



Energy+Environmental Economics

# MN Storage Cost-Benefit Analysis Final Results Review

Third Workshop

10/25/2019

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- + Please mute yourself
- + There will be 20 minutes for Q&A at the end. Please ask questions through the chat box.
- + This webinar will be recorded, and the slides will be shared as well.



# Seeking Stakeholder Input

- + In addition to the analysis conducted, are there any other potential benefits or barriers that we should discuss in the final report?
- + What are the barriers to energy storage development in Minnesota in your opinion?
- + What recommendations and next steps would you suggest to the state legislature?
- + Energy storage pilots provide useful learning opportunities and real-life experience in operation and integration. If conducting a pilot is a possibility, what types of pilots do you think would be the most interesting and valuable to conduct? For example, T&D deferral, wholesale participation, etc.



# Agenda

- + 12:30 – 12:35 **Introduction**
- + 12:35 – 12:45 **Update Summary**
- + 12:45 – 1:10 **Draft Takeaways and Recommendations for Discussion**
- + 1:10 – 1:30 **Stakeholder Feedback Summary**
- + 1:30 – 2:00 **Updated results**
- + 2:00 – 2:20 **Q&A**
- + 2:20 – 2:30 **Next Steps**
- + **Appendix:**
  - More Stakeholder Feedback
  - Study Caveats
  - A List of Benefits Quantified and Not Quantified



# Project Overview

- + This study is made possible by legislation\* passed in 2019
- + E3 is working with the Department of Commerce to conduct an independent analysis of the potential costs and benefits of energy storage systems in Minnesota
- + A public report will be produced to summarize the findings
- + **Tasks:**
  - **Cost-Benefit Analysis**
    - Identify use-cases for modeling
      - Each use case discussed previously will be modeled
    - AURORA production simulation modeling
    - RESTORE Storage cost and benefit modeling
  - **Stakeholder Engagement**
  - **Final Report**
    - Case studies
    - Final report
  - **Presentations to the Minnesota Legislature**



\* [Minnesota Session Laws, 2019 Special Session 1, Chapter 7 \(HF2\), Article 11, Section 14](#)





# Project Focus Areas

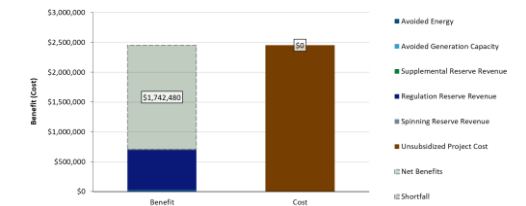
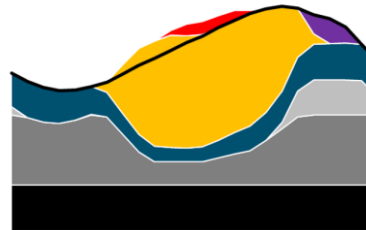
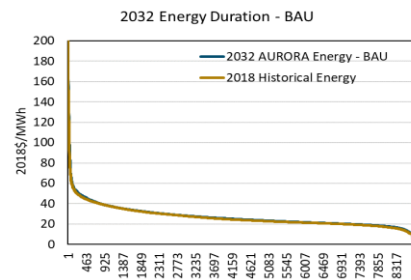
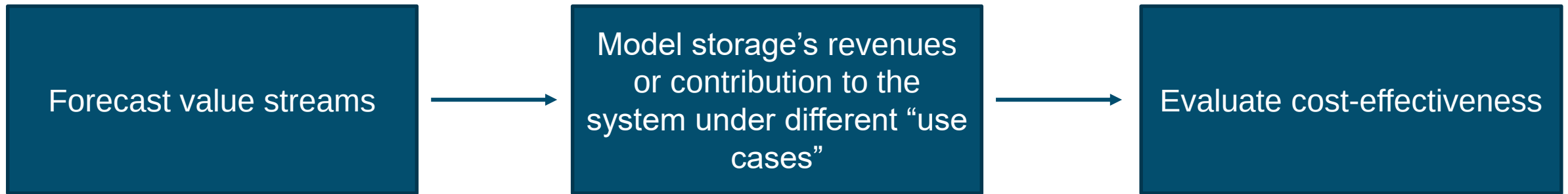
- + This study focuses on 1) providing a high-level valuation for energy storage in Minnesota in the near-term and 2) contributing in developing the evaluation framework for energy storage in Minnesota
- + We try to capture the important factors through our analysis. For those that are difficult to fit into the timeline and budget, we either conduct sensitivity analysis or include a discussion in the report
- + We believe even with simplifications, our major conclusions won't be impacted
- + Limitations are listed below:
  - Transmission and distribution constraints are not considered for power transferring within zones (MN + North Dakota + Iowa).
  - No power-flow analysis is conducted
  - System sub-hourly need is not captured
  - The model dispatches battery optimally with perfect foresight, which renders upper-bounds for the realized storage values
  - Current market participation rules are not modeled as the study aims to provide theoretical values
  - Detailed interconnection studies are not conducted to address reliability and charging feasibility concerns when energy storage is used as a peaker





# Overview of valuation methodology

- + Determine projected value of storage using forecasted price streams based on future system need and cost declines- not just current prices





# Cases Summary

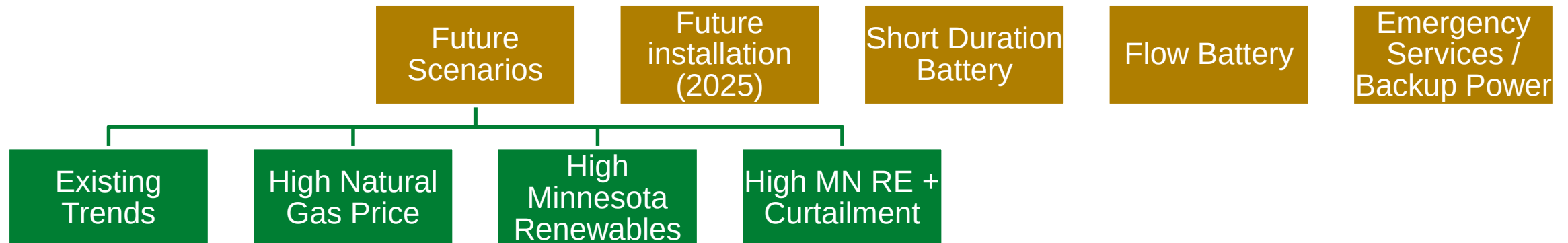
Benefit Streams →

Core Use Cases

| Core Use Cases                  | Wholesale        |                             |                    | Transmission and Distribution  |                                      |                    | BTM          |
|---------------------------------|------------------|-----------------------------|--------------------|--------------------------------|--------------------------------------|--------------------|--------------|
|                                 | Energy arbitrage | Avoided generation capacity | Ancillary services | Transmission congestion relief | Transmission & Distribution deferral | Emergency services | Bill savings |
| Wholesale standard <sup>1</sup> | ✓                | ✓                           | ✓                  |                                |                                      |                    |              |
| Wholesale congestion relief     | ✓                | ✓                           | ✓                  | ✓                              |                                      |                    |              |
| Distribution deferral           | ✓                | ✓                           | ✓                  |                                | ✓                                    |                    |              |
| BTM PV paired with storage      | ?                | ?                           |                    |                                |                                      |                    | ✓            |
| FTM PV paired with storage      | ✓                | ✓                           | ✓                  |                                |                                      |                    |              |

Not a societal benefit unless retail rates are aligned with system values

Sensitivities







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# Update Summary



# Update Summary

## + AURORA benchmarking methodology has been adjusted

- Raw AURORA outputs are post-processed to better capture market behaviors and volatility
  - Previously: Real 2018 prices were scaled by annual month-hour averages relative to 2018 prices
  - Now: Top priced hours in each year are adjusted upwards to capture scarcity pricing, leaving rest of hours as raw AURORA outputs
    - Scalars are the ratio between the 2018 AURORA outputs and 2018 historical prices
- After the adjustment, the new price streams have a better representation of the DA market volatility, which shows more high-price hours and more low-price hours for the high MN renewables scenario

## + New Sensitivities are added per stakeholders' suggestions

- Curtailment: added an additional curtailment sensitivity to analyze the impact when marginal prices are increasingly set by renewables
- Short duration: tested 1-hour duration Li-ion battery
- Low storage cost projection: Investigated storage cost effectiveness under NREL “Low” price scenario

## + Conducted a direct comparison between the cost-effectiveness of a Li-ion battery and a traditional gas peaker – brownfield CT

## + Conducted analysis to estimate the value of providing emergency services



# Major Results Changes

- + Energy storage use cases are closer to cost-effectiveness than what we showed in draft results**
  - Because of the increased price volatility in the newly benchmarked AURORA prices
- + Both BTM and FTM PV + Storage are cost effective in certain configurations**
  - BTM storage is cost effectively mainly from the customer's perspective, and not necessarily from a societal perspective, because the benefits come from demand charge clipping
- + Li-ion batteries installed in 2025 are now cost effective for both the mid and low storage capital cost trajectories**



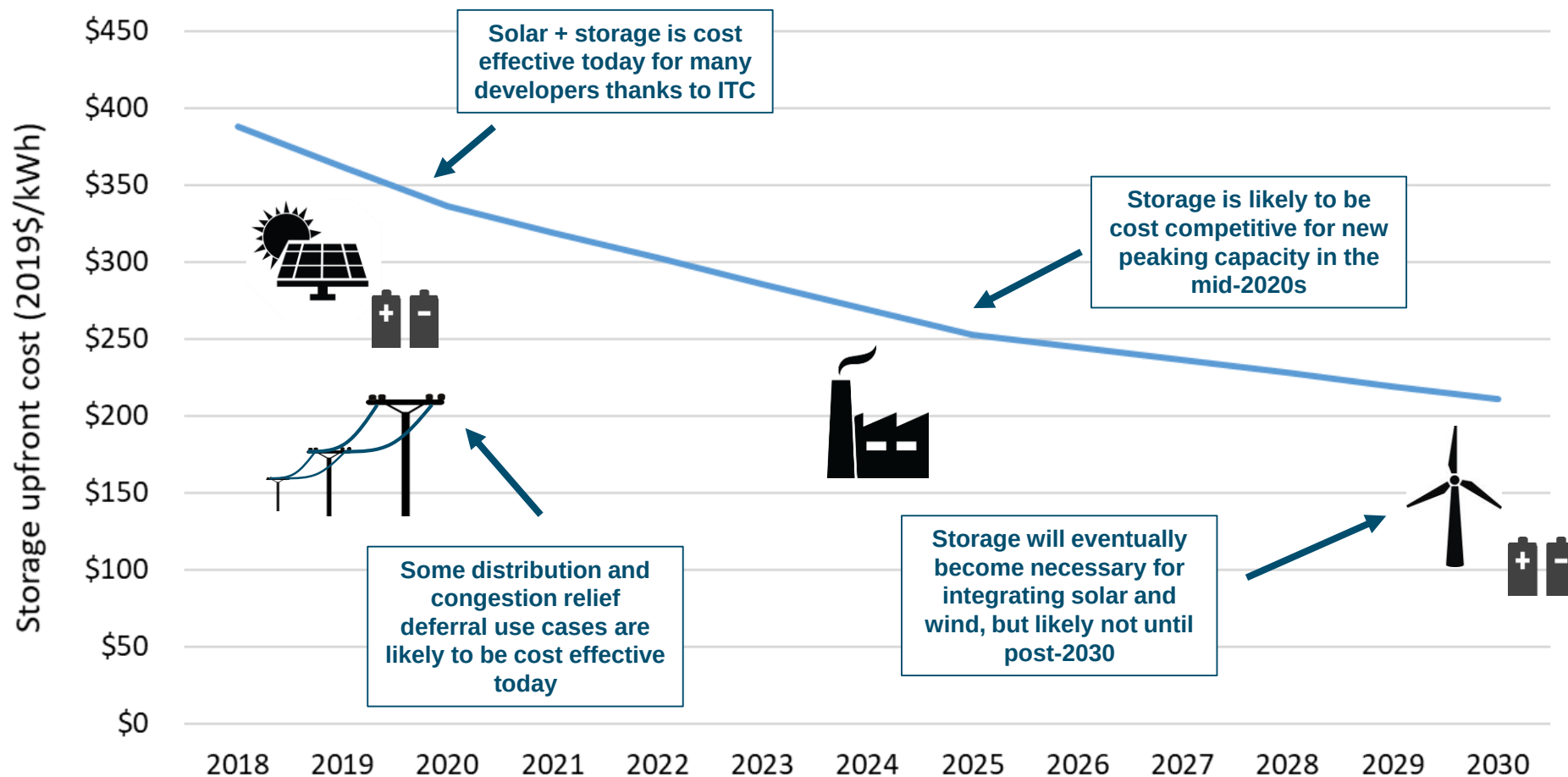
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# Key Takeaways and Recommendations



# Draft Key Takeaways: breakeven costs over time

## NREL “Mid” Utility-Scale Storage Cost Projections



Source: “Cost Projections for Utility-Scale Battery Storage”, NREL, June 2019



# Draft Key Takeaways – FTM

- 1. Energy storage installed in 2020 is not yet cost-effective from the system's perspective if it only provides capacity, hourly energy, and ancillary services values**
  - Regulation reserve value is the largest value stream for storage installed in 2020, followed by capacity value
  - However, energy storage could be cost-effective if it is located in constrained areas with high system and local capacity value. For example, providing T&D deferral value and addressing transmission congestion.
  - Participating in real-time markets and providing sub-hourly flexibility to the system will increase energy storage's overall value. This study did not quantify these two value streams in great detail.
- 2. Li-ion storage installed in 2025 could be cost-effective as a capacity resource due to the lower capital cost and the increased capacity value as MISO starts to procure capacity, but installments are subject to saturation**
  - Some amount of energy storage could take the place of new thermal capacity resources
  - These results are based on theoretical maximum values that can be provided by Li-ion storage. More studies and pilots are needed for each site individually before implementing storage as capacity resource. For example, conducting stochastic analysis to ensure reliability and conducting power flow analysis to understand charging constraints due to congestion.





# Key Takeaways – PV + Storage

## + **Front-of-the-meter (FTM) storage paired with PV is cost-effective in 2020**

- ITC provides additional incentives for storage but also limits the opportunities to provide regulation services, due to the constraint to charge from solar
- Some amount of PV + storage could take the place of new thermal capacity resources

## + **Behind-the-meter (BTM) storage paired with PV is cost-effective from the participant's perspective**

- Demand charge clipping is a significant value stream for these installations, which can represent a cost shift to other ratepayers, if the state and utilities don't provide signals that are aligned with system benefits
- However, PV + storage could provide significant values to the system if utilities provide programs that align customer benefits with system benefits. For example, TOU energy charges, demand response, and allowing utility dispatch battery during system peak days.

## + **Paired storage or even stand-alone storage could serve as a backup generator during emergency events, which could provide benefits to communities**



# Key Takeaways – Others

- + Flow batteries are not as cost-effective as Li-ion batteries in 2020 or 2025 because of their higher capital cost.**
  - Flow batteries can provide the same services as Li-ion batteries. It might become cost competitive in the future given the more aggressive cost decline projections
- + The key factors identified in the report for energy storage's cost-effectiveness are:**
  - Capital cost
  - System and local capacity need (including T&D deferral opportunities)
  - Renewable integration need in the long-term
- + Energy storage in MN is not as cost-effective as those in some other jurisdictions (e.g. New York, California, and Massachusetts). This is due to**
  - 1) the relatively low capacity value resulting from excess capacity in the current system, and inexpensive new capacity due to brownfield CT opportunities
  - 2) MN has a lower renewable penetration level than other jurisdictions
  - 3) In addition, a large portion of renewables are wind, thus, the price spread within a day is not as high as solar-dominant systems
  - 4) MN is in MISO. Regional coordination can help absorb relatively high levels of renewables in MN



# Recommendations and Next Steps

- + Utilities should consider energy storage in their resource planning process, taking into account the multitude of value streams that storage can provide:**
  - Sub-hourly flexibility values
  - Peak capacity
  - T&D upgrade deferral
  - Ancillary services
- + Utilities should non-wires alternatives in their distribution planning process. identify areas with high T&D deferral values when considering opportunities for storage**
- + We recommend that the state look into pilot programs to gain experience in operating energy storage and understand the potential operational constraints.**
  - Potential use cases for pilots are:
    - PV + Storage as an alternative for new peakers
    - Storage stand-alone or PV + storage for T&D deferral
- + We recommend that the state and/or utilities develop initiatives to align customer incentives with system marginal costs, so that behind-the-meter PV and/or storage provides societal benefits and does not create a cost shift to other ratepayers.**



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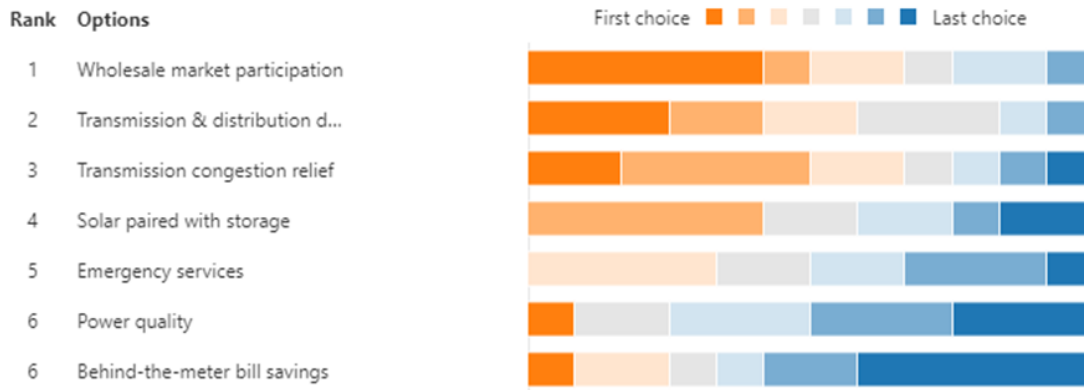
# Stakeholder Feedback



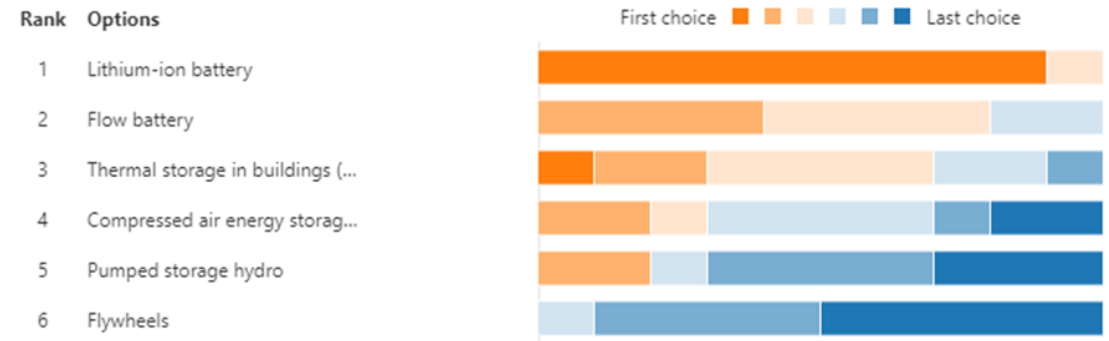
# Feedback Summary: Use Cases and Technology

- + Wholesale market participation and T&D deferral are the two most important use cases
- + Li-ion battery is most people's first choice and flow battery comes second
  - Thermal storage for residential water heating is also mentioned. This technology will be discussed qualitatively in the report
  - CAES case study is very site specific, thus suggested to not include CAES
  - The “storage like” Manitoba hydro run of the river system will also be discussed as an alternative for long-duration storage in the report

## Use Cases in Order of Priority



## Storage Technology in Order of Priority





# Feedback Summary: Study Limitations

## + Stakeholders have pointed out some important study limitations

- E3 thinks many of them are critical, thus E3 conducted additional sensitivities to consider those factors.

