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CAISO ENERGY STORAGE ENHANCEMENTS WORKING GROUP

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RECOMMENDATIONS

- **Reconsider using the minimum state of charge (MSOC) requirement**
  - *The short real-time market horizon does not cause chronic discharge early in the day*
- **Focus on reforming the bidding interface for energy storage resources**
  - *Current bidding interface creates unique challenges for energy storage to represent real marginal costs to the market*
  - *Unlock better market efficiency and more flexible operation*
  - *Incorporate real marginal costs into market clearing prices rather than non-transparent uplift charges*

WHY WOULD REAL-TIME DISPATCH (RTD) MANAGE ENERGY STORAGE DIFFERENTLY THAN OTHER RESOURCES?

- **Energy storage resources have upper and lower state-of-charge limitations**
  - *If these limitations cannot bind over the next 65 minutes, the battery operates based on bids exactly like other resources (i.e. the "normal use")*
  - *If the **upper** state-of-charge limitation can bind over the next 65 minutes, the battery charges at **lowest priced opportunities** (i.e. the "picky charger")*
  - *If the **lower** state-of-charge limitation can bind over the next 65 minutes, the battery discharges at **highest priced opportunities** (i.e. the "picky discharger")*

EXAMPLE (“NORMAL USE”)

- **400 MWh battery with 100 MW pmax and infinite ramp rate**
  - *Battery **currently has 200 MWh SOC***
  - *Charge bid = $50, Discharge bid = $250*
- **Resource SOC constraints not limiting battery use over the 65-minute RTD horizon, *battery dispatched based on bid***
  - *When market prices are $49: Battery will charge*
  - *When market prices are $100: Battery will not charge or discharge*
  - *When market prices are $251: Battery will discharge*

Key observations when there is limited charging capability

- *If prices are rising throughout the RTD horizon: battery will charge when charge bid is in-merit and discharge when discharge bid is in-merit.*
- *Out-of-merit battery will not charge due to higher prices later in the RTD horizon because it already has enough energy stored to meet at least 60 minutes of in-merit discharge*

EXAMPLE (“PICKY CHARGER”)

- **400 MWh battery with 100 MW pmax and infinite ramp rate**
  - *Battery **currently has 308.33 MWh SOC***
  - *Charge bid = $50, Discharge bid = $250*
- **Resource SOC constraints limit battery charging over the 65-minute RTD horizon, *battery only charges if in-merit and it’s among the cheapest opportunities***
  - *When market prices are $49: Battery will charge if binding interval price is not the highest priced in the RTD horizon*
  - *When market prices are $100: Battery will not charge because it is cheaper to use stored energy to meet future high prices*
  - *When market prices are $251: Battery will discharge in-merit*

Key observation when there is limited charging capability

If prices are rising throughout the RTD horizon: battery will charge when charge bid is in-merit

EXAMPLE ("PICKY DISCHARGER")

- **400 MWh battery with 100 MW pmax and infinite ramp rate**
  - *Battery **currently has 91.67 MWh SOC***
  - *Charge bid = $50, Discharge bid = $250*
- **Resource SOC constraints limit battery discharging over the 65-minute RTD horizon, *battery discharges if in-merit and it's among the highest priced opportunities***
  - *When market prices are $49: Battery will charge*
  - *When market prices are $100: Battery will not charge or discharge*
  - *When market prices are $251: Battery will discharge if binding interval price is not the lowest priced in RTD horizon*

Key observation when there is limited discharge capability

If prices are rising throughout the RTD horizon: battery will not discharge when discharge bid is in-merit

