NREL
Transforming ENERGY

The Future of Energy Storage

EESAT
January 29, 2024
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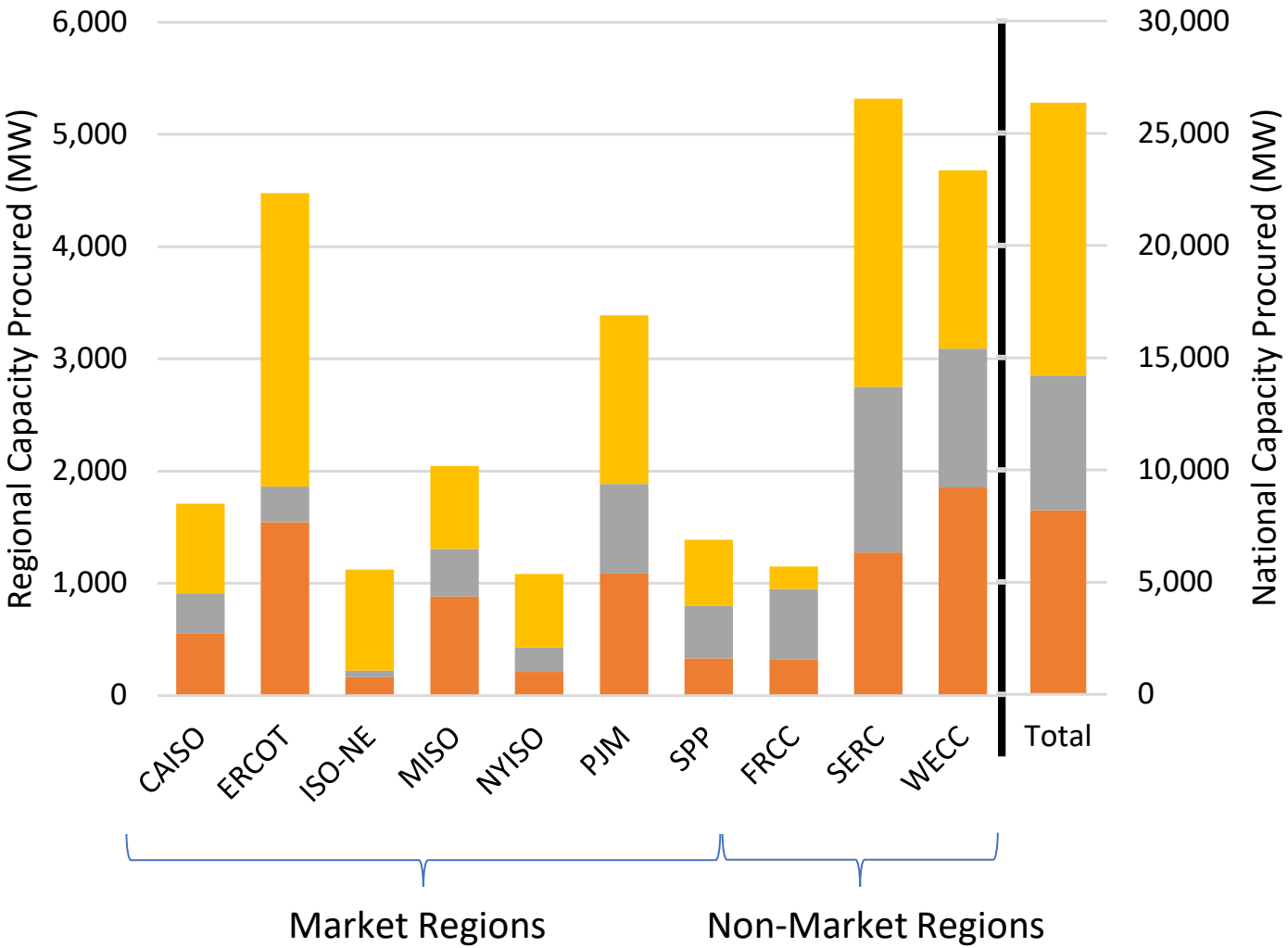
Two Big Questions….

- How big is the opportunity?
- Which technology is going to win?

How Big is the Opportunity?

- But first…What exactly is the opportunity?
- What does storage actually do?
- Forget the classic eyechart of multiple services. It's three big ones:
  - Ancillary services
  - Capacity
  - Energy time shifting

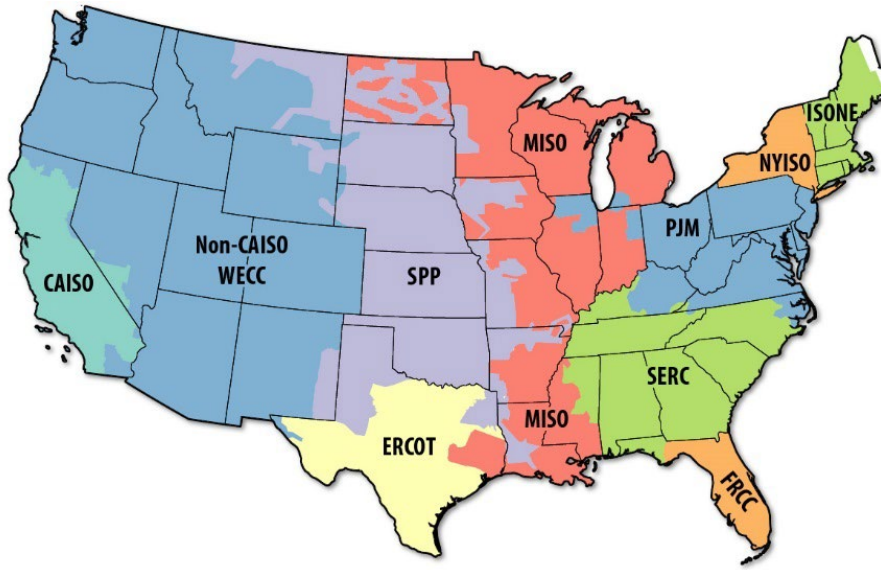
Operating reserves have been an important entry point for shorter duration storage