## + Feedback: *“Surprised that there is very little amount of curtailment even in the High Renewables Scenario”*

- This is due to two related reasons:
  - 1) Even though MN is moving toward deep decarbonization in the High Renewables Scenario, the neighboring states, including direct neighbors North Dakota and Iowa as well as more progressive Michigan and Illinois are assumed to continue today’s trends. Thus neighboring states have low renewable penetrations and can help integrate the renewables in MN
  - 2) The production simulation model only represents the transmission constraints between zones, and thus is not able to capture the transmission constraints within the zone. In the study, MN, North Dakota, and Iowa are modeled in the same zone.
- E3 recognizes and agrees with this limitation, thus a congestion sensitivity is included to assess the impact of locating in a congested zone today. A curtailment sensitivity is also tested to see the effect of 10% statewide curtailment by 2030.



# Feedback Summary: Study Limitations – cont.

- + ***“The model doesn’t include energy storage revenues in the real-time market and the sub-hourly ramping needs”***
  - E3 recognizes and agrees with these limitations. A sensitivity analysis is conducted to evaluate the theoretical additional revenues from participating in real-time markets. The values are added to all applicable use cases to reflect the potentials
  - Sub-hourly ramping needs and primary frequency response could add additional revenue stream in a near-term as shown in the PJM market a couple of years ago. This market might be saturated quickly because 1) the market size is relatively small, and 2) energy storage could face competition from dispatchable wind/solar and other flexible resources in the future
- + ***“The cost assumptions are too conservative”***
  - E3 added in a low battery cost sensitivity
- + ***“The assumptions in the Existing Trends Scenario are too conservative, suggest to change to MISO’s ‘Continuous Change’ scenario”***
  - E3 would love to update the assumptions to the “Continuous Change” scenario, but it is difficult to fit in the current timeline and budget
  - In addition, we don’t think this update will change our system marginal prices significantly given the prices stay similar even in the High Renewables Scenario. And we tested most of the use cases in both the Existing Trends and High MN Renewables scenarios

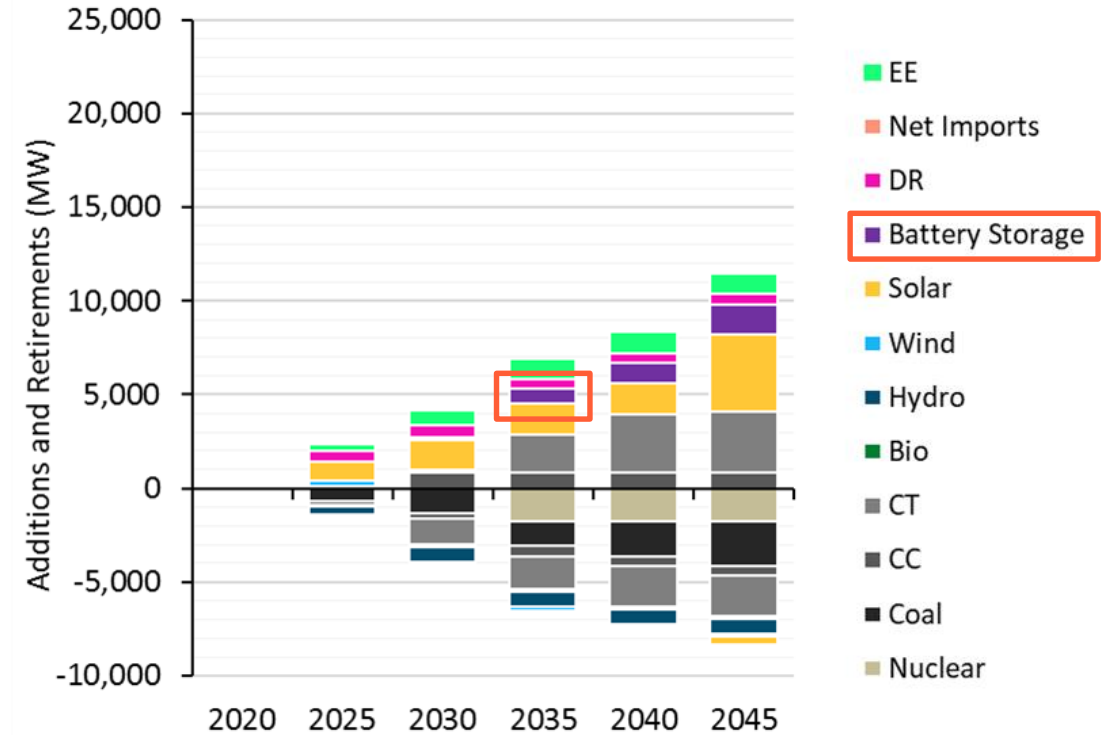




# Feedback Summary: Study Limitations – cont.

- + **Feedback:** *“The study needs to include statewide deployment scenarios and quantify sources of value in aggregate”*
  - E3 agrees that it is important to quantify the optimal level of storage adoption from the state’s perspective along with the other renewable build-out.
  - In fact, E3 did an initial capacity expansion modeling to assess the optimal build with the same policy goal as the High Renewable scenario. In this initial case, no energy storage is selected (through 2032).
  - This is also consistent with modeling done by E3 for Xcel in preparation for the recent IRP, which is from a capacity expansion model and shows battery installation starting from 2035.
  - **However, no selection of energy storage doesn’t mean that there is no cost-effective energy storage in the system. Energy storage can still be cost-effective in areas with congestion and T&D deferral opportunities**

Resource Additions and Retirements (MW) from E3 modeling for Xcel IRP





# Feedback Summary: Clarifications – Capacity Value

## + Capacity Value

- In the study, we quantify the capacity value as the value of avoiding new capacity build by shifting the load from peak hours to off-peak hours.

## + Value of peak demand reduction includes both the capacity value and the value of avoiding the high variable costs during peak hours, and that is captured as energy value in the study

- In the historical 2018 run we conducted, a 1 MW, 4-hour battery provides 785 kW peak reduction. And from energy value's perspective, it saves \$399/day for the peak day we looked at.

## + Peaker Alternative

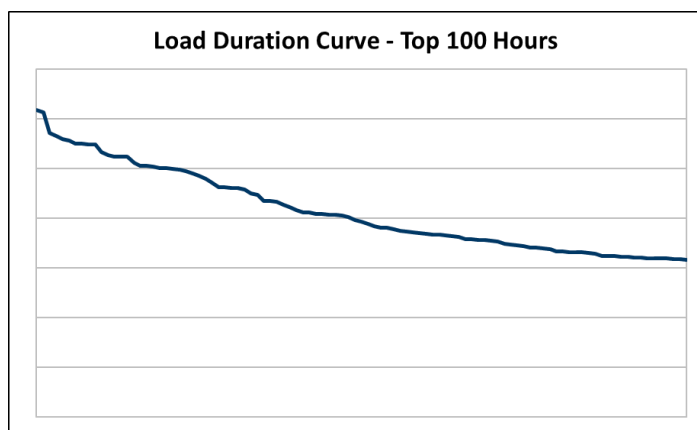
- Energy storage could potentially replace gas peaking units in certain situations when the economics work out. NREL study estimates around 1000 MW peaking potential for energy storage providing full peak demand reduction credit in 2020.
- We have discussed the energy storage serving future capacity additions and replacing existing peakers in the study:
  - Serving future capacity addition: this is the main value stream the study captures as energy storage is likely to be cheaper than gas peakers with promising price decline trajectories. We compare the net cost of a “brownfield” frame CT unit to the net cost of energy storage to determine the relative cost-effectiveness. And this analysis will be further discussed in the results section
  - Replacing existing peakers: we also did a high-level screening of the existing peakers to understand the feasibilities and potentials for MN. This use case could be valuable for reducing NOx and GHG emissions in urban dense areas but might not be cost-effective in the near term without including societal benefits. There are limitations of this simplified approach.
- Detailed studies are needed for each potential peaker alternative to examine and address reliability concerns, which is not part of the scope of this study.



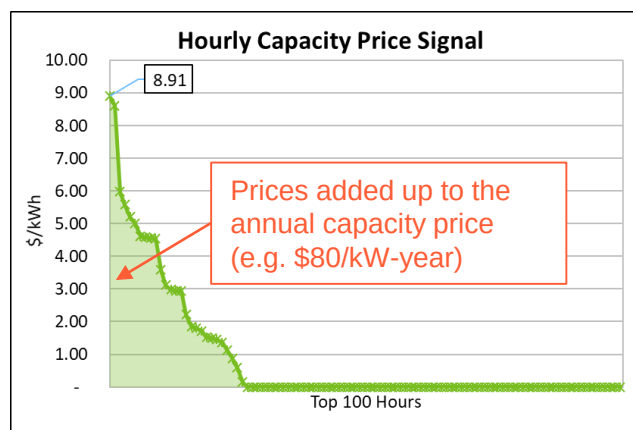
# Capacity Value Accreditation in RESTORE

- + **RESTORE calculates the capacity values provided by energy storage and PV based on how much energy it can provide during system peak hours**
  - Annual capacity price (e.g. \$80/kW-year in 2025) is allocated to system peak hours proportionally
  - Storage is then dispatched against the allocated capacity prices along with other available benefits. The final capacity values provided are based on how much energy storage can provide during peak hours and how “peaky” those peak hours are
- + **This method assumes the system operator has perfect knowledge and total control of the storage system, and thus renders a theoretical maximum total value that can be provided by energy storage**

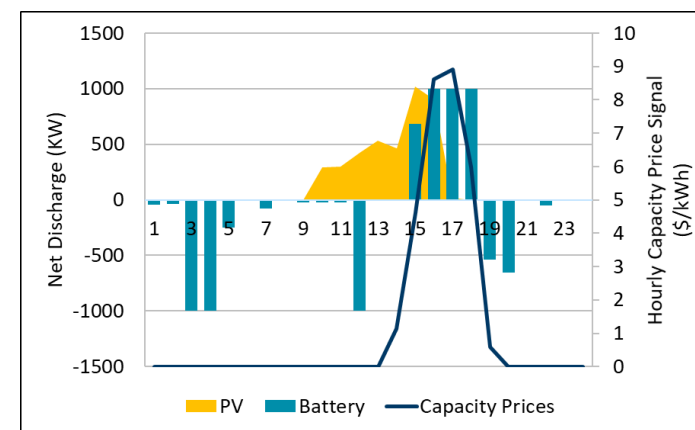
## Get System Load Duration Curve



## Convert Annual Capacity Price to Hourly Signal



## Calculate Capacity Contribution based on generation during peak hours





# Feedback Summary - Others

- + Thank you for submitting feedback!
- + We have a more in-depth stakeholder feedback summary in the appendix. We will also include a detailed summary and discussion in the report
- + As stakeholders suggested, we put together study caveats and a list of benefits quantified in the appendix



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# Updated Results



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# AURORA Price Results



# AURORA Scenarios

## + Three scenarios to capture a range of possibilities for MN:

1. Existing Trends
2. High Natural Gas Price
3. High Minnesota Renewables

## + Existing Trends scenario uses capacity additions from MISO MTEP18 Limited Change Scenario

- 750 MW wind, 400 MW solar, 1,200 MW CCGT and 3,800 MW CT added linearly by 2032

Generation mix stays largely the same in Existing Trends and High NG Price scenarios

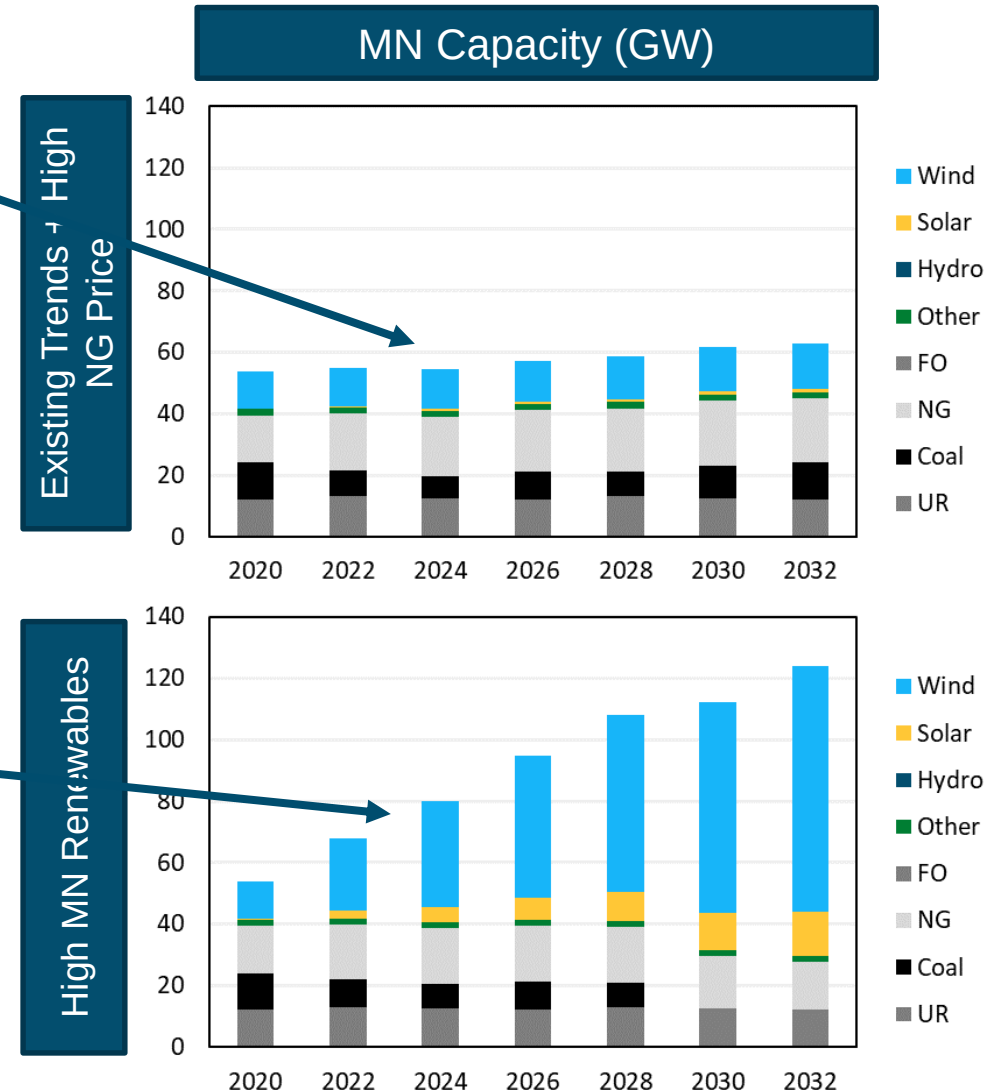
## + High MN Renewables scenario features over 75% of load met by renewables by 2032

- All nuclear is relicensed
- Gas generation < 12% of load
- All coal is retired

In High MN Renewables scenario, wind and solar ramp up quickly, and coal is retired

## + High NG price scenario uses forecast from Xcel's 2018 IRP 'High Gas' assumptions

## + Neighboring states are assumed to follow their existing trends



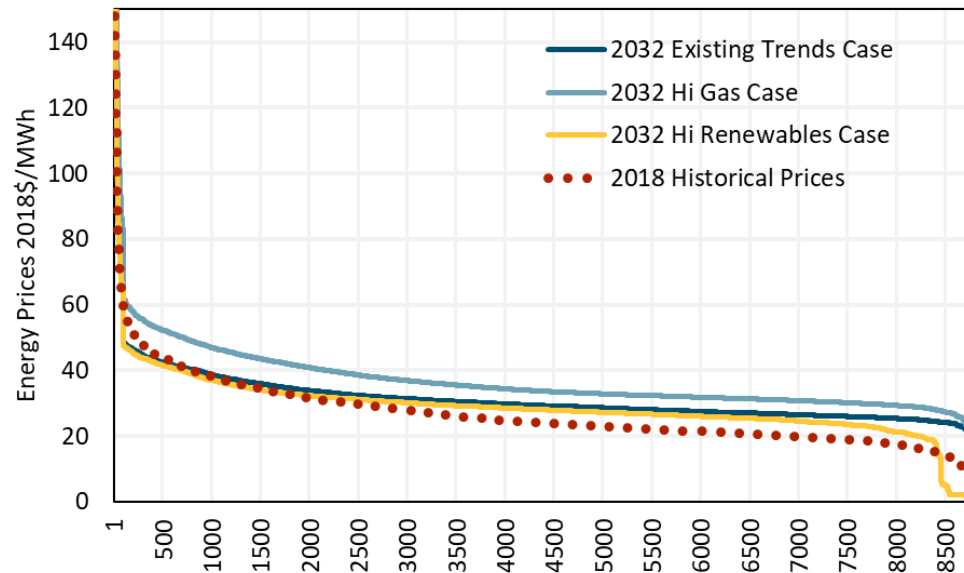




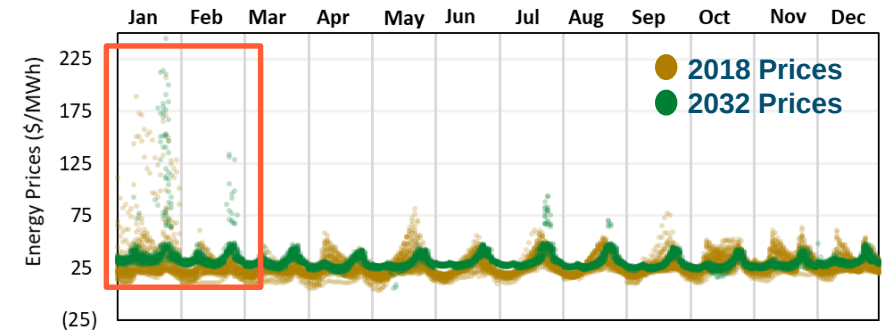
# AURORA Energy Prices

- + In the High NG Scenario, increased gas prices push marginal energy prices upwards
- + In the High Renewables Scenario,
  - Increased renewable capacity pushes some gas units off the supply stack
  - Low priced hours are prevalent in spring and fall, coinciding with strong RE generation and lower load
  - Low average curtailment in the system due to 1) regional coordination that helps renewable integration and 2) no with-in zone transmission constraints are assumed

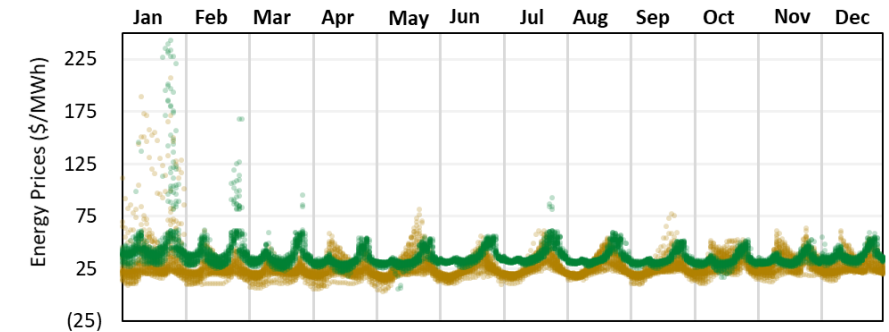
Energy Prices (2018 \$/MWh)