EVALUATE EXPECTED DISPATCH OVER THE DAY

Current State-of-Charge

MID
HIGH
LOW

Behavioral Pattern

Normal Use
Picky Charger
Picky Discharger

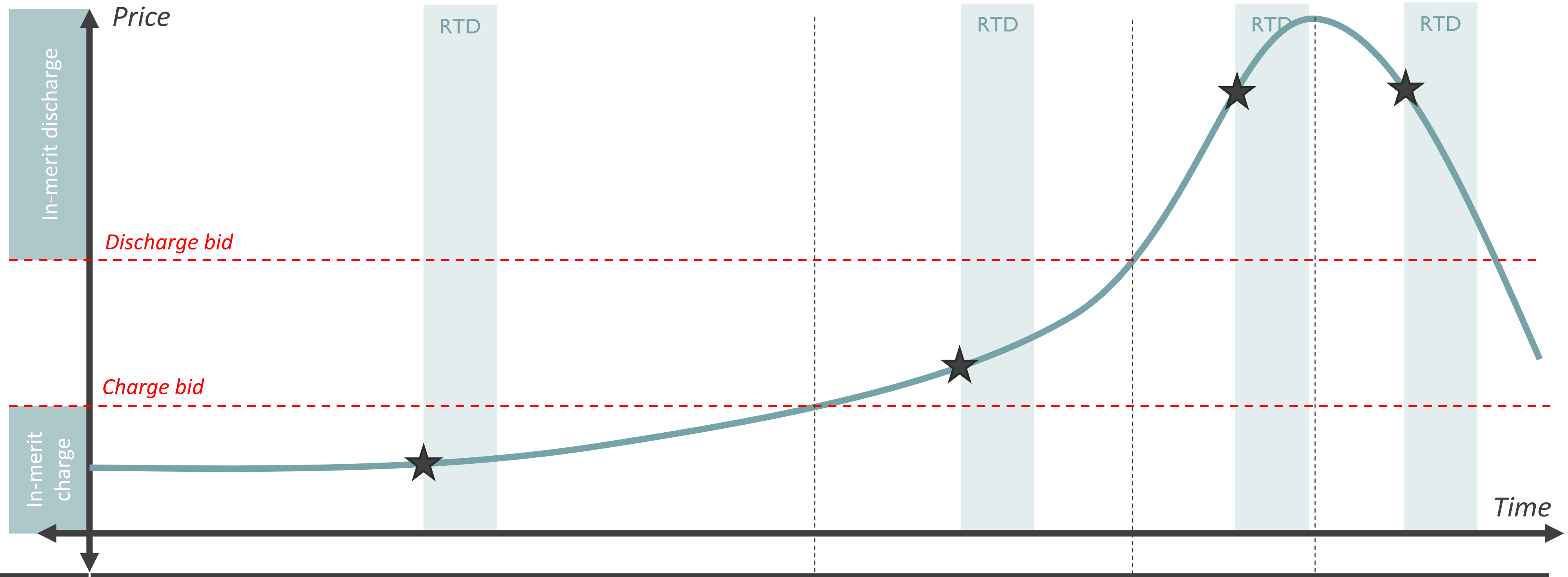
Market Prices

RTD Horizon
Price Forecast

Dispatch

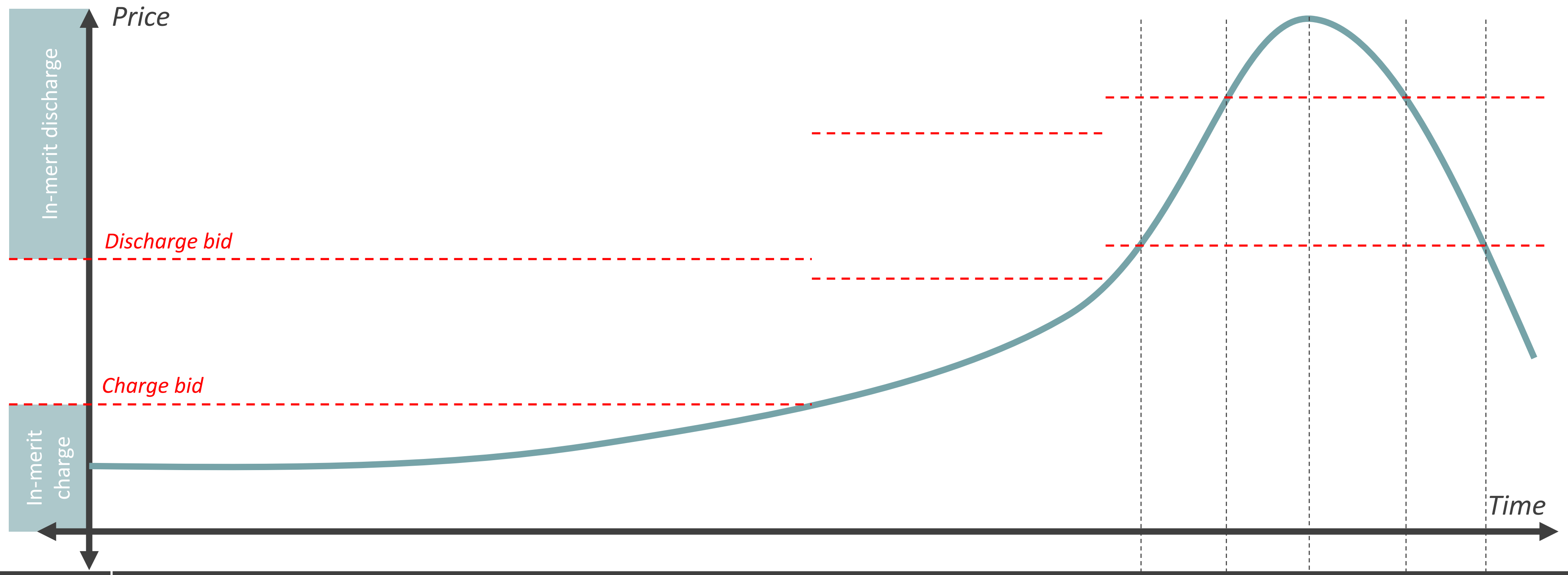
Charge, Hold, or Discharge

ENERGY STORAGE RESOURCES WILL TEND TO CHARGE AND HOLD CHARGE INTO THE EVENING



SOC	Behavioral Pattern	Dispatch			
MID	Normal Use	Charge	Hold	Discharge	Discharge
HIGH	Picky Charger	Charge	Hold	Discharge	Discharge
LOW	Picky Discharger	Charge	Hold	Hold	Discharge

SCHEDULING COORDINATORS UPDATE BIDS THROUGHOUT THE DAY



SOC	Behavioral Pattern	Dispatch					
MID	Normal Use	Charge	Hold	Disc.	Disc.	Hold	Charge
HIGH	Picky Charger	Charge	Hold	Disc.	Disc.	Hold	Charge
LOW	Picky Discharger	Charge	Hold	Hold	Disc.	Hold	Charge

BIDDING INTERFACE: SQUARE PEG, ROUND HOLE

- **Bidding interface accepts $/MWh cost curve**
- **Actual operating cost is a function of throughput *and state-of-charge***
- **Energy storage operators must incorporate assumptions into their bids to ensure cost recovery**
  - *Delay between bid submission and dispatch introduces assumptions and cost*
  - *Actual operating cost depends on energy storage use profile*
- **More required assumptions lead to less market efficiency and less operational flexibility**