Spinning Contingency Reserves

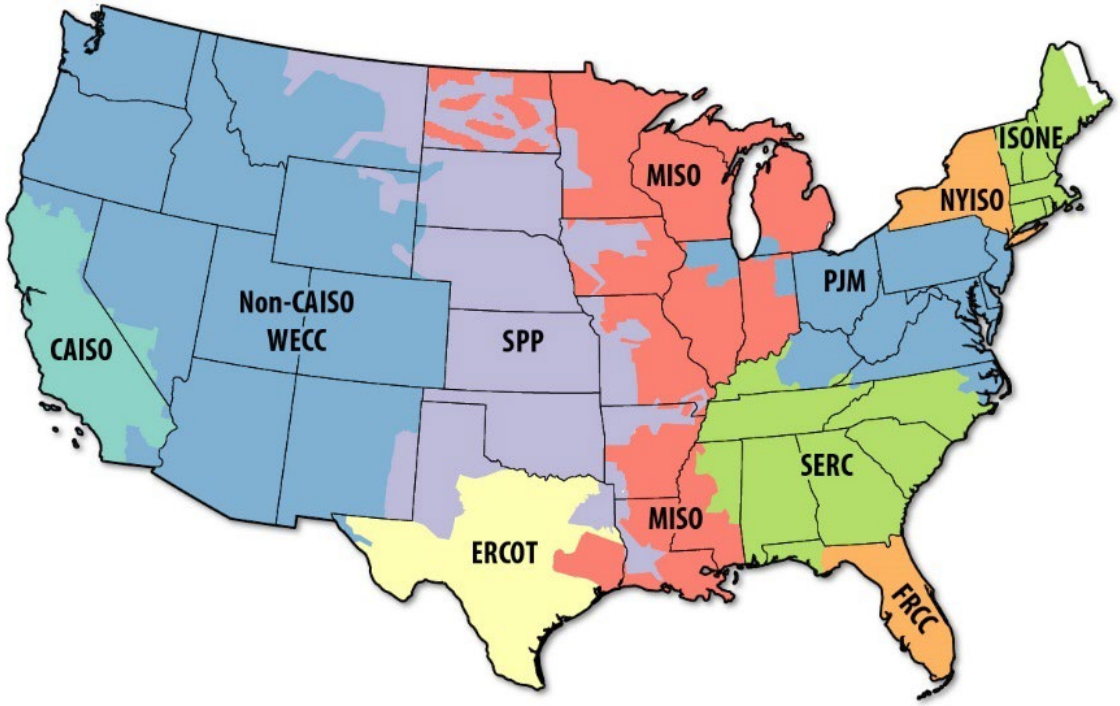
Regulating Reserves

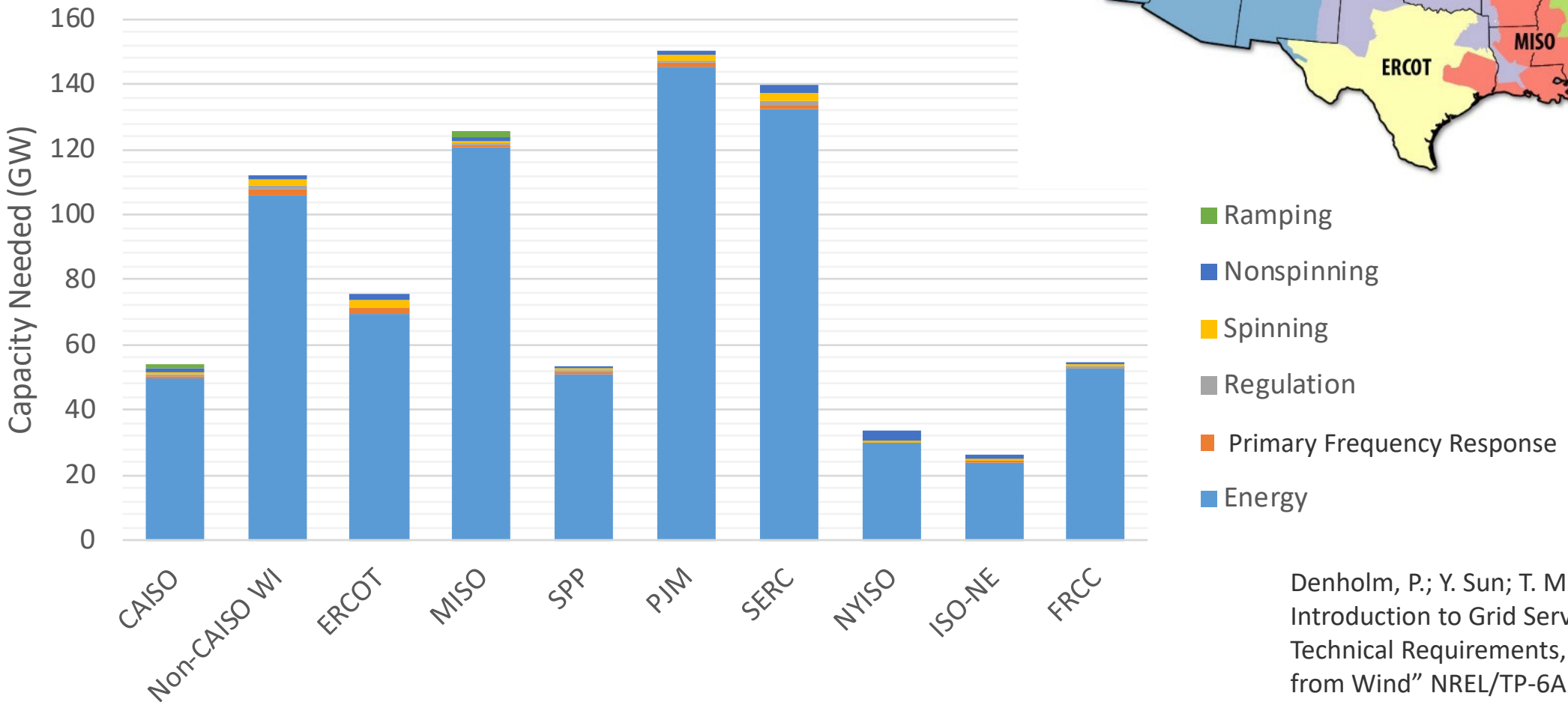
Frequency Response



Ancillary services are where things going in the period of 2010-2015

Focus of Storage is Shifting to Peaking/Firm Capacity