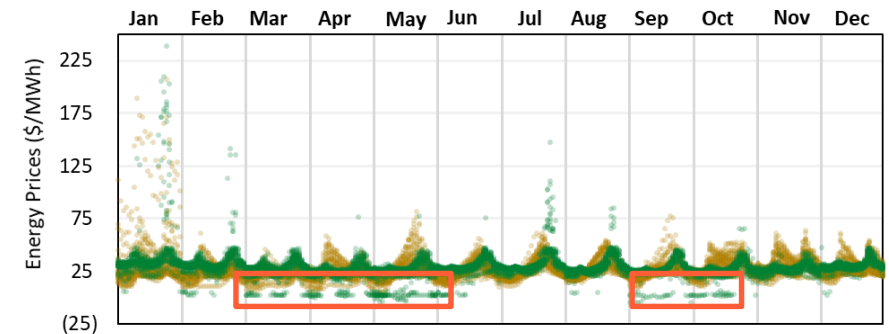
2032 Energy Prices (2018\$ / MWh)



Existing Trends



High Gas Price

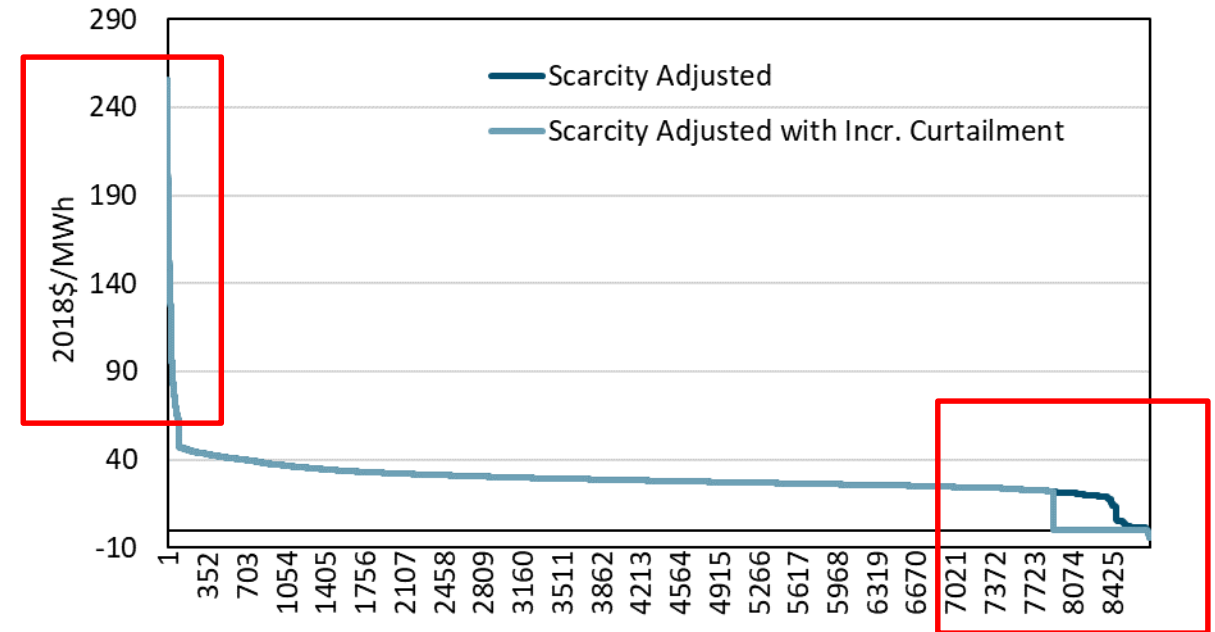


High MN  
Renewables



# Energy Price Post-Processing

- + **Prices are post-processed to capture volatility in real markets**
  - AURORA's perfect foresight as well as network simplifications may not capture volatility and market behavior, resulting in flatter prices than in reality
- + **Scarcity adder is applied to the top 100 hours in each year based on a ratio calculated from real 2018 prices**
- + **A sensitivity is conducted to study the impacts when frequency of renewables on the margin increases to 10% average curtailment**
  - Manually adjusted prices so that those in the lowest 10<sup>th</sup> percentile are set to  $\leq 0$
  - Negatively priced hours are retained while positive prices are set to 0

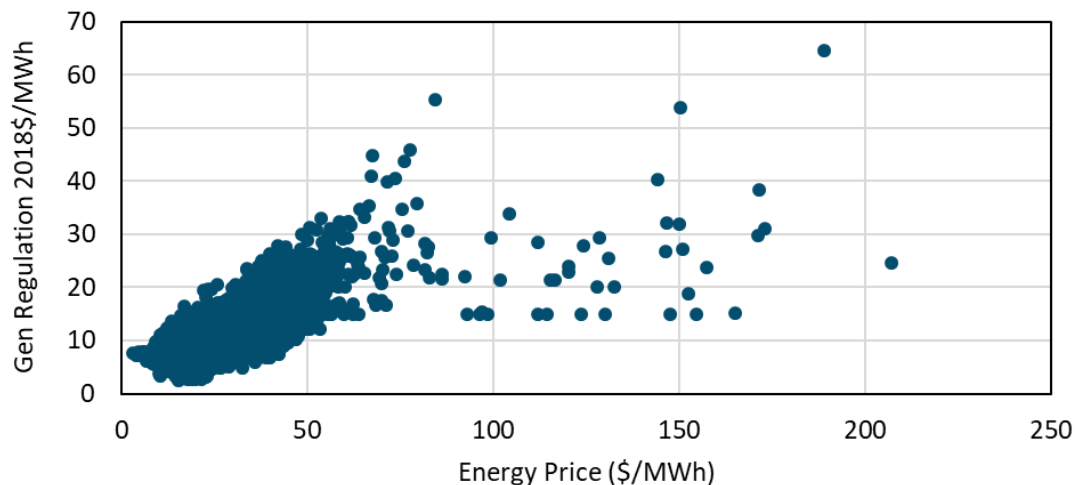




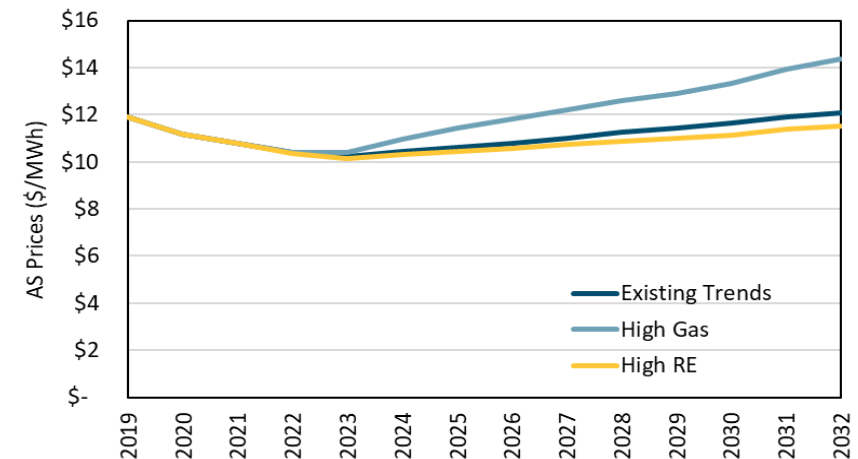
# Ancillary Services Prices

- + Historically, energy and AS prices are strongly correlated, and this correlation is assumed to hold into the future, especially when thermal units are predominantly on the margin.
- + MN System is long on capacity in the near-term until coal retirements in the middle of the 2020s
- + E3 estimated the future regulation prices based on the historical relationship between energy prices and AS prices

## Historical Regulation Prices (\$/MWh)



## Forecasted Regulation Prices (\$/MWh)





# Capacity Prices

- + **Capacity value is one of the important value streams that energy storage can provide to the market.**
  - Capacity value alone sometimes might be able to make energy storage cost-effective in areas with capacity needs that are difficult to be fulfilled by other alternatives (e.g. due to transmission and land use constraints)
- + **Utilities procure capacity through bilateral contracts and MISO's resource adequacy program.**
  - Currently the prices in the resource adequacy program are relatively low due to the overall excess capacity in MISO North
- + **With many upcoming coal retirements planned, MN is projected to have a capacity need in the mid-2020s, which could result in higher capacity prices in the future**
  - Once a capacity shortage is realized, capacity prices are assumed to be set by the payments needed to allow for the building of a new Combustion Turbine (CT)– this amount is known as the “Net Cost of New Entry” or “Net CONE”
  - Storage could eventually be the marginal capacity resource

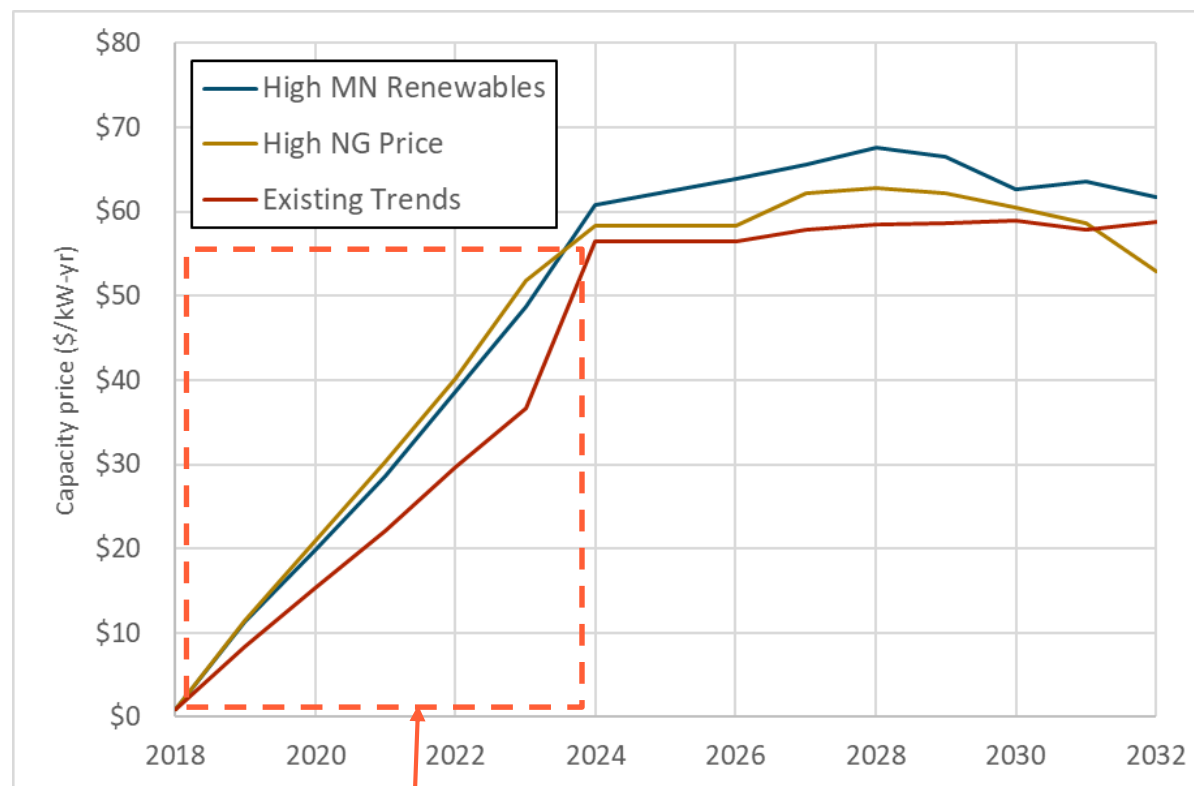
| Year      | MISO Zone 1 Capacity Prices<br>(\$/kW-yr) |
|-----------|-------------------------------------------|
| 2014-2015 | \$1.20                                    |
| 2015-2016 | \$1.27                                    |
| 2016-2017 | \$7.20                                    |
| 2017-2018 | \$0.55                                    |
| 2018-2019 | \$0.37                                    |
| 2019-2020 | \$1.09                                    |



# Capacity Price Forecast

- + **Net CONE is calculated by subtracting the estimated energy and AS revenues of a brownfield frame CT from its resource cost**
  - Resource costs for brownfield frame CT adopted from Xcel's 2018 IRP
  - Energy and AS revenues are estimated with AURORA results
- + **Historical prices are linearly increased to meet projected CT net CONE in the resource balance year (2024)**

## Capacity Prices ( \$/kW-yr) - Existing Trends Scenario



Period with excess capacity in MISO North



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# Cost-Effectiveness Results



# Cases Summary

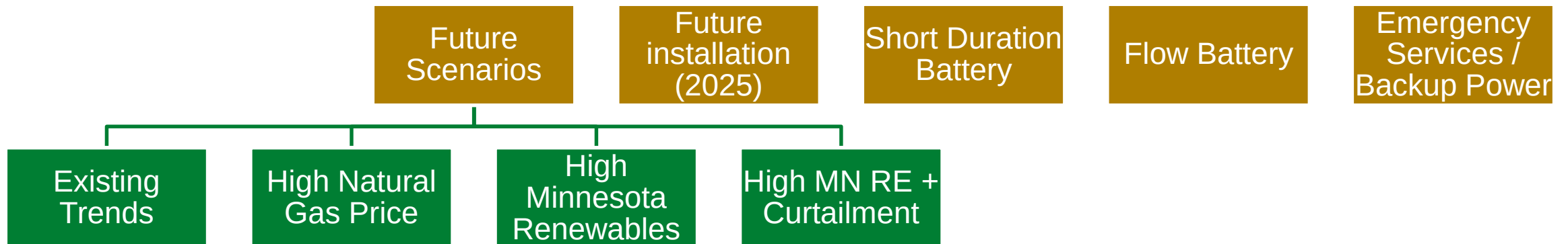
Core Use Cases

Benefit Streams →

| Core Use Cases                  | Wholesale        |                             |                    | Transmission and Distribution  |                                      |                    | BTM          |
|---------------------------------|------------------|-----------------------------|--------------------|--------------------------------|--------------------------------------|--------------------|--------------|
|                                 | Energy arbitrage | Avoided generation capacity | Ancillary services | Transmission congestion relief | Transmission & Distribution deferral | Emergency services | Bill savings |
| Wholesale standard <sup>1</sup> | ✓                | ✓                           | ✓                  |                                |                                      |                    |              |
| Wholesale congestion relief     | ✓                | ✓                           | ✓                  | ✓                              |                                      |                    |              |
| Distribution deferral           | ✓                | ✓                           | ✓                  |                                | ✓                                    |                    |              |
| BTM PV paired with storage      | ?                | ?                           |                    |                                |                                      |                    | ✓            |
| FTM PV paired with storage      | ✓                | ✓                           | ✓                  |                                |                                      |                    |              |

Not a societal benefit unless retail rates are aligned with system values

Sensitivities





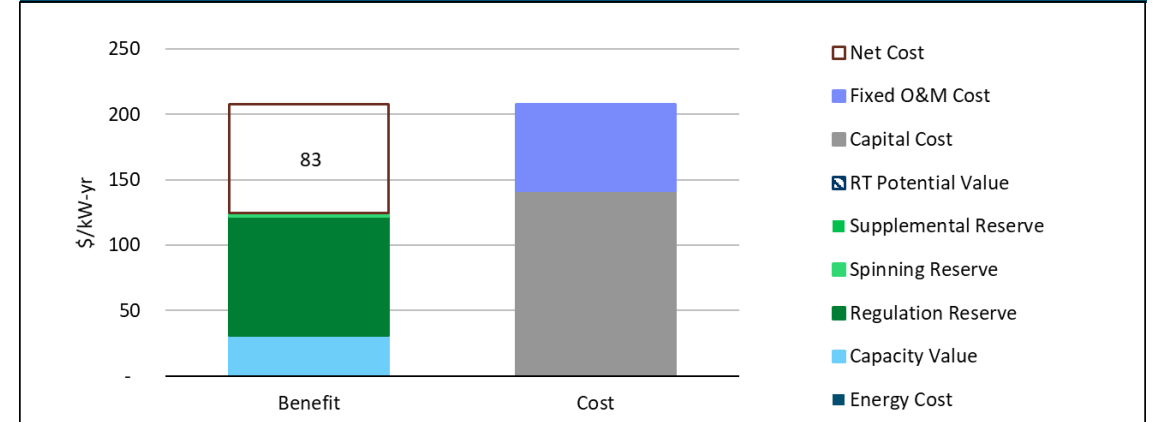


# Wholesale Base Case: Overview

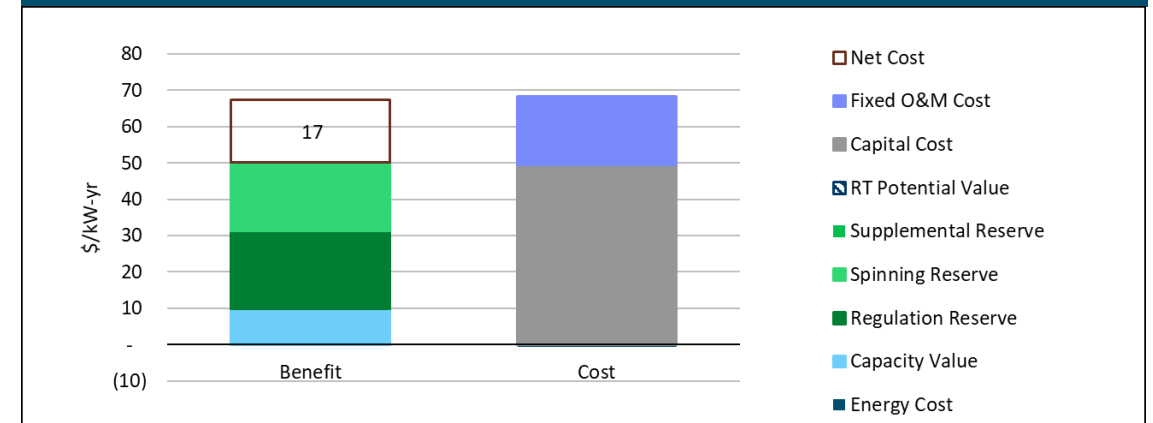
| Case Characteristics | Value                                         |
|----------------------|-----------------------------------------------|
| Installation Year    | 2020                                          |
| Battery Sizes        | 1 MW, 4-hour duration & 1 MW, 1-hour duration |

- + Both 1-hour and 4-hour Li-ion batteries are not yet cost-effective in 2020 if the only revenue streams are from participating in energy, capacity, and regulation markets
  - Breakeven cost for this use case: \$160/kWh for 4-hour (happens around 2025 in NREL “low” price trajectory); \$280/kWh for 1-hour
  - 1-hour battery is closer to cost-effectiveness than the 4-hour battery
  - Most of the revenues come from regulation reserves: the model decide to forgo the energy arbitrage opportunity because the regulation market is more lucrative
  - Due to battery degradation concerns, our model imposes an annual cycle limit of 365 cycles to comply with common warranty requirements.
    - If cycling limit is removed, the net cost reduces to \$7/kW-year, meaning storage could reach cost-effectiveness sooner than 2025