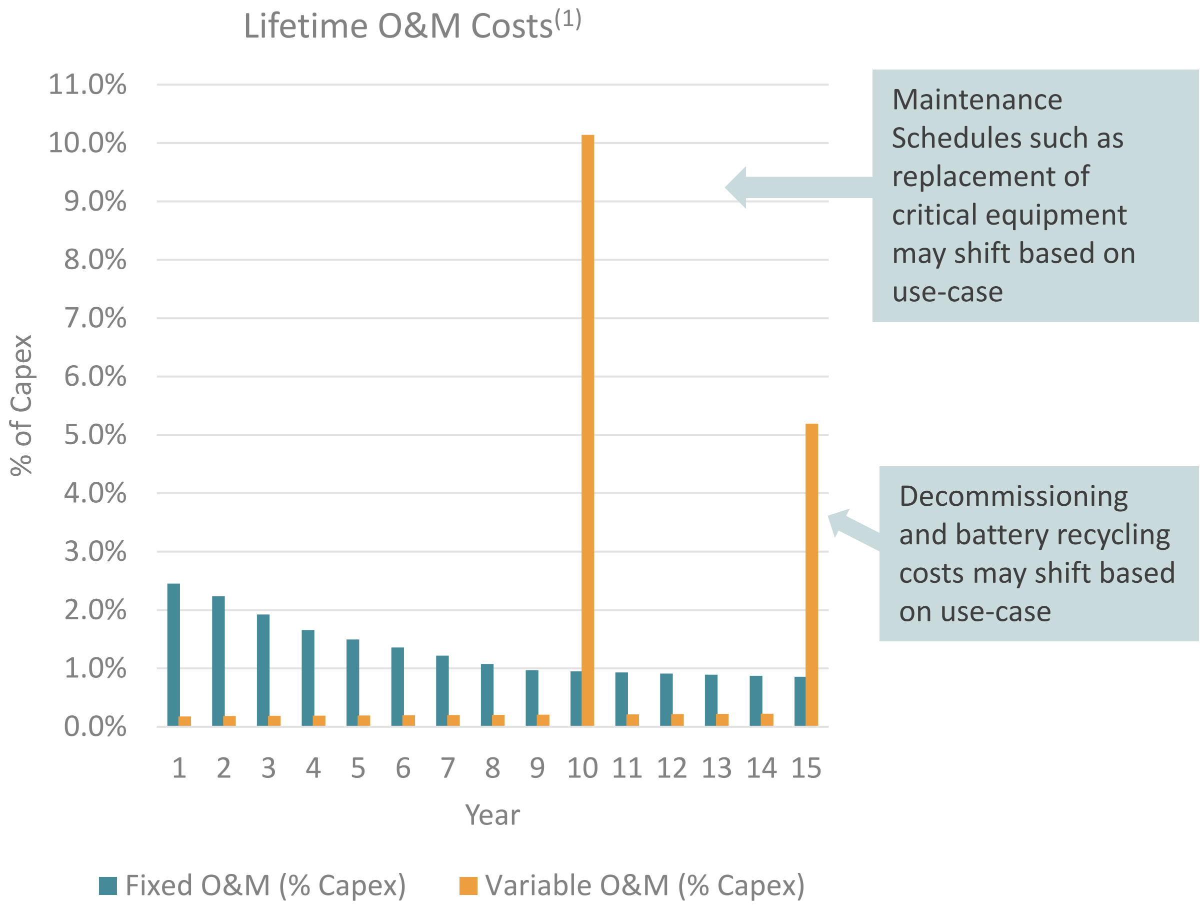
MARGINAL COST AND VARIABLE O&M

Marginal Costs stem from three "*categories*"

- **Energy cost**
  - *C*ost to buy energy from the grid, parasitic loses, and round-trip efficiencies
- **Opportunity costs**
  - *F*ailing to charge during the lowest priced hours or failing to discharge during the highest priced hours.
- **Cycling costs**
  - *Function of depth of discharge, current rate, and average state of charge*
  - *<u>Service Life:</u> Cost related to run hours on equipment, increased maintenance intervals, or to account for unplanned increased end-of-life costs*
  - *<u>Degradation:</u> Cost related to degradation of batteries and energy capacity lifecycle management.*

O&M COST EXAMPLE

- 6-month preventive maintenance intervals on most major equipment
- HVAC repair and service
- Minor overhaul may occur at some point in the project to add batteries or to replace HVAC, inverters, other major equipment.
- End of life can cost 3%-8% of Capex depending on chemistry



1. Internal estimates based on project specific parameters

BATTERY DEGRADATION

- More throughput (MWh) tends to increase capacity Fade and is typically the most impactful variable
- Higher currents will accelerate degradation
- SoC movement during cycling and average SoC can significantly impact degradation
- Temperature and thermal management performance can also impact degradation