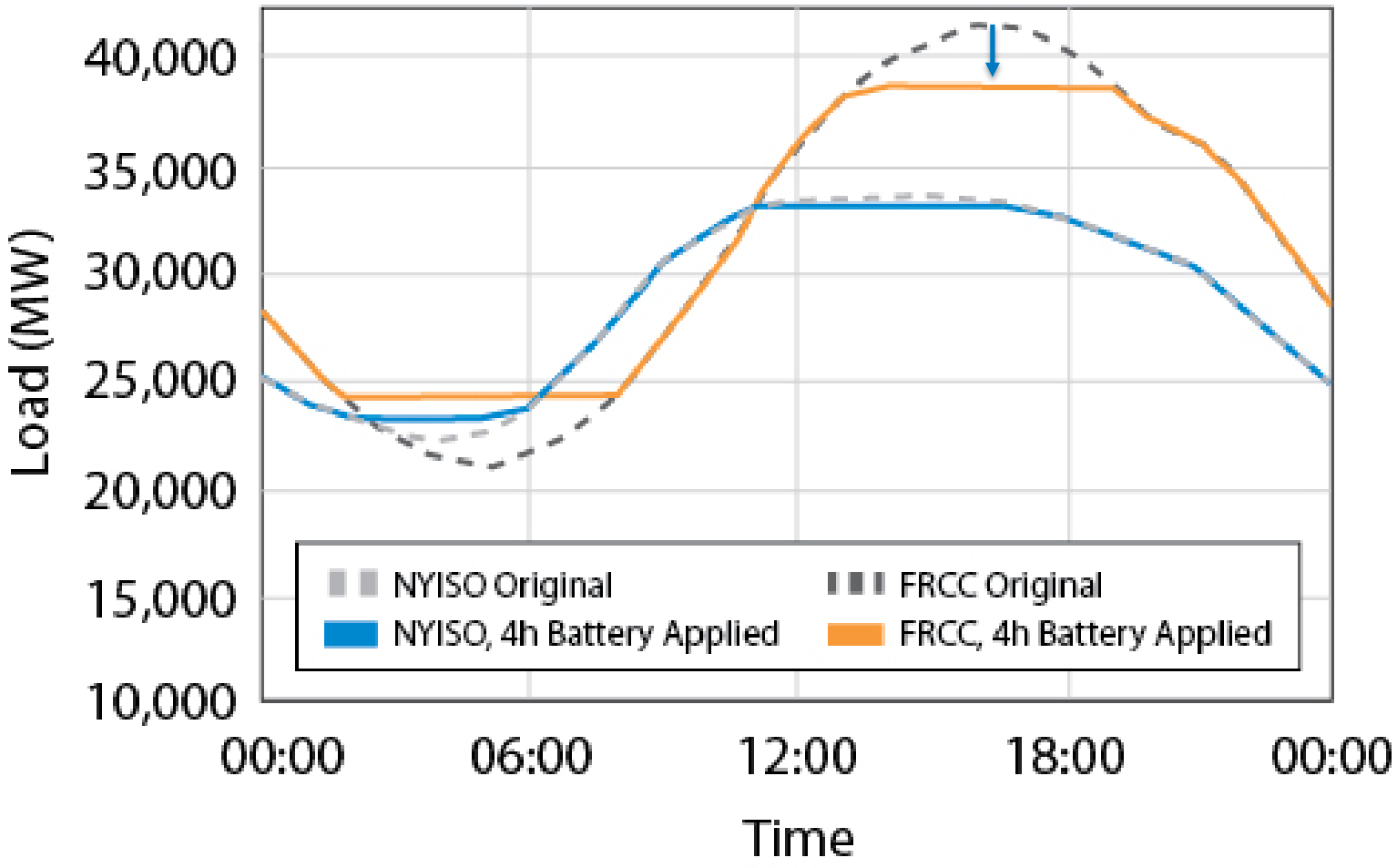




Denholm, P.; Y. Sun; T. Mai. (2019) "An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind" NREL/TP-6A20-72578.

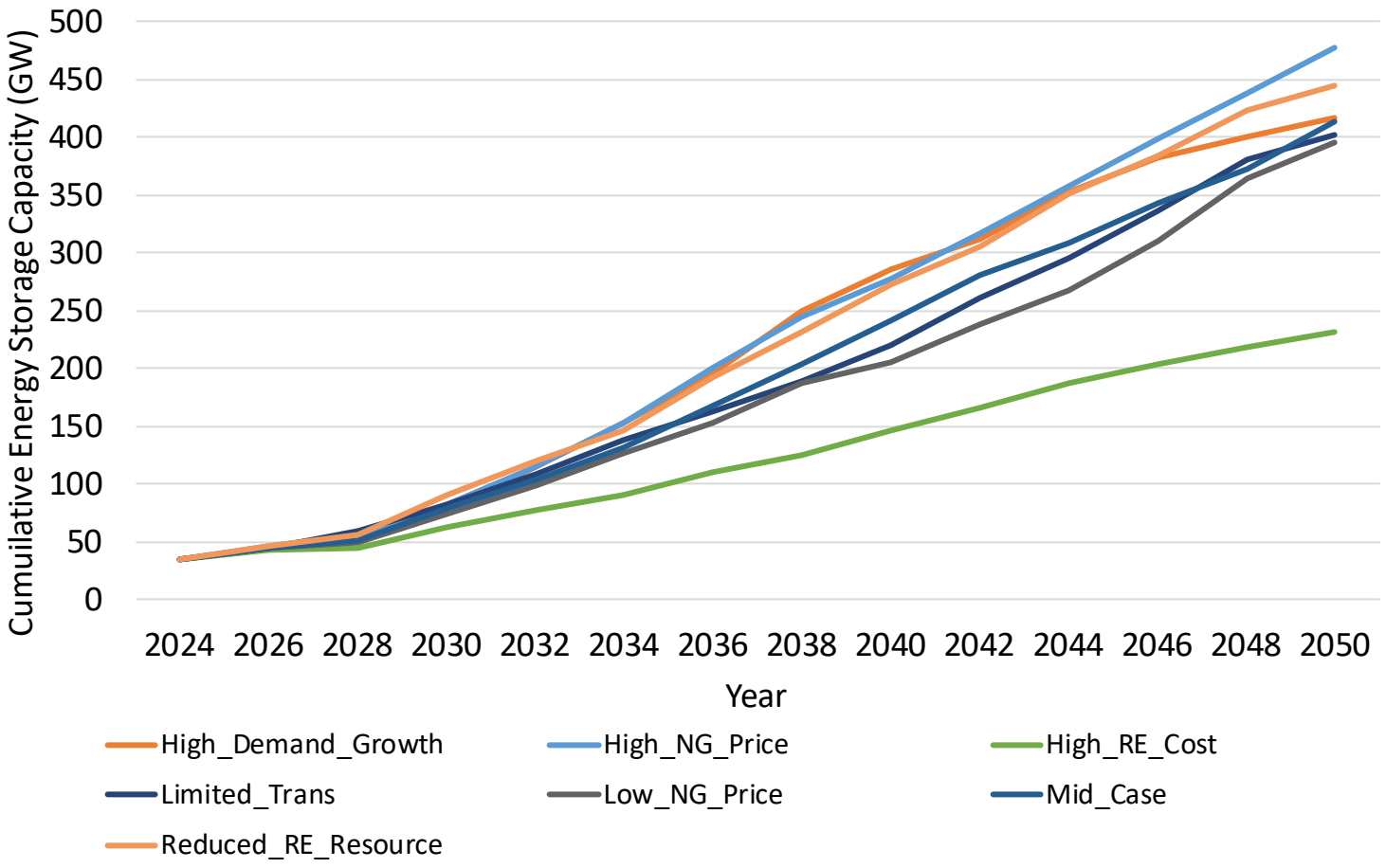
Storage Clipping the Summer Peak and Providing Firm Capacity