## Total Resource Cost Test for a 4-hour Battery



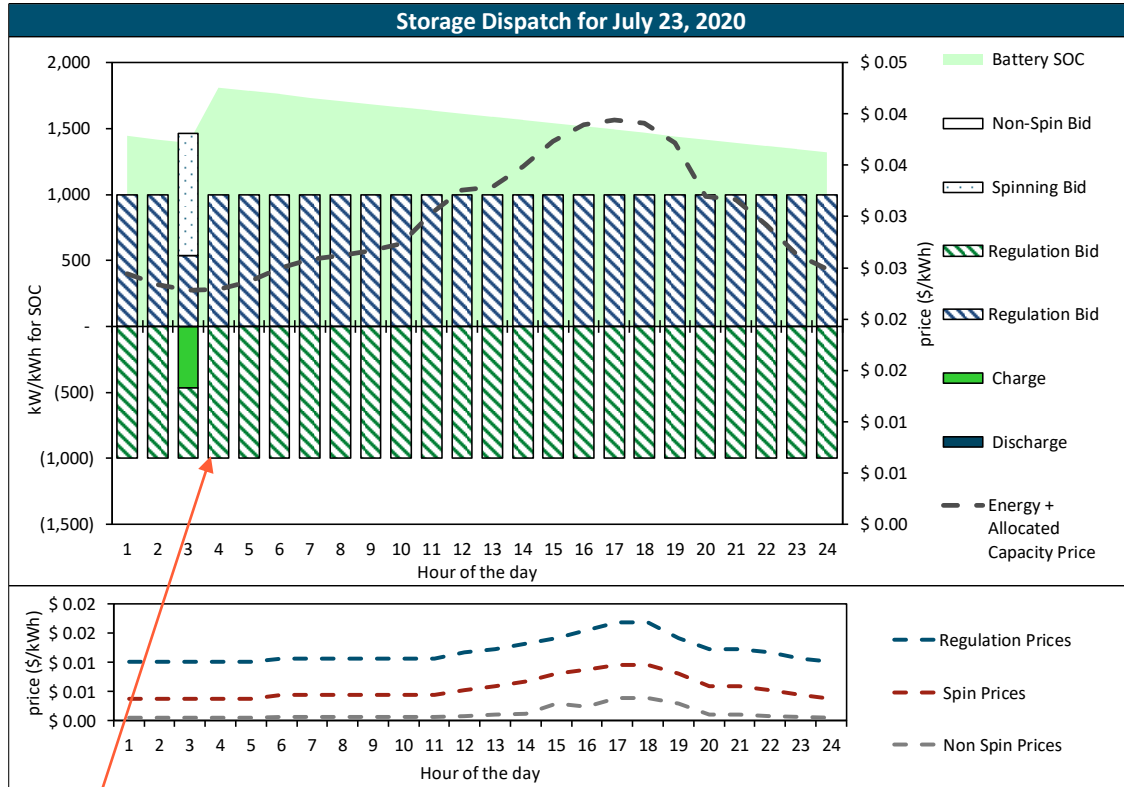
## Total Resource Cost Test for a 1-hour Battery





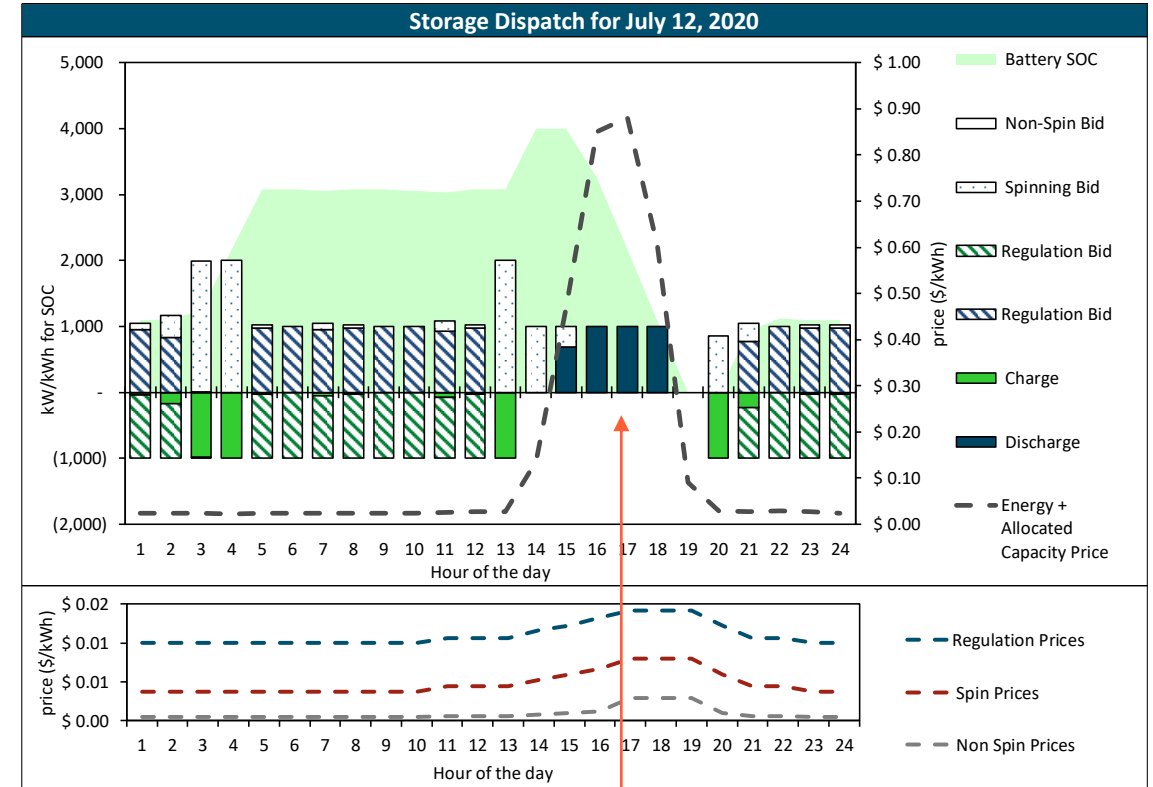
# Wholesale Base Case: Operations

## Storage Dispatch for a Typical Day



Participating in the regulation market during typical days due to the lack of energy arbitrage opportunities

## Storage Dispatch for a Peak Day



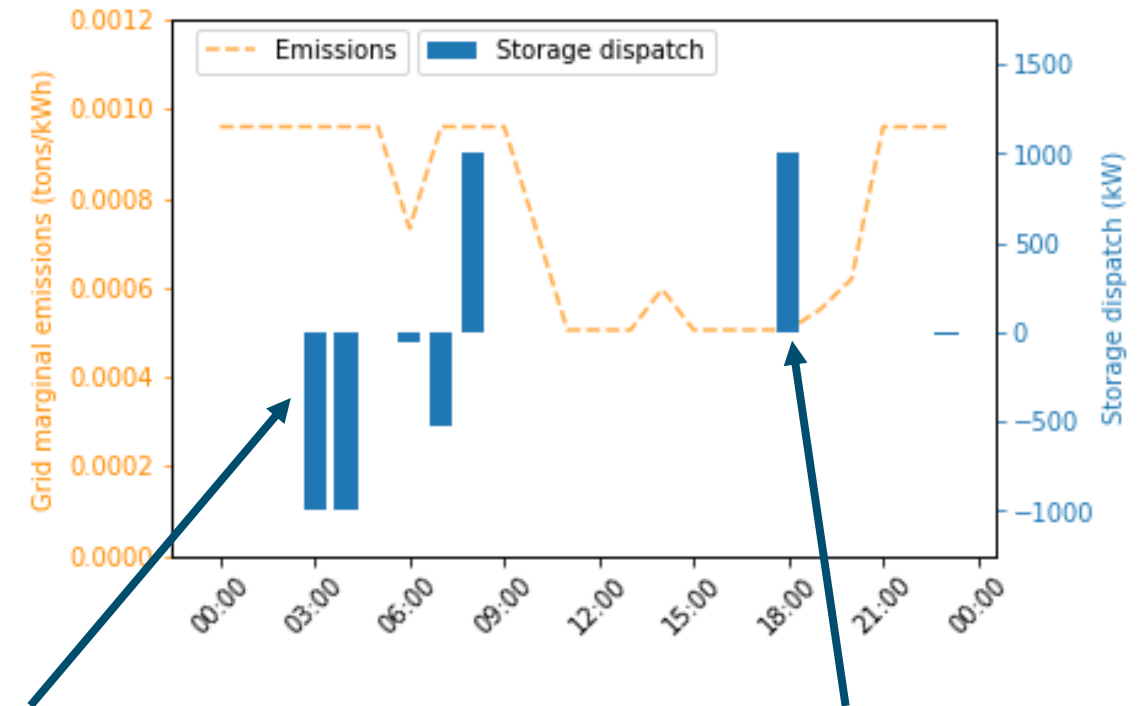
Provide peak capacity during system peak hours



# Wholesale Base Case: Emissions

- + To get an idea of the potential effect on emissions, we also ran a battery simulation using 2018 historical real-time prices, and used MISO “real time fuel on the margin” data to estimate grid emissions resulting from storage
- + On the current grid, storage generally charges from coal at night, and discharges on-peak to displace some coal/gas
- + In our historical run, a 1 MW storage installation increased grid emissions by about 168 tons over the course of a year (the equivalent of about 37 passenger vehicles’ worth of yearly emissions)
- + Until the grid changes composition to the point where storage can charge from mostly renewables on the margin, these dynamics will continue
- + In the final report, we will include the effect on emissions in 2030 under the high MN renewables scenario (analysis still in progress for this)

Storage indirect electric grid emissions: July 17, 2018



Storage generally charges at night from off-peak coal, causing some (high) emissions...

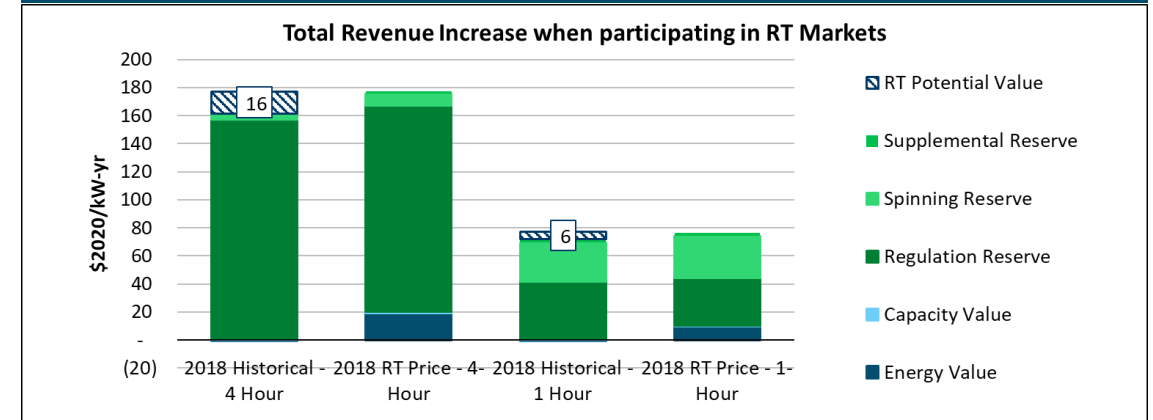
... and discharges on-peak during the day, frequently displacing lower-emitting natural gas



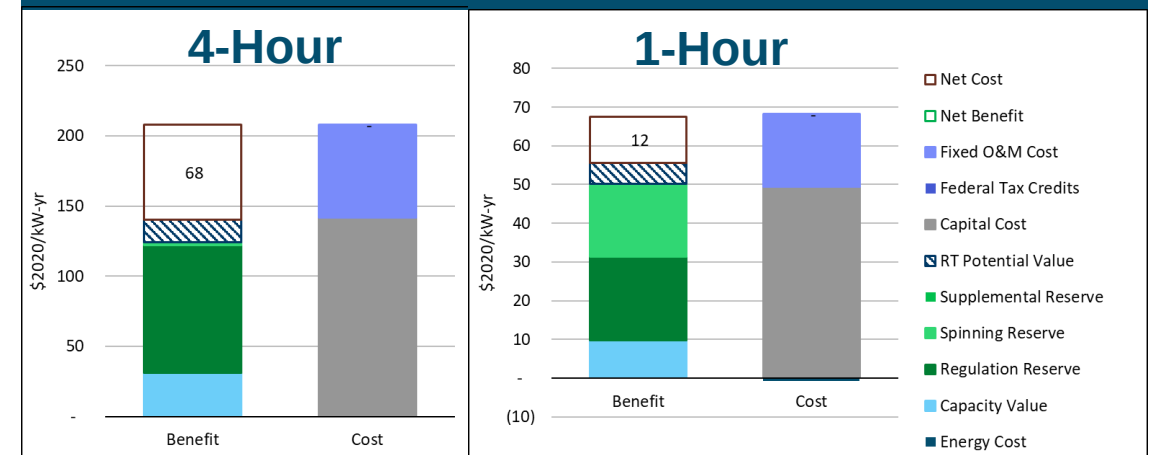
# Wholesale Base Case: Real-Time Market Opportunity

- + Energy prices are forecasted as day-ahead hourly prices in AURORA due to the complexity of simulating real-time fluctuations for the future
- + To estimate how much revenue could increase from participating in the real-time market, we compared simulations using historical data, for storage participating in the 2018 day-ahead and real-time markets
- + The ability to participate in real-time markets enabled more lucrative energy arbitrage opportunities
  - results in a **\$16/kW-yr benefit** for 4-hour batteries and **\$6/kW-yr benefit** for 1-hour batteries in total revenues
  - The additional revenues are added in the analysis to represent the additional potential from participating in the real-time market

## Additional Real-Time Revenues Estimated for 2018



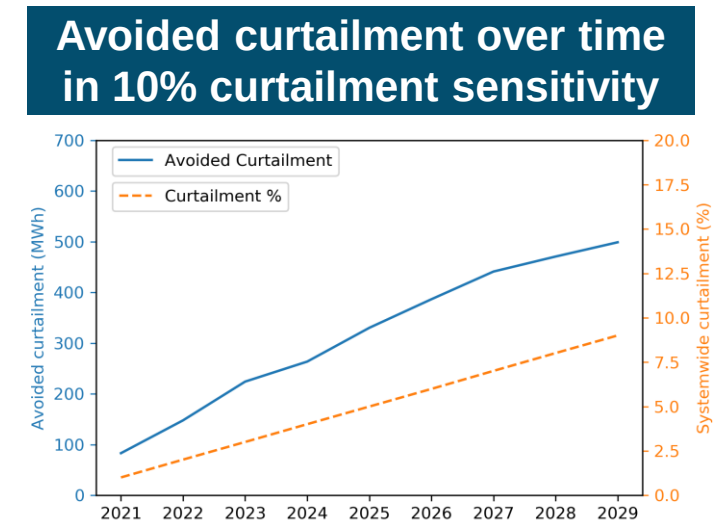
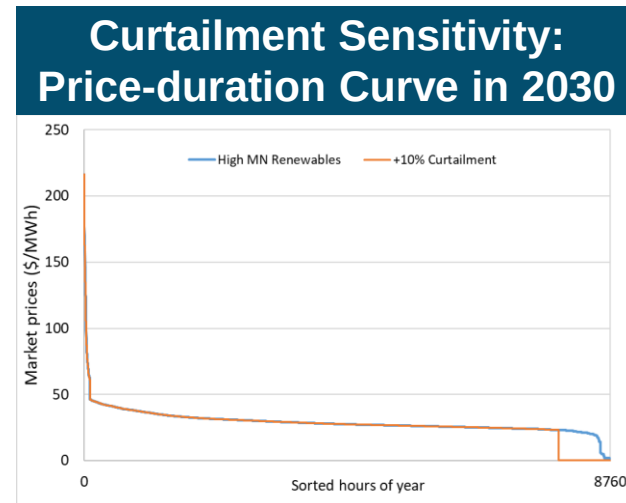
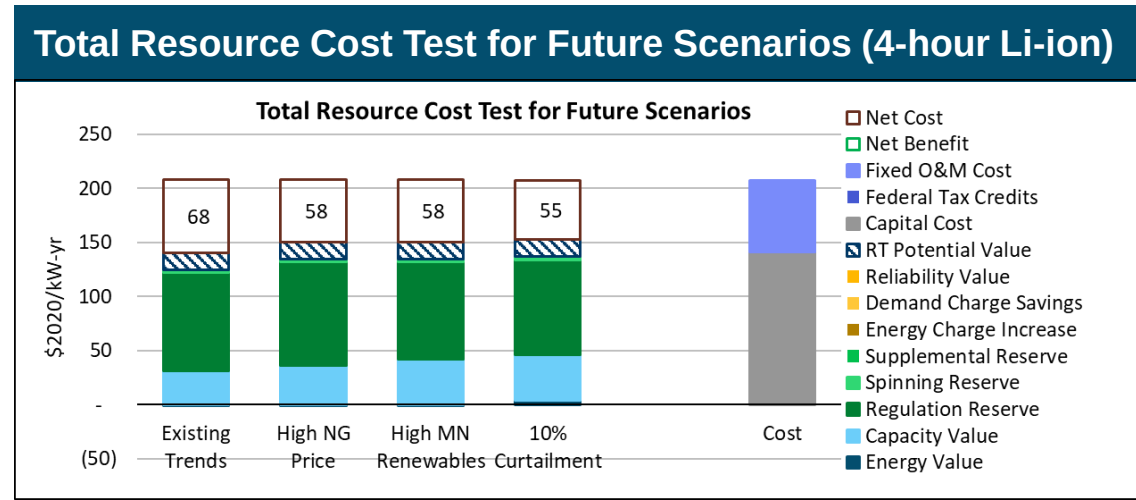
## TRC with the additional RT market potential





# Sensitivities: Price Scenarios

- + **Scenario results don't differ significantly because:**
  - North Dakota and Iowa remain at low renewable penetration levels and thus can help MN in renewable integration
  - AURORA doesn't model transmission constraints within MN, North Dakota, and Iowa. Some constrained areas might experience higher curtailment.
- + **1-hour storage is close to being cost-effective in the 10% curtailment scenario with \$8/kW-year net cost**
- + **A sensitivity analysis is conducted to show the impact of curtailment in constrained area:**
  - 10% curtailment is assumed for the High MN RE Case

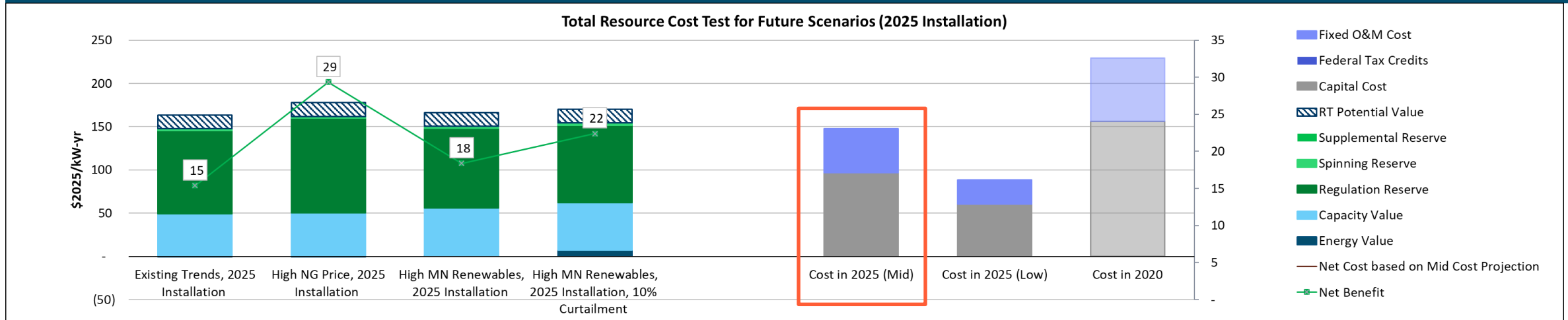




# Sensitivities: 2025 Installation

- + 1 MW, 4-hour storage is cost-effective when installed in 2025 and it is mostly driven by capital cost declines
  - Net benefits range from \$15 to \$29/kW-year based on the mid project decline projection. In a more aggressive price decline assumption (Low), the net benefits are even higher
- + This result also means that a Li-ion battery is more cost-effective than a “brownfield” gas peaker in 2025. We will elaborate more in the next slides