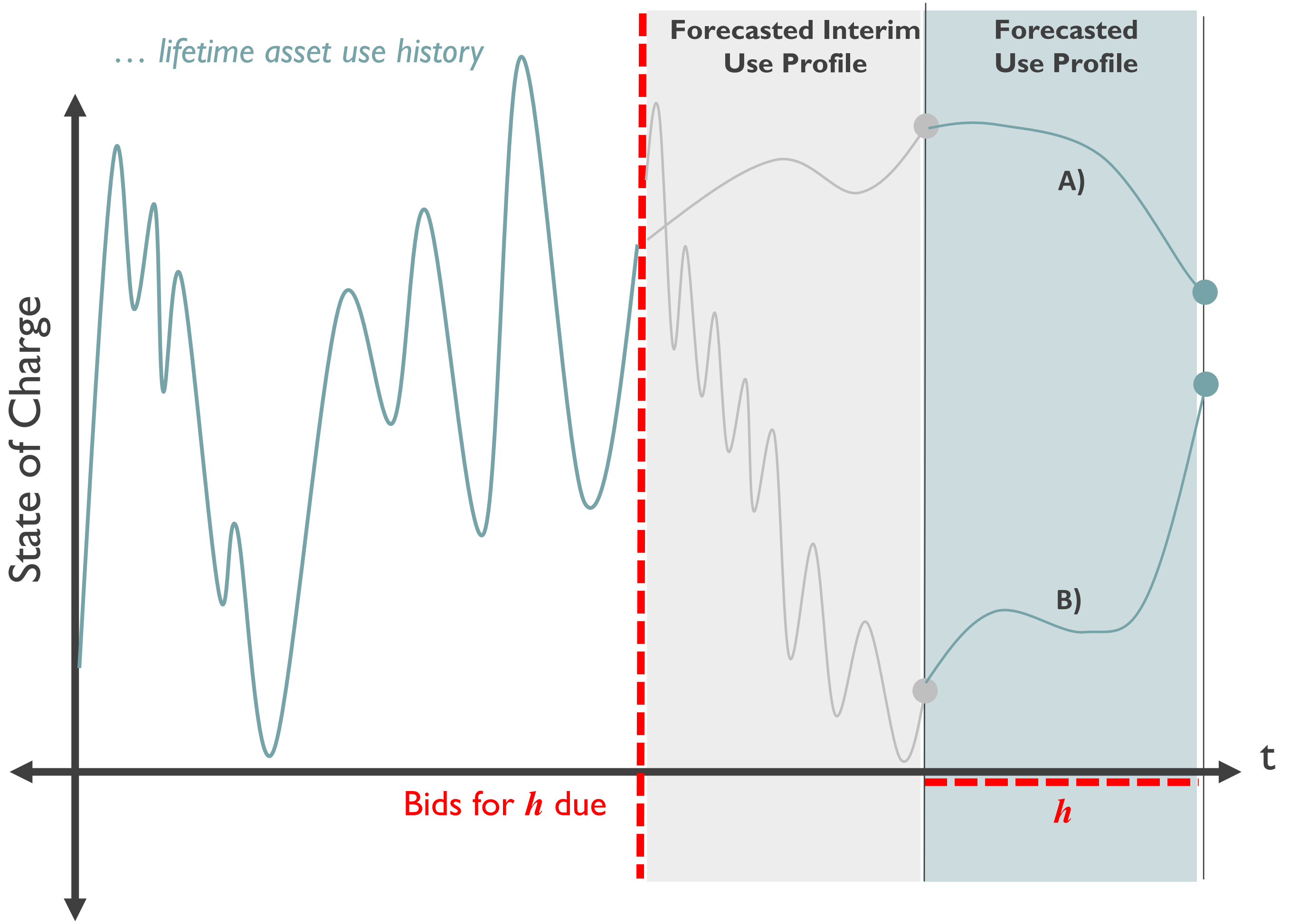
Typical Energy Capacity Cycle Degradation Per cycle under different circumstances **(%/hour)**[1]

Average SOC	%DOD 100%	75%	50%	25%
2 Hour Rate				
75%			0.00054%	0.000127%
63%		0.00087%	0.00044%	0.000113%
50%	0.00124%	0.00071%	0.00033%	0.000099%
38%		0.00054%	0.00029%	0.000079%
25%			0.00025%	0.000059%
4 Hour Rate				
75%			0.00026%	0.000096%
63%		0.00041%	0.00022%	0.000087%
50%	0.00055%	0.00034%	0.00018%	0.000077%
38%		0.00027%	0.00015%	0.000062%
25%			0.00013%	0.000047%
8 Hour Rate				
75.00%			0.00020%	0.000083%
62.50%		0.00043%	0.00018%	0.000075%
50.00%	0.00039%	0.00032%	0.00016%	0.000068%
37.50%		0.00021%	0.00013%	0.000055%
25.00%			0.00010%	0.000043%
20 Hour Rate				
75.0%			0.00020%	0.000078%
62.5%		0.00027%	0.00017%	0.000071%
50.0%	0.00036%	0.00024%	0.00015%	0.000064%
37.5%		0.00021%	0.00012%	0.000053%
25.0%			0.00010%	0.000041%