Storage can replace conventional peaking capacity



Denholm, P.; J. Nunemaker, P. Gagnon; W. Cole (2020) The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States. NREL/TP-6A20-74184.)

NREL's 2023 Standard Scenarios Projections



>350 GW by 2050 in most of the scenarios

At $1,500/kW that's more than $500 billion of cumulative investments…

Which technology is going to win?

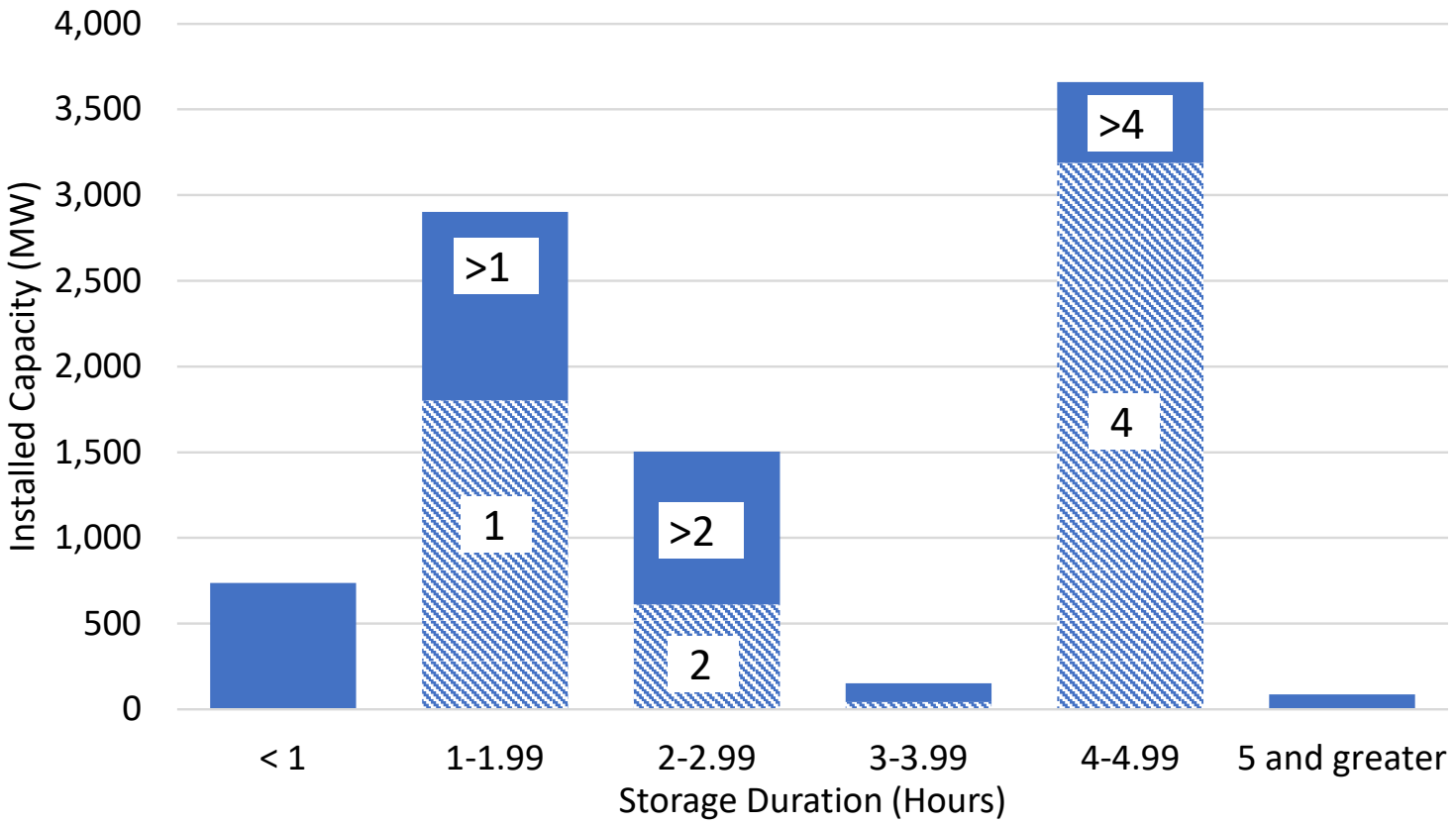
- I don’t know
- But I can tell you who is winning *now* and what has to happen for someone else to start taking market share..

Who is winning now?

- Lithium-Ion
- Why?
- Because its cheaper than anything else *for what the market is currently asking for*….
- And that comes down to duration…

Recent Storage Installations

Year	Power (MW)	Weighted Avg. Duration (Hours)
2010–2014	210	0.7
2015	150	0.5
2016	200	1.3
2017	130	2.2
2018	220	2.3
2019	190	2.7
2020	500	1.2
2021	3,380	2.9
2022	4,160	2.7
Total	**9,140**	**2.6**



