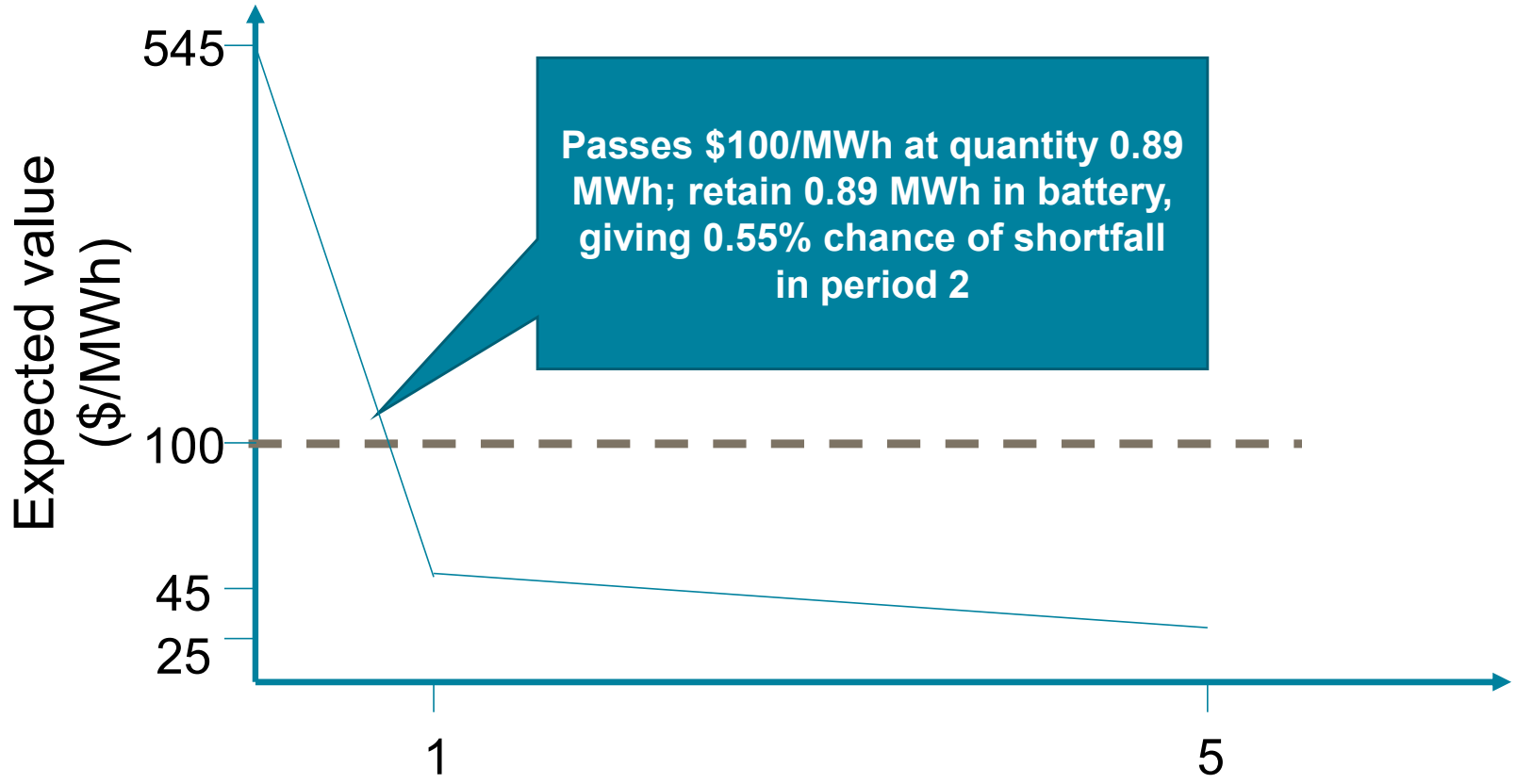
Observation 3: consistency within hour

- **For both conventional price–quantity pairs and terminal values, it is a conceptual problem that offers must be the same for each 5-minute interval within an operating hour**
- **With conventional price–quantity pairs, model has the opportunity to use the cheapest pairs repeatedly even if SOC is drawn down over the course of the hour**
- **This may mean that participants have to assume lower SOC and/or offer at higher values to compensate**
- **Same terminal value functions may not be appropriate as rolling horizon moves**

Example 2: scarcity potential

- **Modify example 1**
- **Suppose that instead of 8 MW of wind in period 1, we had only 5 MW**

Optimal risk-neutral dispatch



Lookahead dispatch

- **One-period dispatch model with terminal value function gives the socially optimal dispatch**
- **Once marginal value of stored energy >$100/MWh, use the gas plant instead and preserve SOC**
- **Suppose instead we solve a two-period deterministic lookahead model and assume average wind outcome of 10 MW in hour 2**
- **Two-period model would empty storage in period 1, leaving higher probability of scarcity**
- **Terminal value approach does not resolve this issue, since value at end of hour 2 is 0**

A longer deterministic lookahead can give a worse solution if it neglects uncertainty within the horizon