## Total Resource Cost Test for Future Scenarios (2025 Installation)

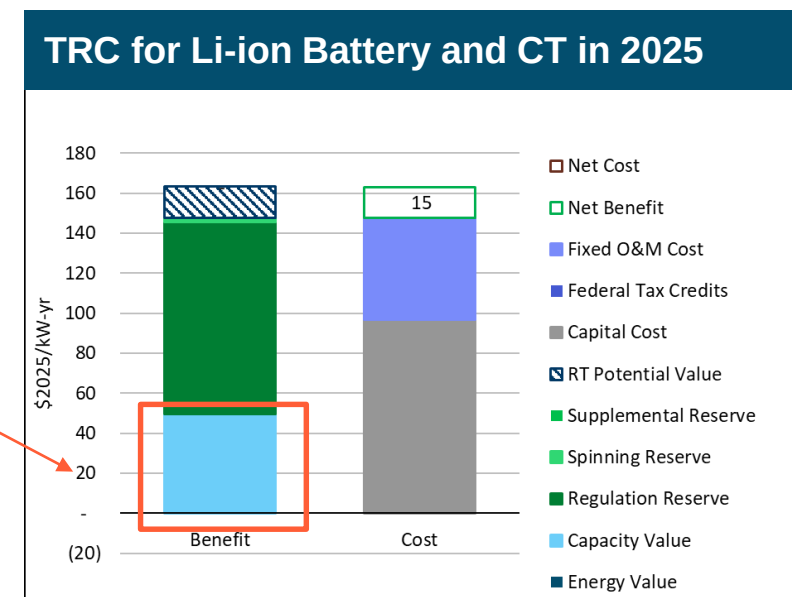
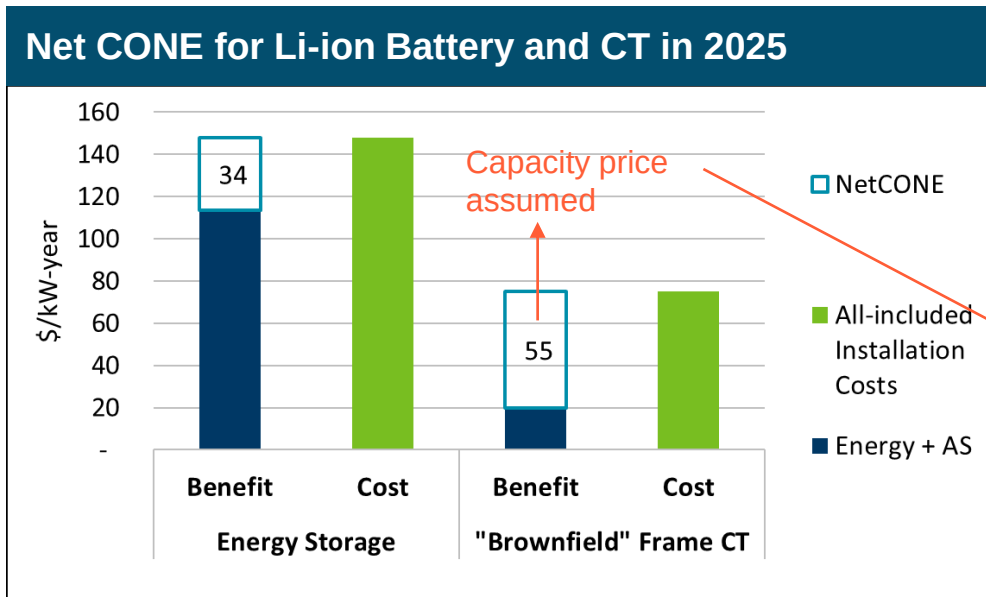






# Comparing to a “Brownfield” Frame CT

- + The capacity value is calculated based on the availability during peak hours. But there are usually more contractual agreements and constraints in real life
  - E.g. MISO: 4-hour storage can get full capacity credit as long as it bids in for a 4-hour period overlapping with the projected peak, into the day-ahead market
  - And because of these constraints, the overall values provided by the battery might be lower than the optimal value shown here.
- + Comparing energy storage to a gas peaker in 2025:

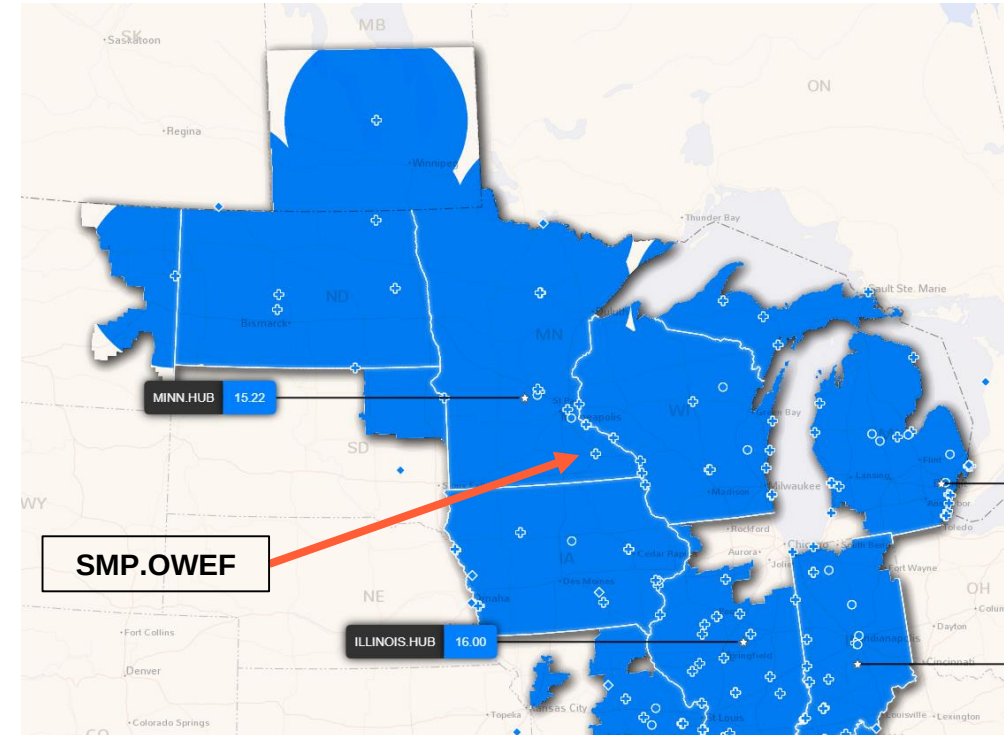
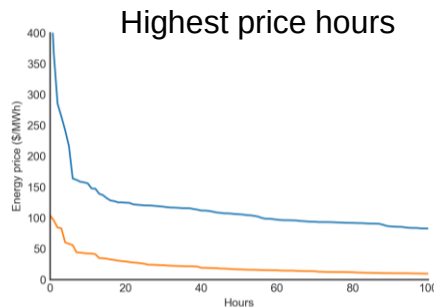
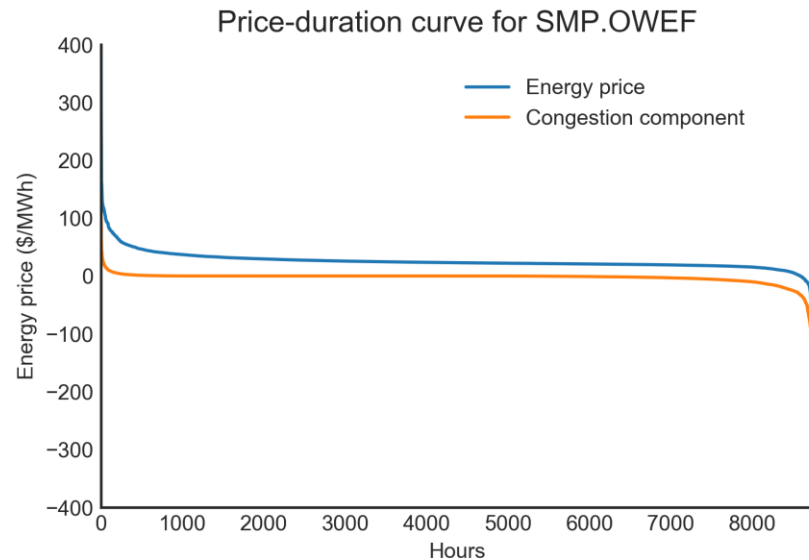






# Sensitivities: Congestion Reduction

- + Modeled the base case 4-hr storage system located at a congested node in SE MN (SMP.OWEF)
  - Near the congested Wabaco-Rochester 161 kV transmission line mentioned in the MTEP 18 Market Congestion Planning Study



Many negative-priced hours due to surplus wind



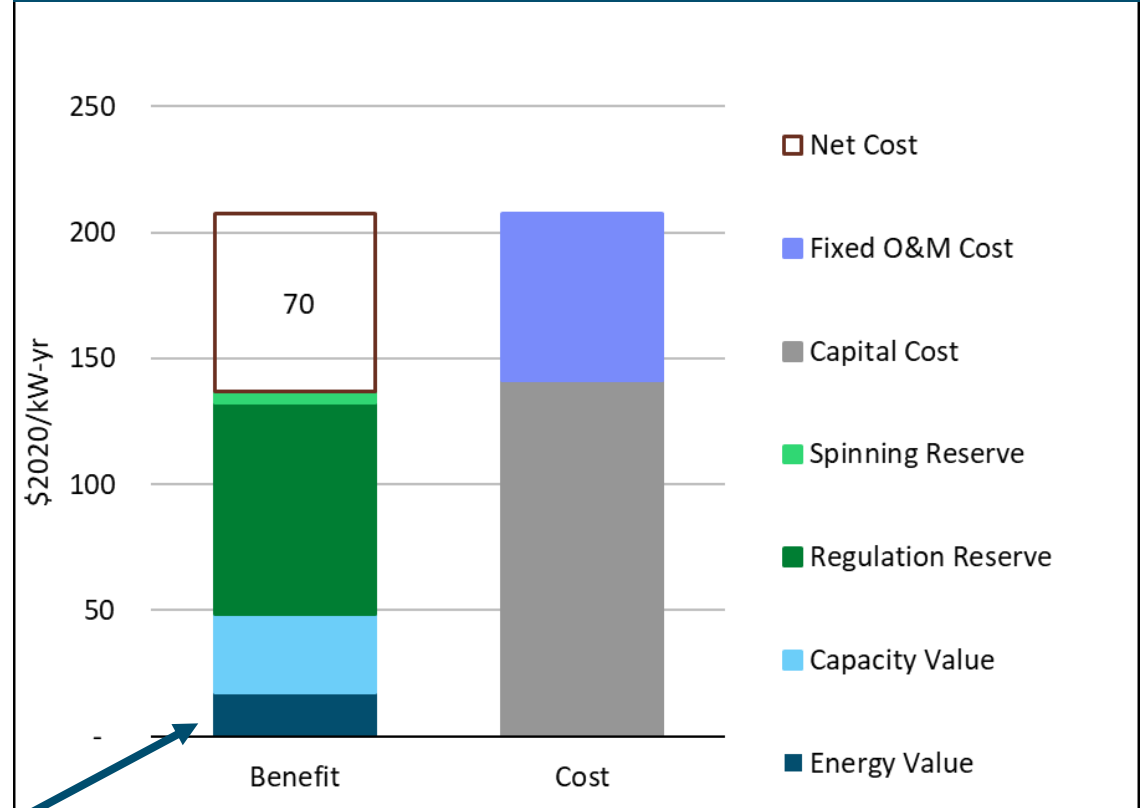
# Sensitivities: Congestion Reduction

## + 4-Hour duration storage is closer to cost effectiveness if located in a congested zone

- \$70/kW-yr net cost instead of \$83/kW-yr for the base case
- This type of use case may represent a situation increasingly common in the future if transmission expansion is limited, where many negative-priced hours in the energy market allow storage to arbitrage and make money

Storage arbitrages more than other cases due to many negative-priced hours

Total Resource Cost Test for Storage Located in Congested zone





# Sensitivities: Distribution Deferral

## + Energy storage can serve as a non-wires alternative for local capacity projects if it can reliably reduce the local peak constraints

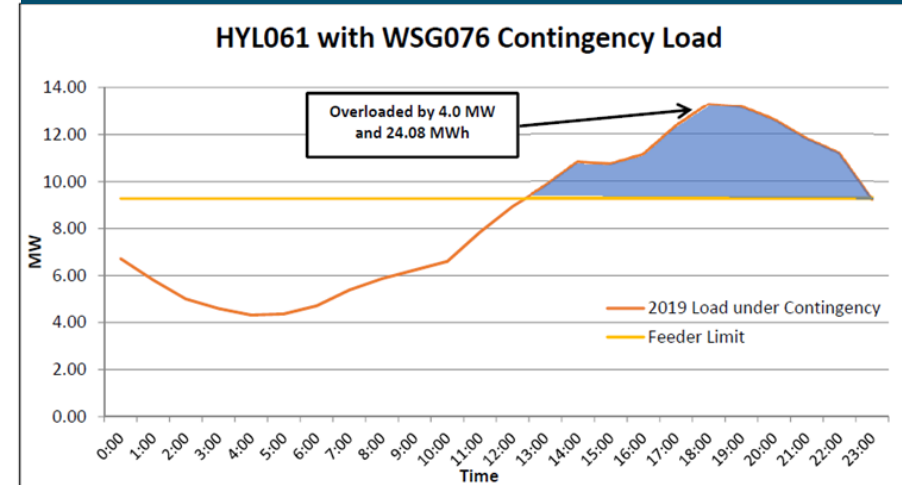
- Candidate deferral projects need to be triggered by load growth; projects with small load growth and expensive traditional solutions due to space constraints or other reasons are the best candidate for non-wires alternatives

## + Used the Viking NWA analysis from Xcel's IDP filing as an example to demonstrate the distribution deferral potential

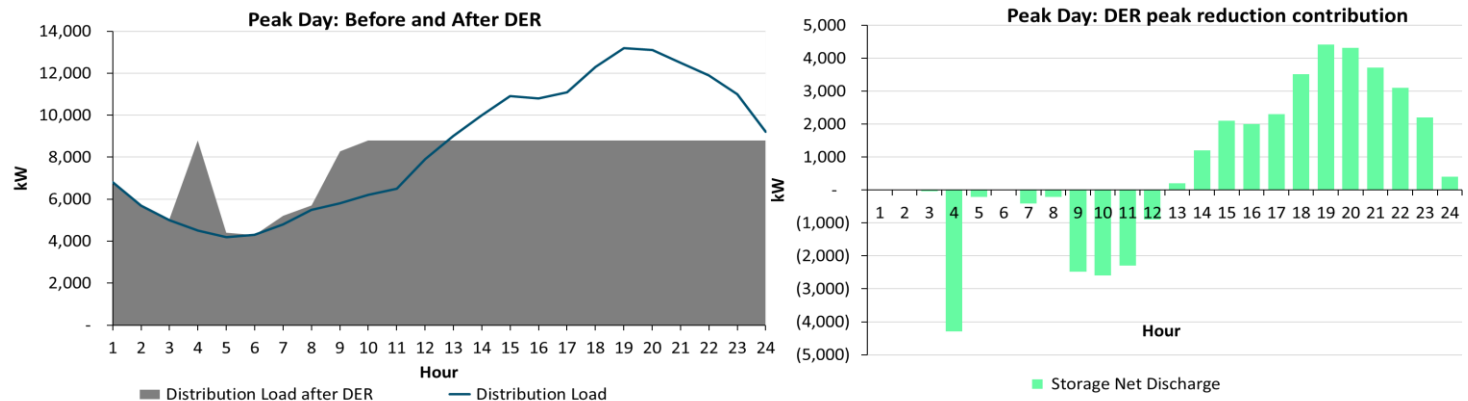
- Energy storage is required to discharge to address the deficiency during identified hours, but it is free to participate in markets the rest of the hours

An **8MW / 32 MWh battery** is selected to address the deficiency

### Deficiency Identified in Xcel's IDP



### Peak Day Shapes

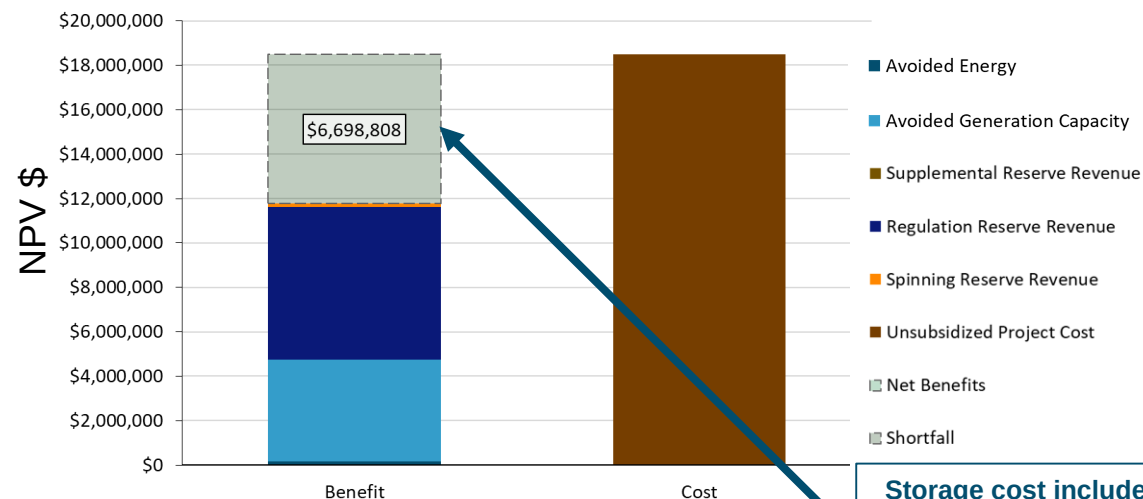




# Sensitivities: Distribution Deferral - Value

- + The 8MW / 32 MW battery is able to defer the upgrades for 10 years
- + When considering non-wires alternatives, we suggest to compare the cost of traditional solutions to the “net cost” of energy storage considering the potential values it can provide outside of the local peak days
  - In the Viking feeder example, compared to the total cost of \$14,450,000, the net cost at \$6,698,808 could be used instead
- + There are certainly more considerations that are required before storage can serve as a non-wires alternative. But we think this is a high-value application for energy storage in the short term and should be explored more
  - For example, how to ensure the battery availability for the local peak while it is participating in the markets all the other days, etc.
- + Transmission deferral has a similar concept but usually requires a longer lead time and deferral time. The study didn’t explicit model a transmission deferral case since the values vary significantly based on projects.
  - The transmission deferral values can be estimated within the same framework of distribution deferral. This study aims to provide an evaluation framework for distribution and transmission deferral