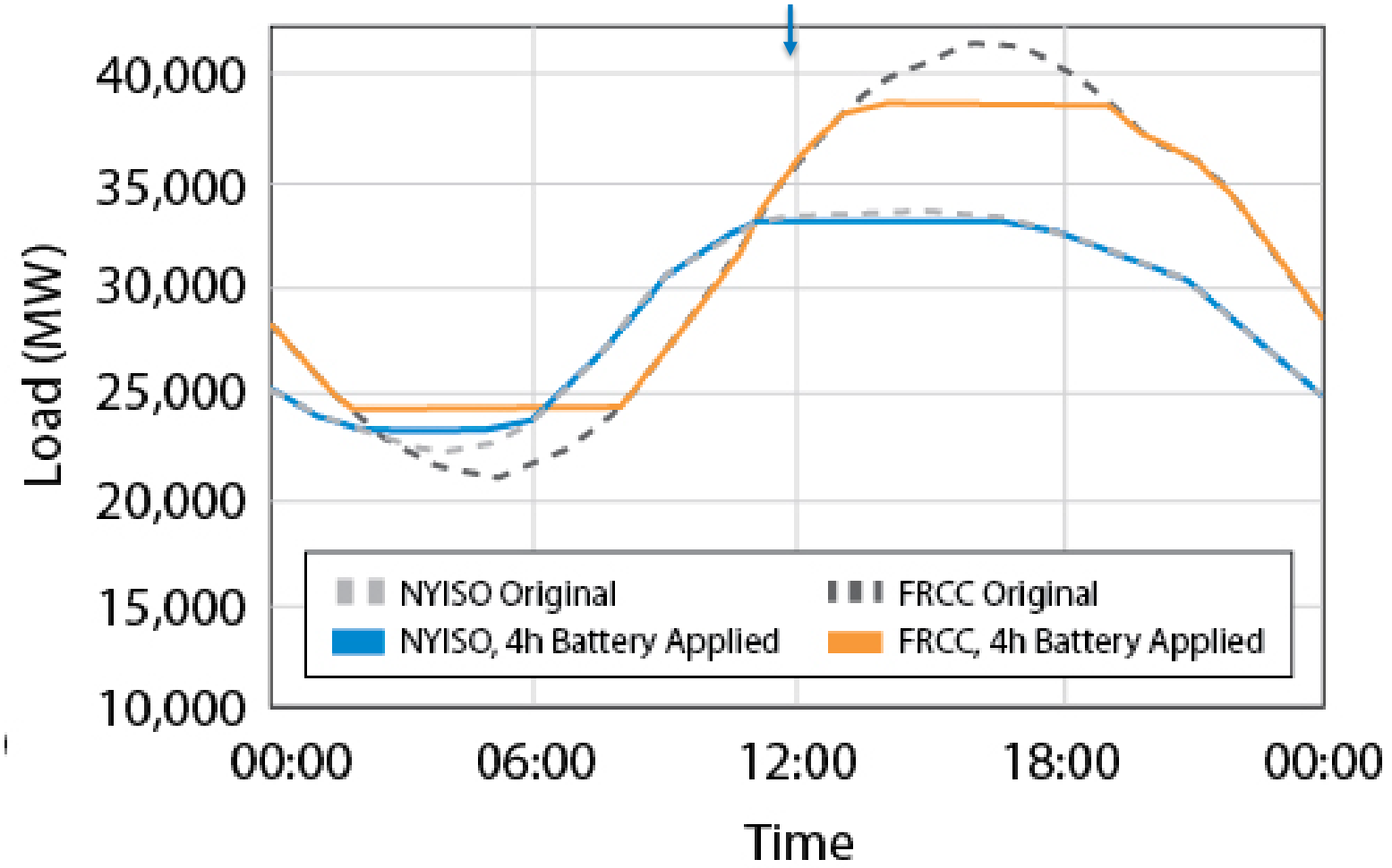
99.8% of capacity in 2021-2022 listed as Lithium-Ion. As of June 2023 another 1,763 MW of batteries competed and 7,165 under construction. Of the completed projects, only about 20% include duration data, but the average of these was below 2 hours.

Less than 7% of total capacity has a duration that exceeds 4 hours.

BUT WHY???

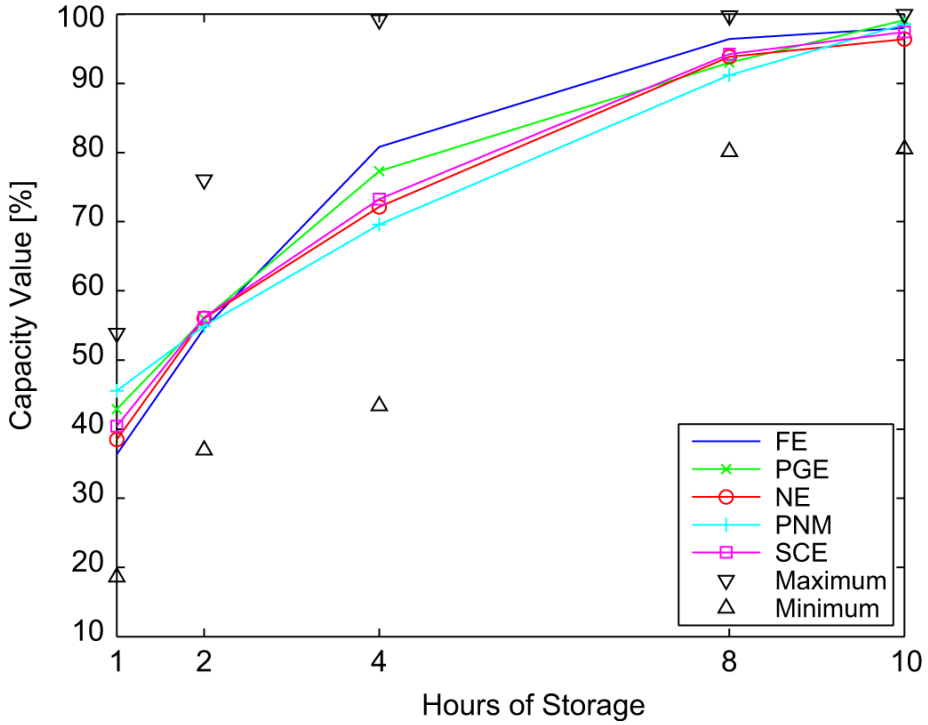
Peaking capacity is a primary driver for storage value being installed

But what duration is needed to replace conventional “firm” capacity for meeting the peak?