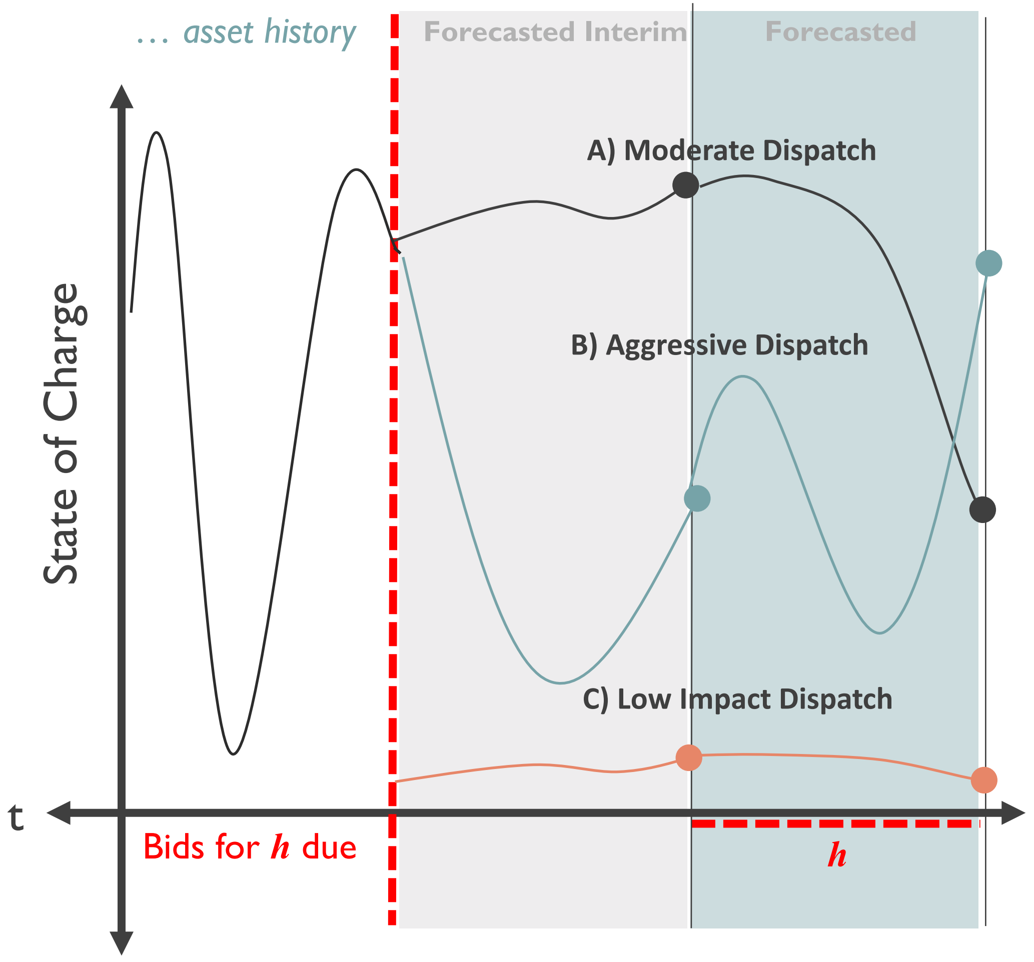
1. Degradation estimates were empirically determined through lifecycle analysis based on typical lithium-ion product