Total Resource Cost: Distribution upgrade deferral



Xcel IDP: Viking feeder NWA

| Capacity Risk                                              | Overload Magnitude |              | Optimal DER Solution |                       | Estimated Cost |
|------------------------------------------------------------|--------------------|--------------|----------------------|-----------------------|----------------|
|                                                            | MW Overload        | MWh Overload | Solar PV (MW)        | Battery Storage (MWh) |                |
| EDP073 N-0 overload, 107%                                  | 0.71               | 0.99         | 0                    | 0.99                  | \$59,000       |
| N-1 overload on WSG065 for loss of EDP073, 2.3 MVA at risk | 2.04               | 11.50        | 0                    | 11.50                 | \$6,900,000    |
| HYL061 N-0 overload, 101%                                  | 0.04               | 0.04         | 0                    | 0.04                  | \$20,000       |
| N-1 overload on HYL061 for loss of WSG076, 4.2 MVA at risk | 4.00               | 24.08        | 0                    | 24.08                 | \$14,450,000   |
| Total                                                      |                    |              | 0                    | 36.61                 | \$21,971,000   |



# Sensitivities: Storage paired with PV

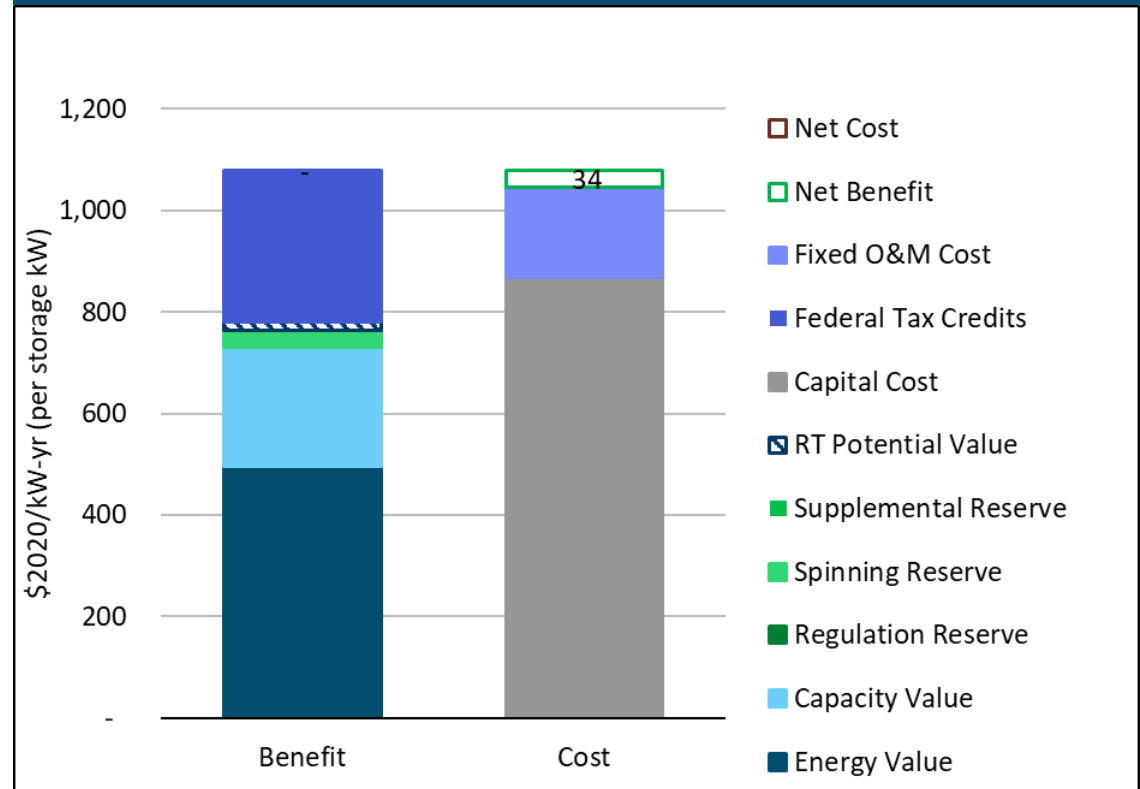
| Case Characteristics | Value                 |
|----------------------|-----------------------|
| Installation Year    | 2020                  |
| Battery Size         | 1 MW, 2-hour duration |
| PV Size              | 8 MW                  |

## + Cost-effective in 2020, mainly due to the ITC

- Larger and longer-duration storage might not be cost-effective

## + Assumed \$79/kW-yr solar after ITC

TRC for PV + Storage

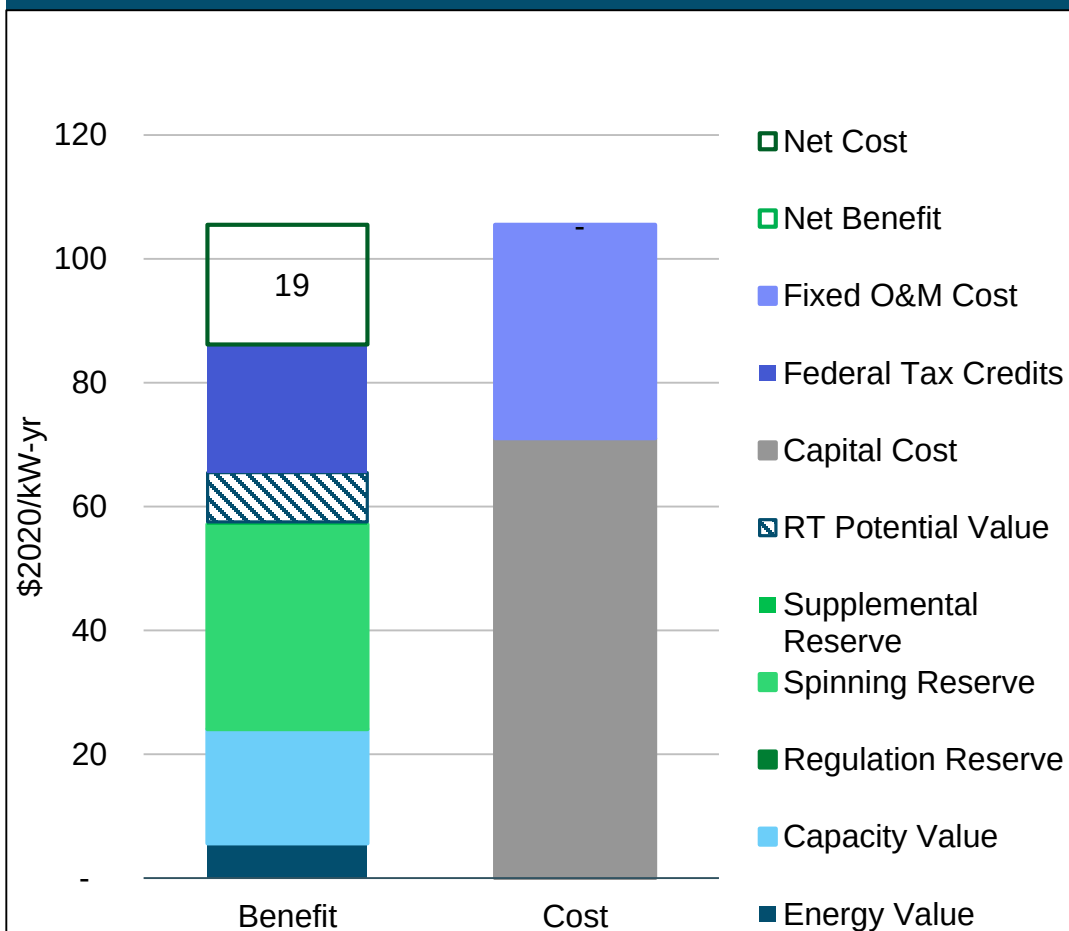




# Sensitivities: Storage paired with PV

- + Looking at the benefits and costs for storage in the paired system, energy storage is not cost-effective on its own
- + Storage gets ITC benefits when pairing with solar but also loses opportunities to provide regulation services and to charge from the grid
- + Storage can also increase the capacity value of the paired PV. This value is not allocated to energy storage in the TRC display here
  - But included in the total system TRC

TRC for Energy Storage Only





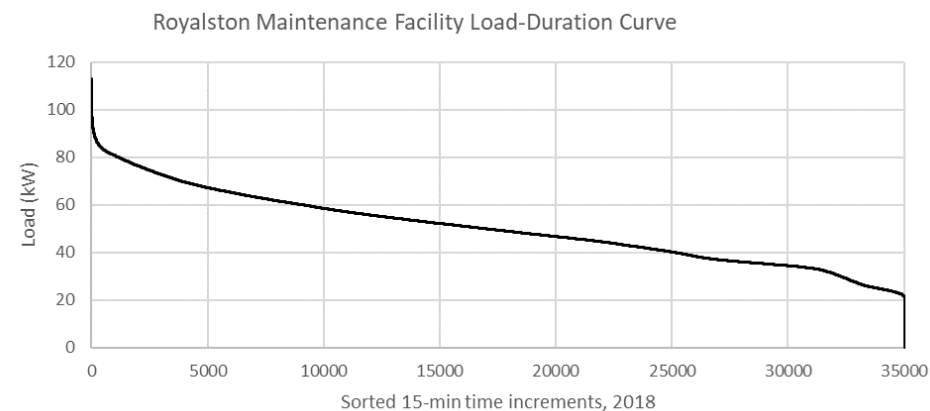
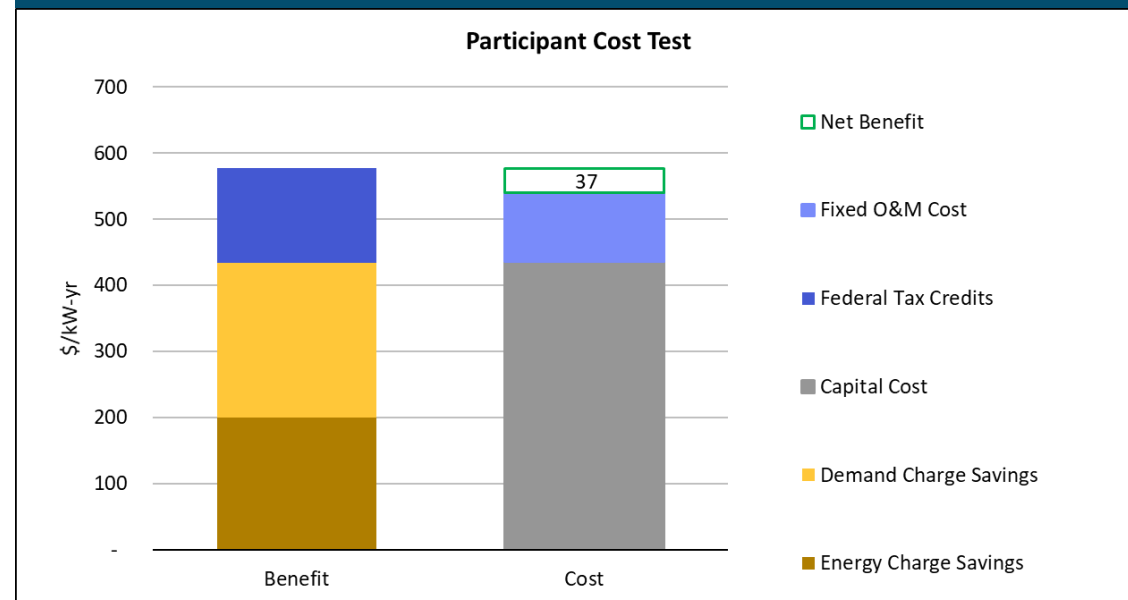


# Behind-the-meter Bill Savings Case

| Case Characteristics | Value                                         |
|----------------------|-----------------------------------------------|
| Installation Year    | 2020                                          |
| Battery Size         | 10 kW, 1-hour duration                        |
| PV Size              | 20 kW                                         |
| Rates                | Xcel A15 (\$14.79 on-peak demand charge)      |
| Load Shape           | Royalston maintenance facility in Minneapolis |

- + **PV + Storage is cost-effective from participant's perspective**
- + **Battery and PV are sized to not incur net export to the grid**
  - Note that this facility already has solar, but we modeled a theoretical new installation to be more widely representative of BTM customers looking to install solar + storage.
- + **Customers with a higher demand charge are likely to be even more cost-effective**

## Participant Cost Test for PV + Storage



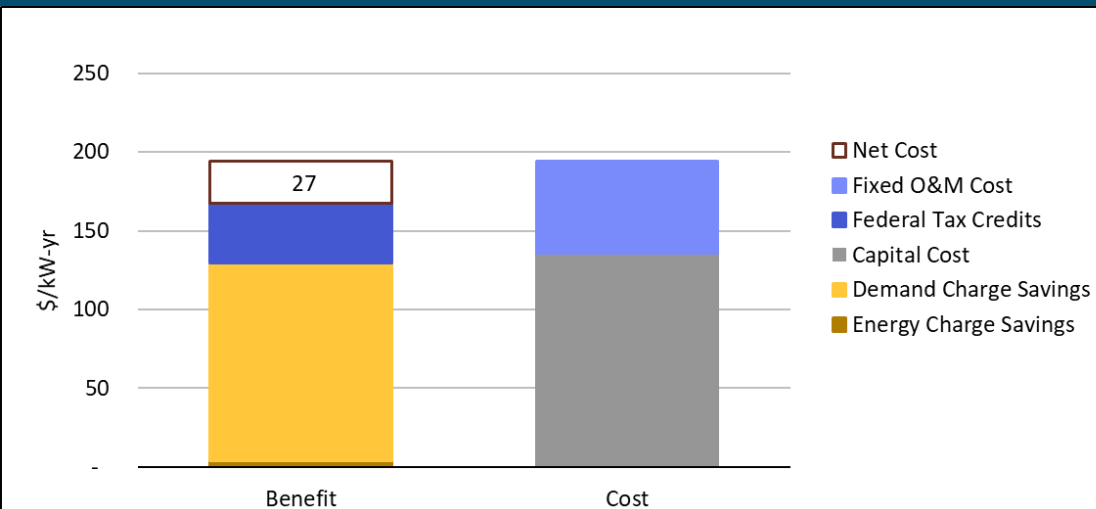




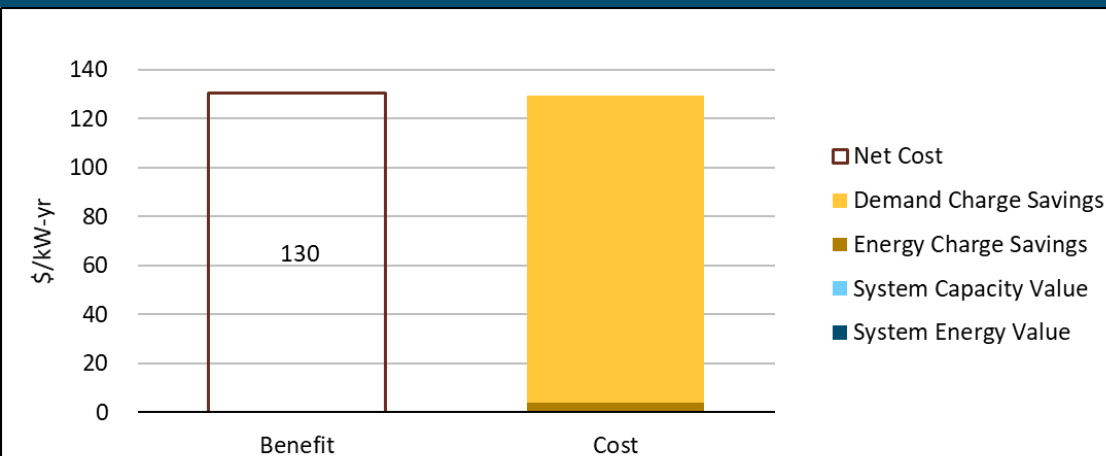
# Behind-the-meter Bill Savings Case – cont.

- + Energy storage is not cost-effective if the benefits and costs are not viewed separately from the PV system**
  - A large portion of revenues comes from demand charge savings, which are \$125/kW-year
  - However, with higher demand charges, energy storage could be cost effective from customers' perspective
- + Energy storage also causes a \$130/kW-year cost shift because the rate signal doesn't align with the system need**
  - The demand charge is targeted to reduce customers' peak which are, in many cases, not aligned with the system peak
- + However, BTM energy storage could be very valuable if utilities are able to send system dispatch signals through rates or utility programs**
  - For example, energy TOU rates, full-value tariffs, demand response programs, partial utility controls, etc.
- + BTM energy storage can also provide distribution deferral values if aggregated**

## Participant Cost Test for Energy Storage Only



## Ratepayer Impact Measure for Energy Storage Only

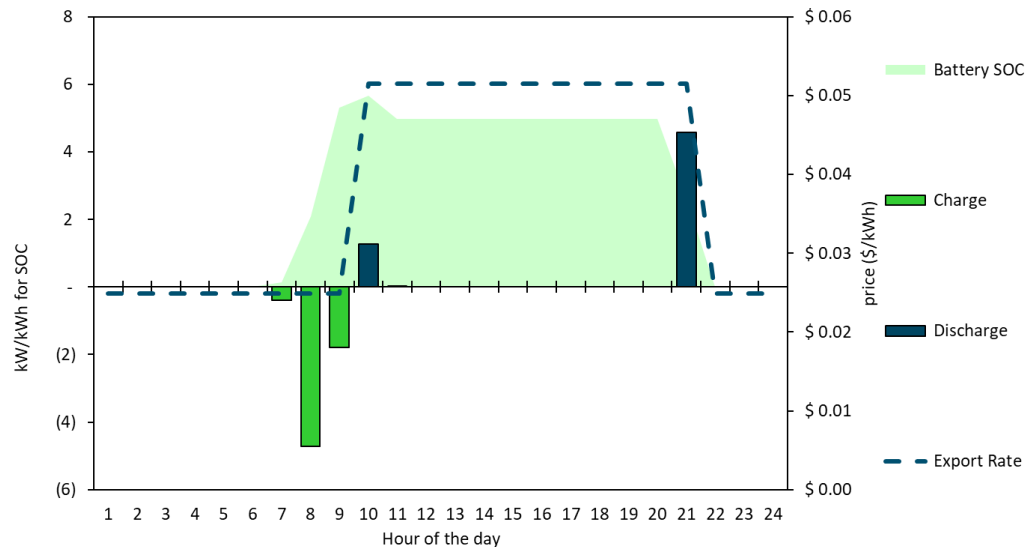
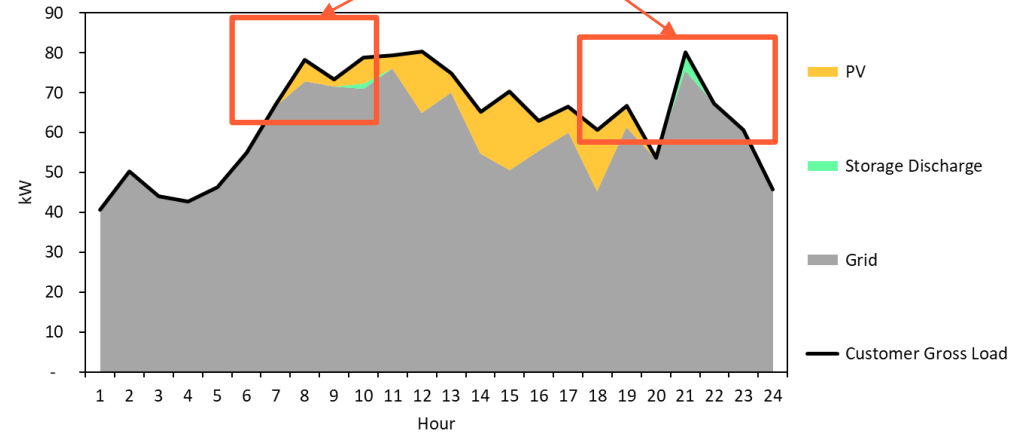