The Value of Capacity Depends on Capacity Credit

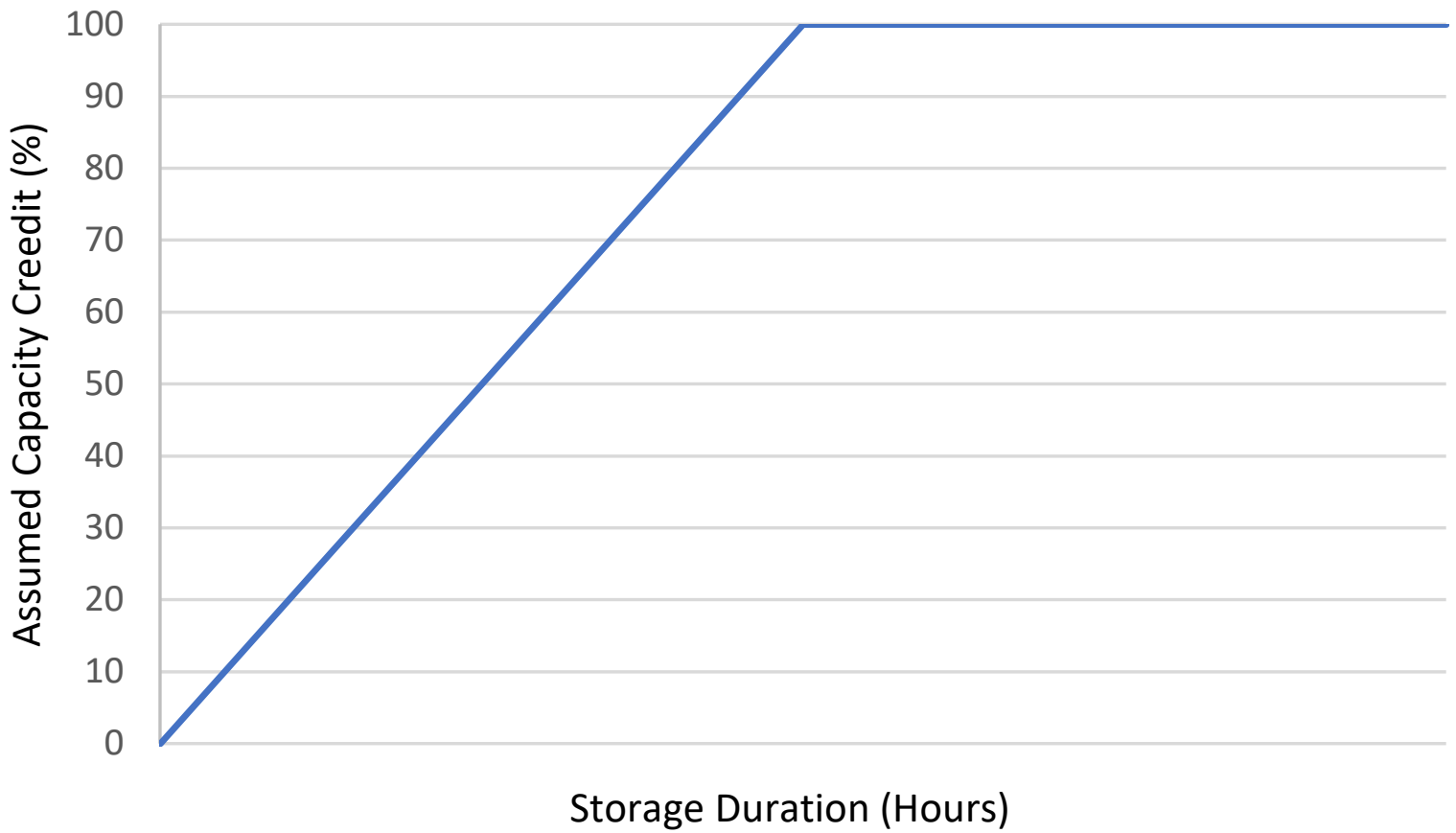
- Fraction of nameplate that can reliably serve load
- Effective load carrying capability (ELCC) varies as a function of duration



The math gets really tricky out here.

Sioshansi, R., S.H. Madaeni, and P. Denholm. (2014) "A Dynamic Programming Approach to Estimate the Capacity Value of Energy Storage" IEEE Transactions on Power Systems 29(1) 395-403.