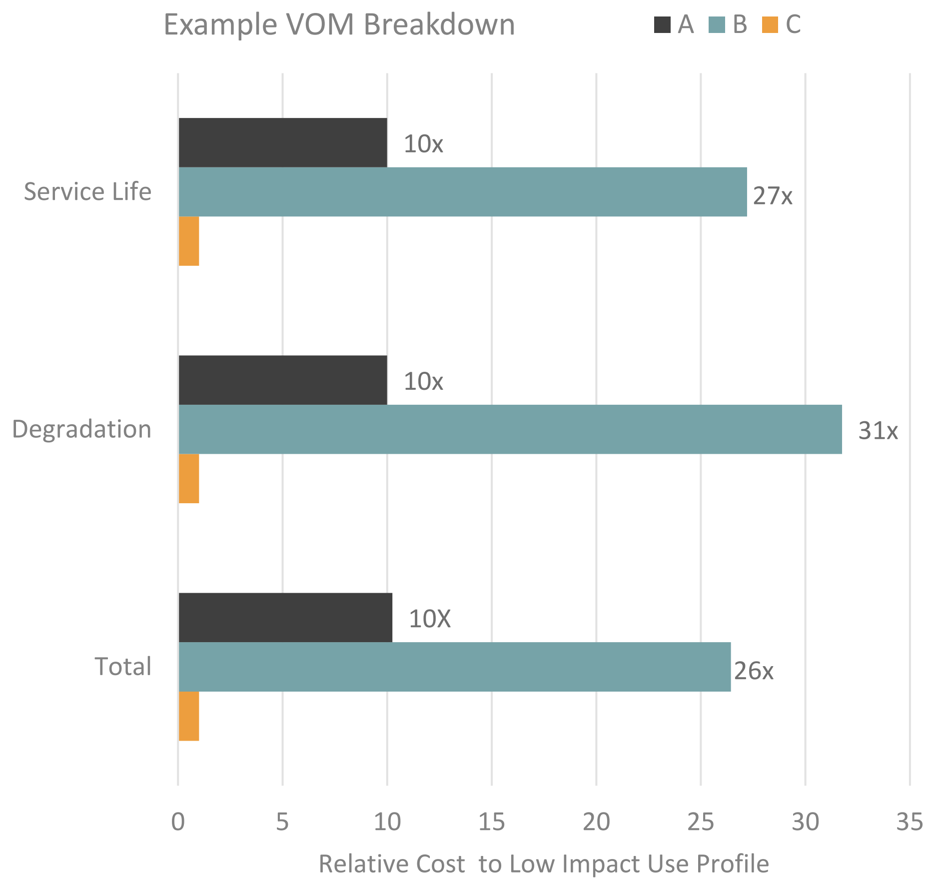
DELAY BETWEEN BID SUBMISSION AND DISPATCH INTRODUCES COSTS

- ☐ **Many use profiles can materialize**
- ☐ **Each with different probability and different cost implications**
- ☐ **Structuring market bids to ensure cost recovery requires assumptions**



USE PROFILE DRIVES OPERATIONAL COSTS





RECOMMEND INVESTIGATING THE BENEFITS AND FEASIBILITY OF THE FOLLOWING BIDDING INTERFACE ENHANCEMENTS

- **Enhancements**
  - *Allow energy storage resources to update market bids as close to the fifteen-minute market execution as possible*
  - *Allow energy storage resources to provide cost adder that is a function of average state-of-charge and depth-of-discharge over the market horizon*
- **Benefits**
  - *Allows scheduling coordinators to provide accurate marginal cost information to the market*
  - *Allows the market to produce an efficient and flexible dispatch*

ABOUT US

Perry Servedio

Mr. Servedio has over 13 years of experience in the electric energy industry with more than three years of service at the Federal Energy Regulatory Commission (FERC) and nine years of operations and policy development experience at California ISO (CAISO). Mr. Servedio has led the design, contemplation, and review among stakeholders of CRR market, day-ahead market, and real-time market reforms. His expertise in CAISO markets and the Western Energy Imbalance Market provides an excellent resource to evaluate changing market landscape in California and the Western Interconnection.

Matt Smith

Mr. Smith has over 17 years of engineering experience in utility scale renewable power generation technology and battery energy storage systems. A large part of his professional career has been centered around technical analysis of solar, wind, and battery energy storage systems, and supporting the economic feasibility analysis for performance and maintenance of those assets, including appropriate O&M schedules and programs to maintain reliability of the projects for the duration of the expected life. His extensive expertise in battery performance and operations, maintenance protocols, and capacity sizing provides an excellent resource to asset developers, owners, and operators.