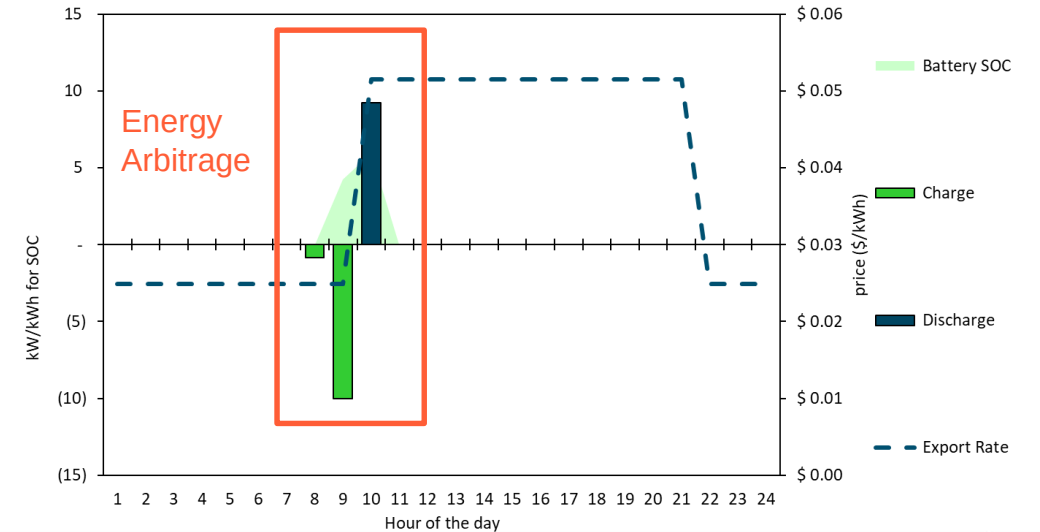
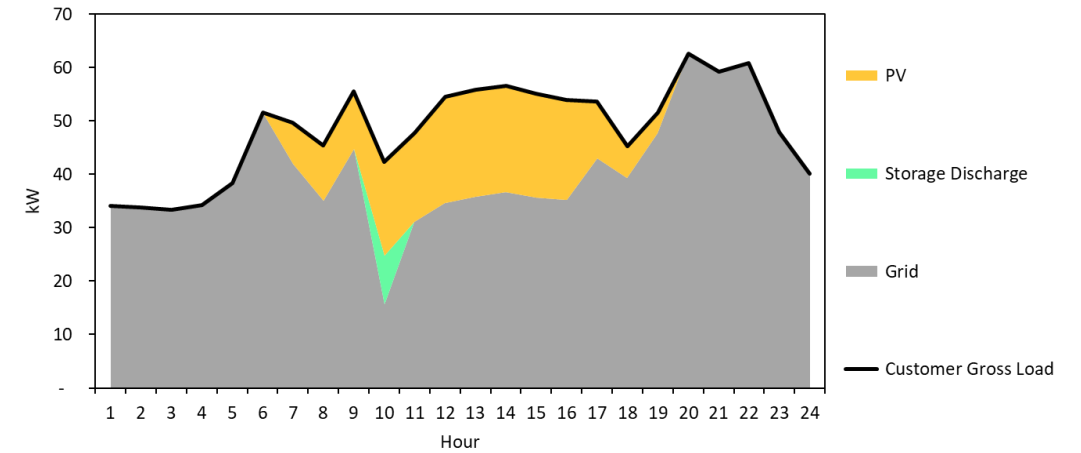
# Behind-the-meter Bill Savings Case: Operation

Energy storage works with the PV system to reduce customer peak during no-solar hours

## A Typical Customer Peak Day



## A Typical Weekday with TOU Energy Charges



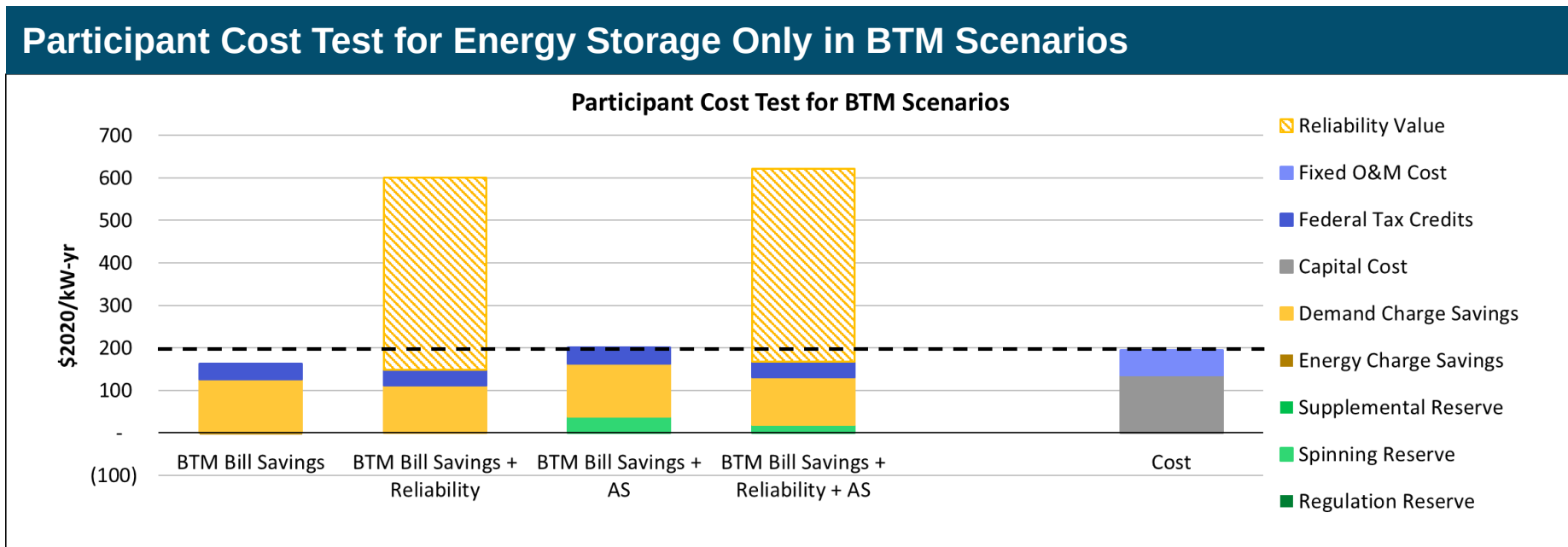


# Behind-the-meter Bill Savings Case: Other Benefits

## + We also tested two additional benefit streams for the BTM customers

- Backup power:
  - Conserve 50% of the battery energy capacity for outage protection
  - Assume \$265/kWh VoLL, from the Lawrence Berkeley National Lab Interruption Cost Estimate Calculator for Small C&I
- Ancillary services: assume battery is able to provide spinning and supplement reserves; regulation is not allowed because of the ITC requirement

## + Backup power can provide huge benefits to customers if the VoLL estimate is accurate





# Other Technologies: Flow Battery

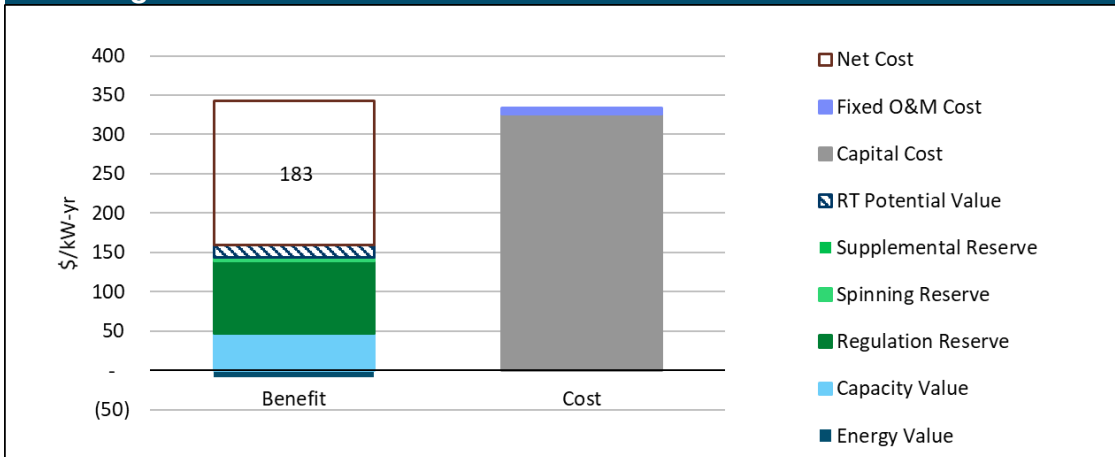
+ Flow batteries are currently more expensive than Li-ion. But because they don't degrade, won't explode, and have a large potential for price declines, some people believe they will have an increasing market share in the future

- Lazard estimates the price decline for flow batteries to be 11% per year in the next 5 years (compared to Li-ion at 8%)

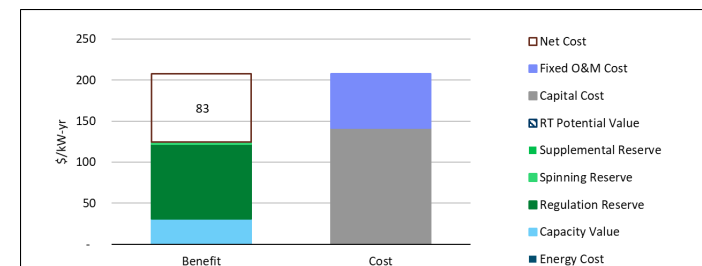
+ Examined a 4-hr Redox Flow battery installed in 2025 (using PNNL 2019 cost projections)

+ The modeled flow battery is not cost-effective in 2025 because it is more expensive than Li-ion, and has a lower round-trip efficiency

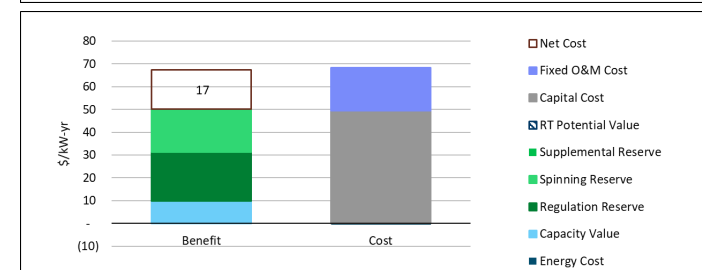
Total Resource Cost Test for a 4-Hour Flow Battery (2025 installation), Existing Trends



4-Hour  
Li-ion



1-Hour  
Li-ion





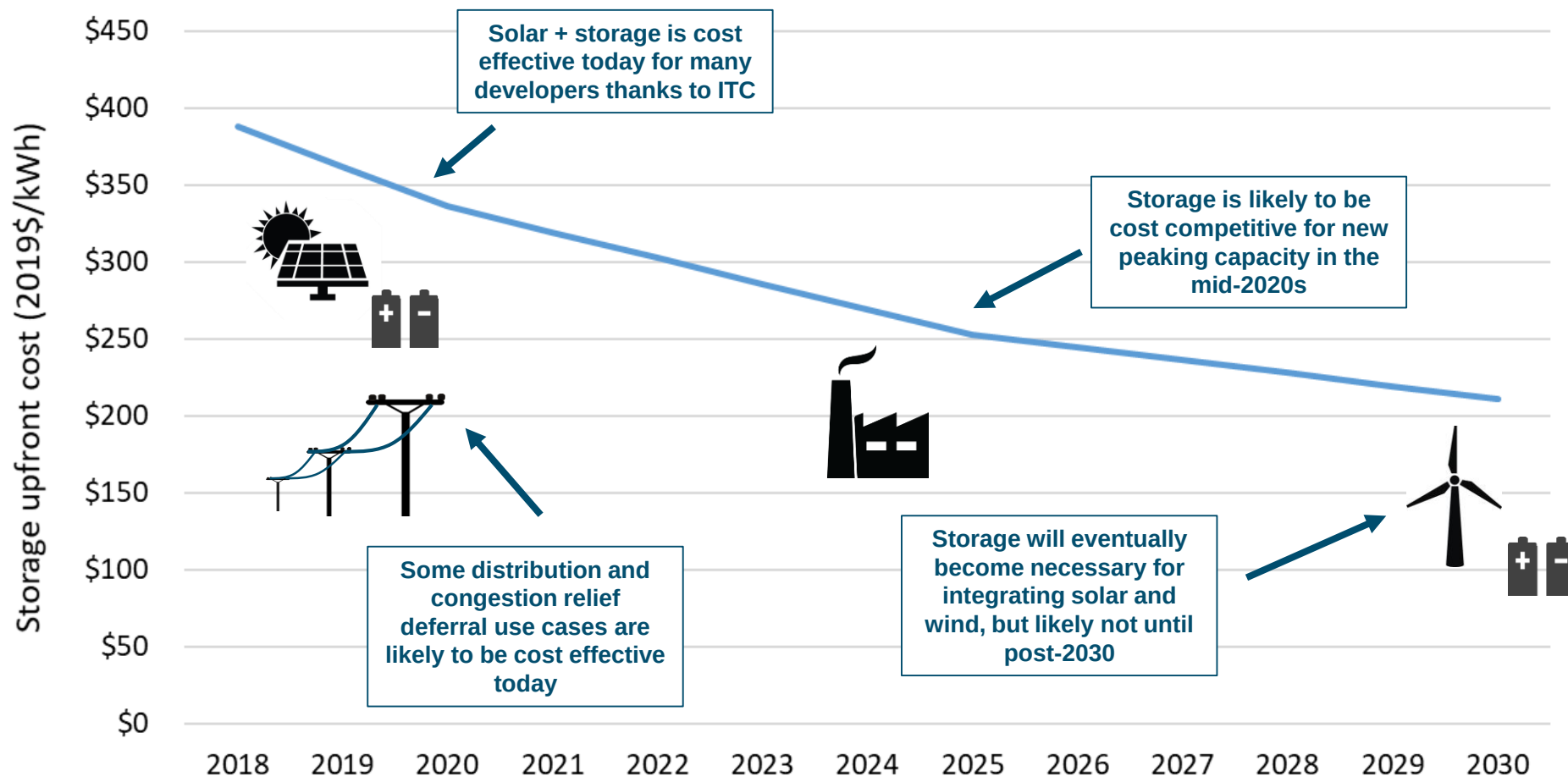
Energy+Environmental Economics

# Key Takeaways and Recommendations



# Draft Key Takeaways: breakeven costs over time

## NREL “Mid” Utility-Scale Storage Cost Projections



Source: “Cost Projections for Utility-Scale Battery Storage”, NREL, June 2019



# Draft Key Takeaways – FTM

- 1. Energy storage installed in 2020 is not yet cost-effective from the system's perspective if it only provides capacity, hourly energy, and ancillary services values**
  - Regulation reserve value is the largest value stream for storage installed in 2020, followed by capacity value
  - However, energy storage could be cost-effective if it is located in constrained areas with high system and local capacity value. For example, providing T&D deferral value and addressing transmission congestion.
  - Participating in real-time markets and providing sub-hourly flexibility to the system will increase energy storage's overall value. This study did not quantify these two value streams in great detail.
- 2. Li-ion storage installed in 2025 could be cost-effective as a capacity resource due to the lower capital cost and the increased capacity value as MISO starts to procure capacity, but installments are subject to saturation**
  - Some amount of energy storage could take the place of new thermal capacity resources
  - These results are based on theoretical maximum values that can be provided by Li-ion storage. More studies and pilots are needed for each site individually before implementing storage as capacity resource. For example, conducting stochastic analysis to ensure reliability and conducting power flow analysis to the understand charging constraints due to congestion.





# Key Takeaways – PV + Storage

## + **Front-of-the-meter (FTM) storage paired with PV is cost-effective in 2020**

- ITC provides additional incentives for storage but also limits the opportunities to provide regulation services, due to the constraint to charge from solar
- Some amount of PV + storage could take the place of new thermal capacity resources

## + **Behind-the-meter (BTM) storage paired with PV is cost-effective from the participant's perspective**

- Demand charge clipping is a significant value stream for these installations, which can represent a cost shift to other ratepayers, if the state and utilities don't provide signals that are aligned with system benefits
- However, PV + storage could provide significant values to the system if utilities provide programs that align customer benefits with system benefits. For example, TOU energy charges, demand response, and allowing utility dispatch battery during system peak days.

## + **Paired storage or even stand-alone storage could serve as a backup generator during emergency events, which could provide benefits to communities**



# Key Takeaways – Others

- + Flow batteries are not as cost-effective as Li-ion batteries in 2020 or 2025 because of their higher capital cost.**
  - Flow batteries can provide the same services as Li-ion batteries. It might become cost competitive in the future given the more aggressive cost decline projections
- + The key factors identified in the report for energy storage's cost-effectiveness are:**
  - Capital cost
  - System and local capacity need (including T&D deferral opportunities)
  - Renewable integration need in the long-term
- + Energy storage in MN is not as cost-effective as those in some other jurisdictions (e.g. New York, California, and Massachusetts). This is due to**
  - 1) the relatively low capacity value resulting from excess capacity in the current system, and inexpensive new capacity due to brownfield CT opportunities
  - 2) MN has a lower renewable penetration level than other jurisdictions
  - 3) In addition, a large portion of renewables are wind, thus, the price spread within a day is not as high as solar-dominant systems
  - 4) MN is in MISO. Regional coordination can help absorb relatively high levels of renewables in MN



# Recommendations and Next Steps

- + Utilities should consider energy storage in their resource planning process, taking into account the multitude of value streams that storage can provide:**
  - Sub-hourly flexibility values
  - Peak capacity
  - T&D upgrade deferral
  - Ancillary services
- + Utilities should non-wires alternatives in their distribution planning process. identify areas with high T&D deferral values when considering opportunities for storage**
- + We recommend that the state look into pilot programs to gain experience in operating energy storage and understand the potential operational constraints.**
  - Potential use cases for pilots are:
    - PV + Storage as an alternative for new peakers
    - Storage stand-alone or PV + storage for T&D deferral
- + We recommend that the state and/or utilities develop initiatives to align customer incentives with system marginal costs, so that behind-the-meter PV and/or storage provides societal benefits and does not create a cost shift to other ratepayers.**



# Seeking Stakeholders Input

- + In addition to the analysis conducted, are there any other potential benefits or barriers that we should discuss in the final report?
- + What are the barriers to energy storage development in Minnesota in your opinion?
- + What recommendations and next steps would you suggest to the state legislature?
- + Energy storage pilots provide useful learning opportunities and real-life experience in operation and integration. If conducting a pilot is a possibility, what types of pilots do you think would be the most interesting and valuable to conduct? For example, T&D deferral, wholesale participation, etc.