Many Markets Do This Instead…

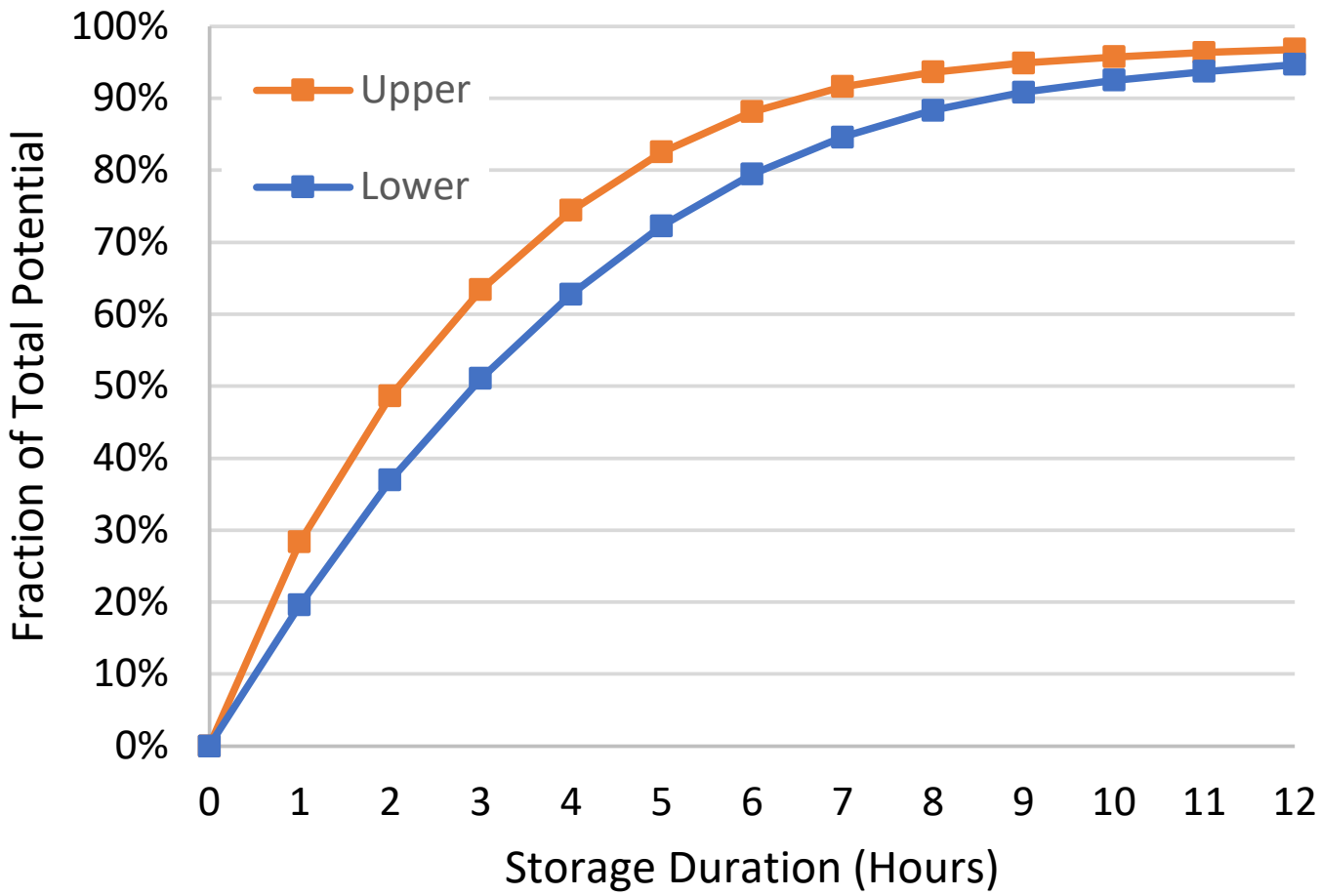


Market Operator	Duration Minimum (hours)
ISO-NE	2
CAISO	4
NYISO	4
SPP	4
MISO	4
PJM	ELCC based

Many regions have implemented a 4-hour requirement for resource adequacy

So the marginal value of adding a fifth hour is **zero**.

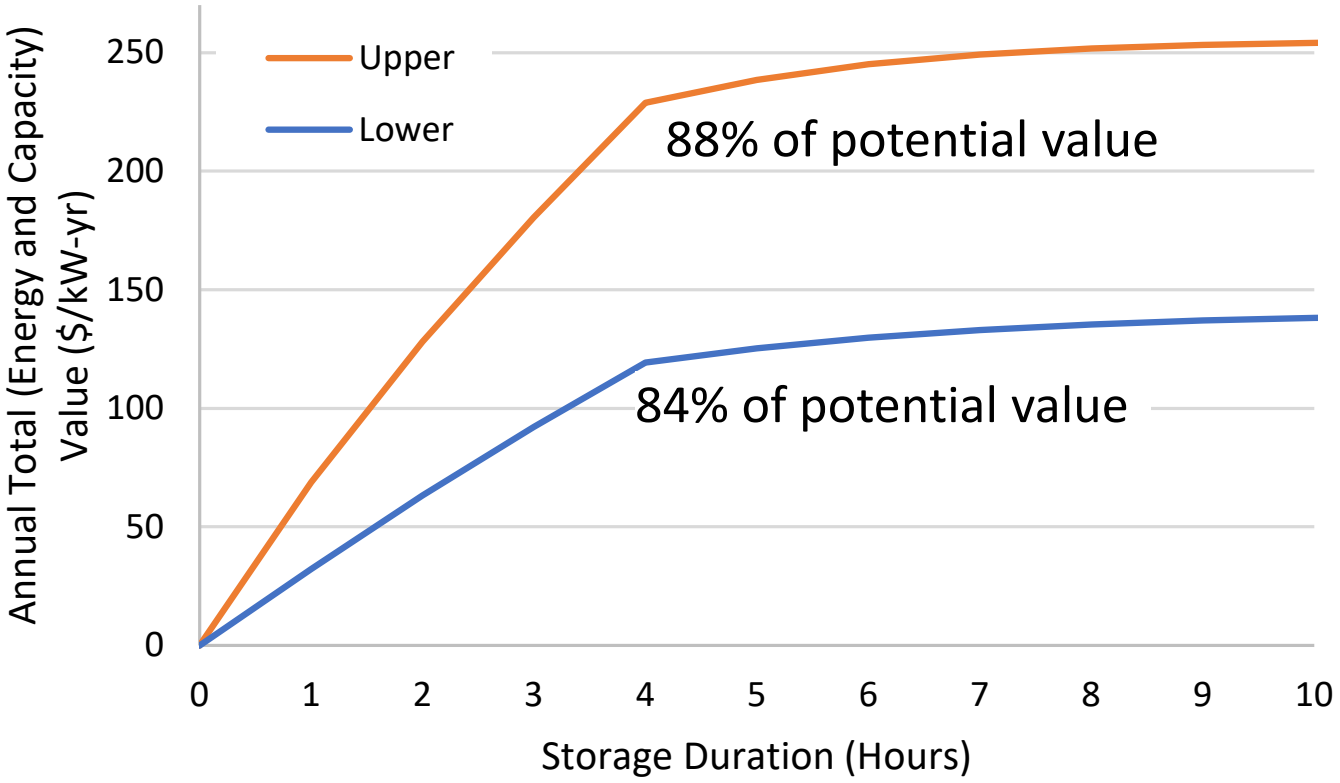
Energy Shifting Value

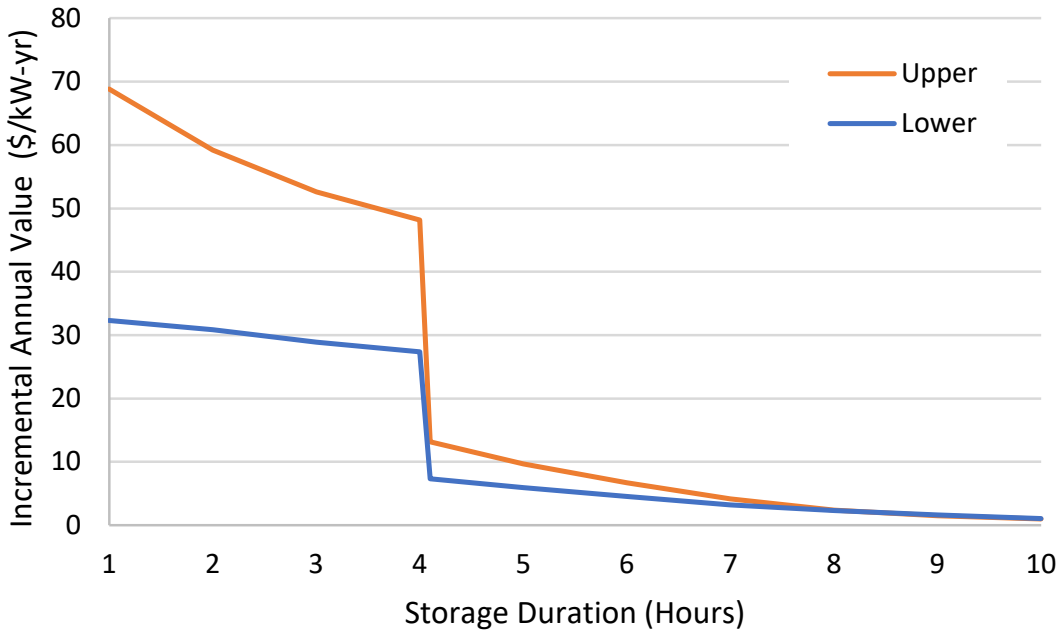


Example of the total value of energy time-shifting using a range of wholesale market prices

Bottom line

- Four hour storage captures most of the value in locations with a four-hour capacity rule





To Summarize

1. Nearly all of the monetizable benefits of storage can be achieved with durations of 4 hours in today's grid.
2. Li-Ion beats every other technology on life-cycle costs at 4 hours and less

- So..when will this change?