Observation 4: length of lookahead

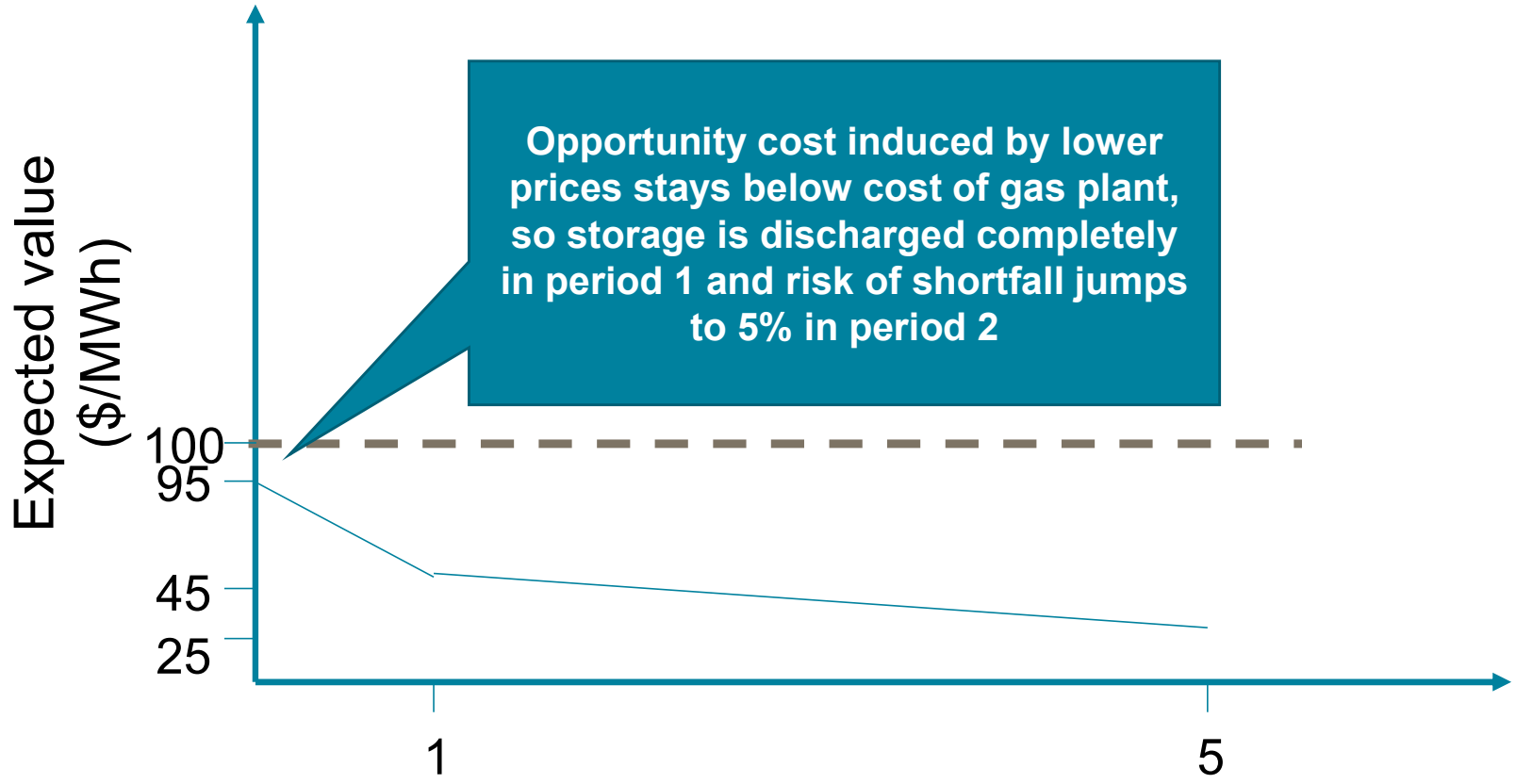
- **A high-quality terminal value function can capture in the impact of uncertainty past the lookahead horizon**
- **A deterministic lookahead model does not explicitly represent uncertainty within the lookahead horizon**
- **It is not clear that a longer lookahead horizon is beneficial when using a deterministic lookahead model**

Traditional price–quantity pairs might outperform terminal value functions if uncertainty within the lookahead horizon is important

Market rules and opportunity cost

- **Now suppose that instead of the true value of lost load of $10,000, we use a power balance penalty of $1,000**

Market-clearing dispatch



Observation 5: parameterization

- **Market-based dispatch depends on participant opportunity costs aligning with social costs**
- **Adequate performance incentives (through prices or non-performance penalties) necessary for optimal storage operation in situations with potential for scarcity**
- **Weak scarcity pricing interferes with dispatch incentives in addition to affecting long-run investment incentives**
- **This is true for both traditional price–quantity pairs and terminal value functions**

Observation 6: cycling

- **Batteries can have cycling costs**
- **An implication is that different paths through the lookahead period can have different cost even if they land at the same SOC**
- **This suggests the need for cost terms attached to the dispatch variables themselves in addition to terminal value**

Observation 7: ancillary service obligations

- **It is relatively straightforward to adjust the terminal value function to ensure a high value on state of charge needed for ancillary service obligations**
- **It is also possible to adjust terminal values to retain state of charge to meet day-ahead positions, if desired**

Observation 8: default energy bids

- **The marginal value of energy is a function of state of charge (as well as changes in the system state)**
- **With a change in offer format, would want to develop default energy bids that reflect the value function**
- **This could improve efficiency relative to a single value**

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Selected references (1/2)

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