# Next Steps

- + Please provide your feedback by Nov 1, 2019, we will share the feedback link
- + Final Report: Dec 15, 2019
- + Presentations to the Minnesota Legislature: TBD





# Thank You

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Kush Patel ([kush@ethree.com](mailto:kush@ethree.com))



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# Appendix





# Feedback Summary: Clarifications – Cont.

- + “The study focus on ‘Where does storage get its value from the grid’ instead of “Where does storage provide value to the system/State and what is that value”**
  - E3 believes the study focuses on answering the second question.
  - The study evaluates the system values based on system needs in three future scenarios. E3 includes most of the values that can be provided by energy storage and obtains the total benefits based on the optimal “value-stacking” without modeling current market rules
- + The study focuses on, per Commerce guidance, near-term scenarios instead of long-term. Energy storage might be proven valuable for MN in future with increasing capacity and renewable integration needs as well as decreasing capital costs**



# Feedback Summary: Suggestions for the Report

## + Include the discussions of

- the estimated relative market size and the scale of the use cases
- regulatory enablers and inhibitors
- creation of public value through use cases. Use cases for public value include but are not limited to critical infrastructure, rural resilience, military and public safety applications

## + Share all the model assumptions when it is available

## + Identify the principle variable(s) that affect energy storage's cost-effectiveness.

## + Compare this study with the energy storage studies conducted for other states



- + This study is completed in a short timeline with limited budget. It is meant to develop a methodology framework for quantifying storage's values and provide a high-level valuation for energy storage in Minnesota in the near term. The main limitations of the study are listed below:**
  - Transmission Constraints: Eastern Interconnection is modeled as multiple zones. Transmission and distribution constraints are not considered for power transferring within zones.
  - No power-flow analysis is conducted
  - System sub-hourly need is not captured
  - The model dispatches battery optimally with perfect-foresights, which renders upper-bounds for the realized storage values.
  - Current market participation rules are not modeled as the study aims to provide theoretical values
  - Detailed interconnection studies are not conducted to address reliability and charging feasibility concerns when energy storage is served as a peaker



## + AURORA Production Simulation Model Caveats:

- **Transmission Constraints:** Eastern Interconnection is modeled as multiple zones in AURORA. Transmission limits between zones as constrained by its forward and backward capacity. No power flow analysis is conducted. Transmission Transmission and distribution constraints are not considered for power transferring within zones.
- **System sub-hourly** need is not captured
- Low-probability, high impact reliability events such as multi-day periods in MISO with no wind, multi-day polar vortex events are not modeled.
- 1-in-2 load forecast is used in the study. There is no consideration of extreme weather events

## + RESTORE Model Caveats

- The model dispatches battery optimally with perfect-foresights, which renders upper-bounds for the realized storage values. (e.g. how to ensure the capacity provision while providing other services when the system peaks are uncertain)
- Current market participation rules are not modeled as the study aim to provide theoretical values
- The impact of temperature on battery performance, electricity needs for station service heating and cooling, and related energy storage service costs are not included



# Caveats - continued

## + Replacing existing peakers:

- doesn't capture how future peaking needs will change
- significantly underestimates the potential for 4-hour storage to provide peak capacity by assuming that you would have to replace 100% of the peaker operations

## + Energy storage serves as alternative peakers

- The study doesn't consider charging constraints due to congestions and other local grid constraints
- Power flow analysis will be needed for actual project siting and interconnection
- The study didn't conduct stochastic analysis to address reliability concerns during extreme grid conditions
- This study doesn't analyze the potential changes to MISO Loss of Load Expectation (LOLE) calculations and associated increases to MISO's Planning Reserve Margin (PRM) calculations which might be impacted by energy storage serving as capacity units

## + Storage's interconnection costs are not included



# Summary of values quantified

| System Values              | Included? | Notes                                                                                                                                                                      |
|----------------------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Arbitrage                  | ✓         | Aka: load shifting                                                                                                                                                         |
| Firm Capacity              | ✓         | Aka: storage's ability to make changes to system peak, reduce system peaking costs, value of peak demand reduction. Market rules and contractual agreement are not modeled |
| Primary Frequency Response | Partial   | MISO doesn't have this product; the service is compensated together with regulation reserve in MISO                                                                        |
| Regulation                 | ✓         |                                                                                                                                                                            |
| Contingency Spinning       | ✓         |                                                                                                                                                                            |
| Supplemental               | ✓         |                                                                                                                                                                            |
| Ramping / Load Following   | Partial   | Ramping need that are longer than an hour is reflected in the marginal energy prices from the production simulation model (AURORA). Sub-hourly need is not quantified      |
| T&D Deferral               | ✓         | Values vary significantly depending on sites; the study provided an example and a way of quantifying the benefits                                                          |
| Black Start                | X         |                                                                                                                                                                            |



## Summary of values quantified – cont.

| System Values                                      | Included? | Notes                                                                                                                      |
|----------------------------------------------------|-----------|----------------------------------------------------------------------------------------------------------------------------|
| Customer Reliability Value                         | ✓         |                                                                                                                            |
| Curtailment Avoidance                              | Partial   | Quantified as kWh avoidance. Related system efficiency, environmental, and land use benefits are not included              |
| Greenhouse Gas Emission Impact                     | Partial   | The GHG impact of ESS related mining, manufacturing and recycling are not included                                         |
| The impact of an alternative diesel gen-sets       | X         | The environmental and economic impact of using a diesel gen-sets to mitigate an outage caused by GHG severe weather events |
| Other environmental or societal costs and benefits | X         |                                                                                                                            |





# Energy Prices: Average Hourly Patterns

+ Energy prices are driven by *net* load, i.e. load net of renewable energy

- Increased load pushes prices up
- Increased wind and solar production pushes prices down

+ Average price spreads by 2032 are low even in the high renewables case

- New storage may be difficult to sustain on energy arbitrage alone

2018 Historical DA Energy Prices (2018\$ / MWh)

|     | 01   | 02   | 03   | 04   | 05   | 06   | 07   | 08   | 09   | 10   | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   | Avg  |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 01  | \$36 | \$31 | \$31 | \$31 | \$32 | \$31 | \$34 | \$44 | \$45 | \$51 | \$55 | \$56 | \$52 | \$50 | \$42 | \$39 | \$43 | \$59 | \$82 | \$73 | \$63 | \$53 | \$48 | \$41 | \$47 |
| 02  | \$18 | \$18 | \$18 | \$18 | \$19 | \$20 | \$21 | \$27 | \$26 | \$24 | \$24 | \$24 | \$22 | \$22 | \$22 | \$22 | \$23 | \$27 | \$39 | \$41 | \$38 | \$33 | \$30 | \$29 | \$25 |
| 03  | \$17 | \$16 | \$16 | \$16 | \$16 | \$18 | \$22 | \$25 | \$24 | \$24 | \$24 | \$24 | \$24 | \$24 | \$23 | \$22 | \$23 | \$25 | \$27 | \$32 | \$29 | \$26 | \$24 | \$23 | \$23 |
| 04  | \$18 | \$18 | \$18 | \$18 | \$19 | \$21 | \$22 | \$24 | \$25 | \$25 | \$24 | \$24 | \$23 | \$22 | \$21 | \$21 | \$22 | \$24 | \$26 | \$33 | \$33 | \$25 | \$21 | \$20 | \$23 |
| 05  | \$5  | \$5  | \$3  | \$4  | \$7  | \$17 | \$18 | \$19 | \$21 | \$22 | \$23 | \$26 | \$27 | \$29 | \$28 | \$29 | \$30 | \$30 | \$30 | \$32 | \$32 | \$26 | \$21 | \$18 | \$21 |
| 06  | \$22 | \$21 | \$18 | \$18 | \$18 | \$20 | \$22 | \$25 | \$29 | \$31 | \$32 | \$32 | \$34 | \$38 | \$40 | \$39 | \$34 | \$33 | \$28 | \$25 | \$23 | \$21 | \$18 | \$16 | \$27 |
| 07  | \$21 | \$20 | \$20 | \$20 | \$19 | \$20 | \$19 | \$20 | \$22 | \$24 | \$28 | \$32 | \$37 | \$42 | \$48 | \$47 | \$48 | \$43 | \$38 | \$34 | \$32 | \$28 | \$24 | \$22 | \$30 |
| 08  | \$21 | \$19 | \$19 | \$19 | \$19 | \$20 | \$21 | \$23 | \$25 | \$25 | \$29 | \$31 | \$33 | \$34 | \$36 | \$39 | \$40 | \$35 | \$32 | \$30 | \$28 | \$24 | \$23 | \$21 | \$27 |
| 09  | \$20 | \$19 | \$19 | \$19 | \$19 | \$20 | \$20 | \$21 | \$22 | \$24 | \$25 | \$26 | \$28 | \$32 | \$31 | \$33 | \$33 | \$30 | \$29 | \$26 | \$25 | \$23 | \$23 | \$21 | \$24 |
| 10  | \$19 | \$18 | \$18 | \$17 | \$19 | \$24 | \$28 | \$27 | \$29 | \$30 | \$31 | \$34 | \$35 | \$36 | \$37 | \$39 | \$39 | \$37 | \$45 | \$43 | \$36 | \$28 | \$23 | \$23 | \$30 |
| 11  | \$25 | \$24 | \$25 | \$24 | \$26 | \$30 | \$43 | \$44 | \$39 | \$39 | \$38 | \$35 | \$33 | \$33 | \$32 | \$33 | \$35 | \$39 | \$44 | \$37 | \$32 | \$29 | \$27 | \$24 | \$33 |
| 12  | \$23 | \$23 | \$23 | \$23 | \$22 | \$21 | \$22 | \$23 | \$25 | \$26 | \$28 | \$27 | \$24 | \$23 | \$22 | \$23 | \$23 | \$33 | \$31 | \$26 | \$24 | \$23 | \$21 | \$21 | \$24 |
| Avg | \$20 | \$19 | \$19 | \$19 | \$20 | \$22 | \$24 | \$27 | \$28 | \$29 | \$30 | \$31 | \$31 | \$32 | \$32 | \$32 | \$33 | \$35 | \$38 | \$36 | \$33 | \$28 | \$25 | \$23 | \$28 |

2032 Energy Prices (2018\$ / MWh)

|     | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Avg |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 01  | 33 | 32 | 32 | 32 | 33 | 36 | 39 | 39 | 36 | 34 | 33 | 33 | 32 | 32 | 35 | 41 | 58 | 81 | 89 | 75 | 47 | 36 | 35 | 33 | 42  |
| 02  | 31 | 30 | 30 | 30 | 32 | 34 | 36 | 35 | 33 | 31 | 30 | 29 | 29 | 29 | 30 | 31 | 34 | 41 | 54 | 50 | 48 | 38 | 33 | 31 | 35  |
| 03  | 29 | 28 | 28 | 28 | 30 | 31 | 33 | 31 | 30 | 28 | 27 | 27 | 26 | 27 | 29 | 31 | 33 | 37 | 40 | 40 | 38 | 33 | 31 | 29 | 31  |
| 04  | 26 | 26 | 25 | 26 | 27 | 28 | 28 | 27 | 26 | 25 | 24 | 24 | 25 | 25 | 26 | 28 | 31 | 35 | 37 | 37 | 38 | 33 | 28 | 27 | 28  |
| 05  | 27 | 26 | 26 | 26 | 27 | 28 | 27 | 27 | 25 | 25 | 26 | 26 | 27 | 27 | 29 | 31 | 34 | 37 | 38 | 37 | 38 | 33 | 30 | 28 | 29  |
| 06  | 29 | 28 | 28 | 28 | 28 | 29 | 28 | 28 | 27 | 28 | 28 | 29 | 29 | 30 | 32 | 34 | 38 | 42 | 43 | 40 | 38 | 34 | 31 | 30 | 32  |
| 07  | 29 | 28 | 28 | 27 | 28 | 29 | 28 | 27 | 27 | 28 | 28 | 29 | 30 | 31 | 33 | 36 | 40 | 53 | 56 | 46 | 38 | 33 | 31 | 30 | 33  |
| 08  | 27 | 26 | 26 | 26 | 26 | 28 | 27 | 26 | 26 | 26 | 26 | 27 | 28 | 30 | 32 | 35 | 41 | 48 | 46 | 41 | 36 | 32 | 30 | 28 | 31  |
| 09  | 26 | 26 | 25 | 25 | 26 | 26 | 27 | 26 | 25 | 25 | 25 | 26 | 26 | 27 | 29 | 32 | 36 | 40 | 41 | 40 | 36 | 30 | 27 | 27 | 29  |
| 10  | 26 | 25 | 25 | 25 | 26 | 27 | 28 | 27 | 25 | 25 | 24 | 25 | 25 | 25 | 27 | 29 | 32 | 37 | 38 | 38 | 32 | 28 | 27 | 26 | 28  |
| 11  | 26 | 26 | 26 | 26 | 27 | 28 | 29 | 29 | 28 | 28 | 27 | 27 | 26 | 26 | 28 | 29 | 30 | 35 | 37 | 36 | 32 | 31 | 28 | 27 | 29  |
| 12  | 30 | 29 | 28 | 29 | 30 | 31 | 32 | 32 | 30 | 30 | 30 | 29 | 29 | 29 | 31 | 31 | 33 | 40 | 42 | 39 | 36 | 33 | 31 | 30 | 32  |
| Avg | 28 | 28 | 27 | 27 | 28 | 29 | 30 | 30 | 28 | 28 | 27 | 28 | 28 | 28 | 30 | 32 | 37 | 44 | 47 | 43 | 38 | 33 | 30 | 29 | 32  |

Existing Trends

High Gas

|     | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18  | 19  | 20 | 21 | 22 | 23 | 24 | Avg |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|-----|----|----|----|----|----|-----|
| 01  | 38 | 38 | 38 | 39 | 41 | 47 | 52 | 52 | 42 | 40 | 38 | 37 | 36 | 37 | 39 | 50 | 68 | 108 | 113 | 98 | 71 | 49 | 41 | 39 | 52  |
| 02  | 35 | 34 | 34 | 35 | 37 | 43 | 47 | 46 | 39 | 36 | 33 | 32 | 31 | 31 | 32 | 34 | 38 | 52  | 63  | 68 | 69 | 51 | 40 | 37 | 42  |
| 03  | 32 | 32 | 32 | 32 | 34 | 37 | 41 | 38 | 34 | 32 | 31 | 30 | 29 | 30 | 32 | 33 | 37 | 46  | 50  | 52 | 52 | 41 | 36 | 33 | 37  |
| 04  | 30 | 30 | 30 | 30 | 31 | 33 | 34 | 32 | 30 | 29 | 28 | 27 | 28 | 28 | 29 | 31 | 33 | 41  | 44  | 44 | 48 | 38 | 33 | 31 | 33  |
| 05  | 30 | 30 | 30 | 30 | 30 | 32 | 32 | 30 | 28 | 28 | 29 | 29 | 30 | 30 | 32 | 34 | 38 | 44  | 46  | 44 | 46 | 39 | 34 | 32 | 34  |
| 06  | 33 | 32 | 31 | 31 | 32 | 33 | 33 | 32 | 31 | 31 | 32 | 33 | 34 | 35 | 37 | 40 | 45 | 49  | 50  | 49 | 51 | 43 | 36 | 34 | 37  |
| 07  | 34 | 33 | 32 | 32 | 33 | 34 | 33 | 32 | 32 | 32 | 33 | 34 | 35 | 36 | 39 | 43 | 47 | 55  | 57  | 50 | 50 | 43 | 38 | 36 | 38  |
| 08  | 32 | 32 | 31 | 31 | 31 | 33 | 32 | 31 | 31 | 31 | 32 | 32 | 33 | 34 | 36 | 40 | 45 | 51  | 51  | 49 | 47 | 38 | 36 | 34 | 36  |
| 09  | 31 | 30 | 30 | 30 | 30 | 32 | 33 | 32 | 31 | 30 | 30 | 31 | 32 | 32 | 34 | 37 | 42 | 44  | 44  | 47 | 44 | 36 | 33 | 32 | 34  |
| 10  | 30 | 30 | 30 | 30 | 31 | 33 | 34 | 32 | 30 | 29 | 28 | 28 | 29 | 30 | 31 | 34 | 39 | 42  | 43  | 45 | 41 | 34 | 32 | 31 | 33  |
| 11  | 31 | 31 | 31 | 31 | 32 | 34 | 36 | 36 | 33 | 32 | 31 | 30 | 30 | 30 | 32 | 33 | 37 | 40  | 43  | 43 | 39 | 36 | 33 | 32 | 34  |
| 12  | 35 | 34 | 33 | 33 | 35 | 38 | 40 | 40 | 36 | 35 | 34 | 33 | 33 | 33 | 35 | 37 | 41 | 46  | 49  | 50 | 48 | 42 | 37 | 35 | 38  |
| Avg | 33 | 32 | 32 | 32 | 33 | 36 | 37 | 36 | 33 | 32 | 32 | 31 | 32 | 32 | 34 | 37 | 43 | 52  | 54  | 53 | 50 | 41 | 36 | 34 | 37  |

High MN  
Renewables

|     | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Avg |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 01  | 31 | 30 | 29 | 29 | 31 | 34 | 37 | 40 | 38 | 33 | 32 | 31 | 30 | 31 | 32 | 40 | 55 | 78 | 75 | 65 | 43 | 35 | 34 | 31 | 39  |
| 02  | 28 | 27 | 27 | 27 | 29 | 31 | 34 | 34 | 31 | 30 | 28 | 27 | 26 | 27 | 28 | 29 | 32 | 40 | 48 | 46 | 46 | 35 | 32 | 30 | 32  |
| 03  | 24 | 23 | 23 | 24 | 25 | 28 | 31 | 30 | 28 | 26 | 24 | 23 | 23 | 23 | 25 | 27 | 30 | 35 | 36 | 36 | 35 | 29 | 26 | 24 | 27  |
| 04  | 20 | 20 | 21 | 21 | 23 | 26 | 28 | 26 | 24 | 23 | 21 | 20 | 21 | 21 | 22 | 24 | 27 | 32 | 33 | 32 | 32 | 27 | 23 | 21 | 24  |
| 05  | 19 | 17 | 17 | 18 | 19 | 24 | 25 | 24 | 23 | 22 | 22 | 21 | 22 | 23 | 24 | 26 | 29 | 34 | 33 | 31 | 30 | 27 | 22 | 21 | 24  |
| 06  | 26 | 25 | 25 | 24 | 24 | 25 | 27 | 27 | 26 | 26 | 26 | 25 | 27 | 27 | 28 | 30 | 32 | 35 | 40 | 41 | 37 | 36 | 32 | 29 | 28  |
| 07  | 28 | 27 | 26 | 26 | 27 | 28 | 28 | 27 | 26 | 26 | 27 | 28 | 29 | 30 | 32 | 35 | 40 | 55 | 61 | 48 | 38 | 32 | 31 | 29 | 33  |
| 08  | 25 | 24 | 24 | 23 | 24 | 27 | 27 | 26 | 25 | 25 | 25 | 26 | 26 | 28 | 30 | 33 | 39 | 47 | 47 | 40 | 35 | 30 | 28 | 27 | 30  |
| 09  | 23 | 23 | 23 | 23 | 23 | 24 | 26 | 25 | 24 | 24 | 24 | 24 | 25 | 25 | 27 | 30 | 34 | 39 | 39 | 38 | 34 | 28 | 25 | 23 | 27  |
| 10  | 23 | 23 | 22 | 22 | 23 | 25 | 27 | 25 | 23 | 22 | 22 | 22 | 22 | 22 | 24 | 28 | 31 | 36 | 37 | 37 | 32 | 27 | 26 | 25 | 26  |
| 11  | 24 | 24 | 24 | 24 | 25 | 27 | 28 | 28 | 28 | 27 | 26 | 26 | 25 | 25 | 26 | 27 | 29 | 31 | 33 | 32 | 30 | 28 | 26 | 25 | 27  |
| 12  | 29 | 27 | 27 | 27 | 28 | 30 | 31 | 31 | 30 | 29 | 29 | 28 | 28 | 28 | 29 | 30 | 32 | 39 | 40 | 38 | 35 | 32 | 30 | 29 | 31  |
| Avg | 25 | 24 | 24 | 24 | 25 | 28 | 29 | 28 | 27 | 26 | 25 | 25 | 25 | 26 | 27 | 30 | 35 | 42 | 44 | 40 | 35 | 30 | 28 | 26 | 29  |