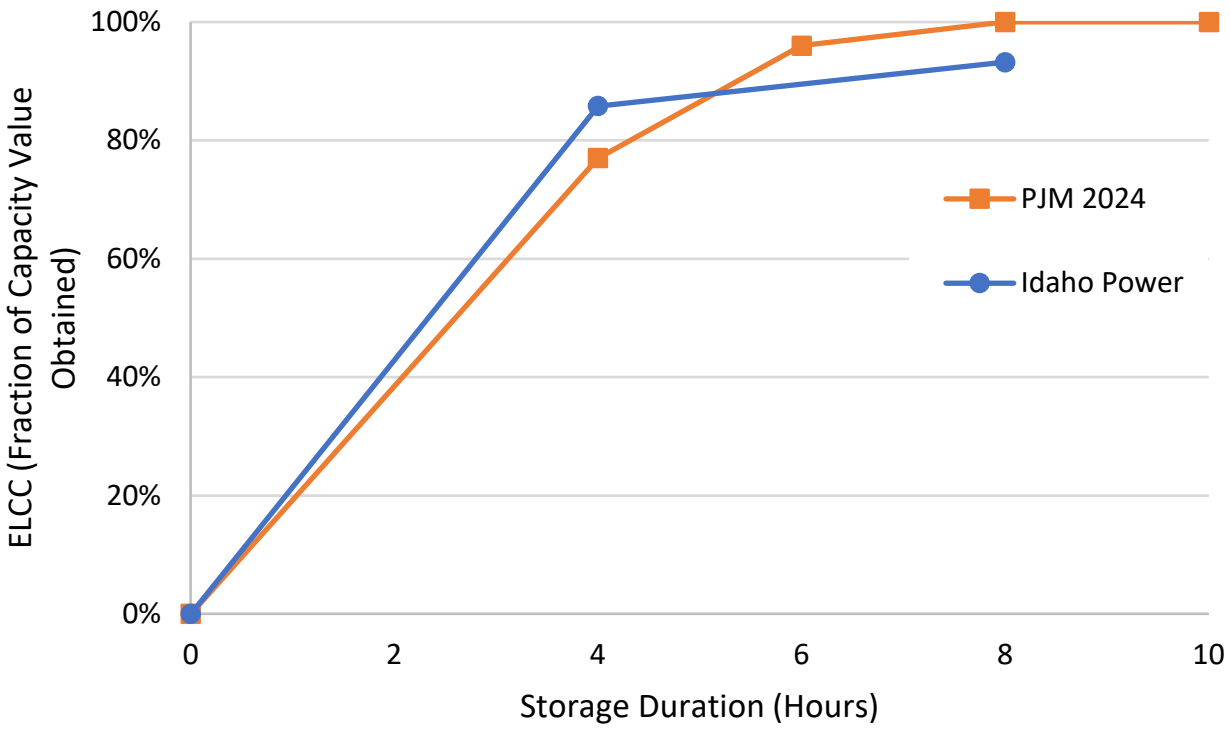
Changes in Value that Favor Longer Duration

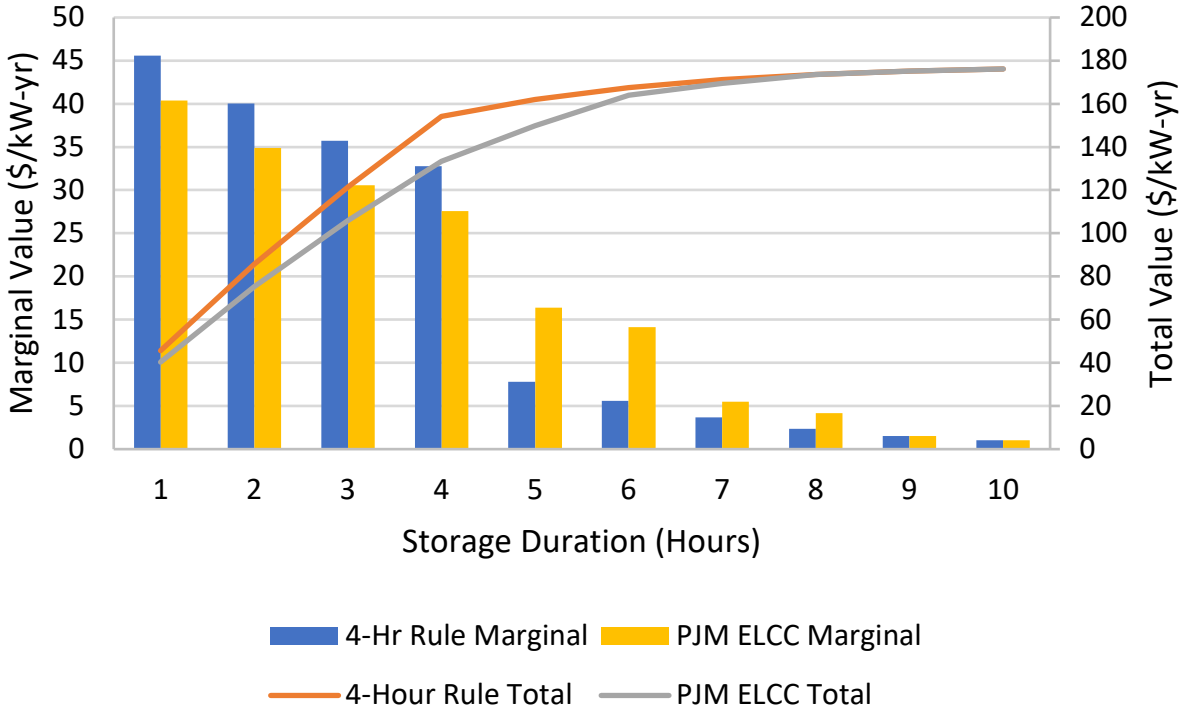
- Shift in Value
  - Capacity
  - Energy
- Additional Values
  - Transmission
  - Resilience

Shift in Capacity Value

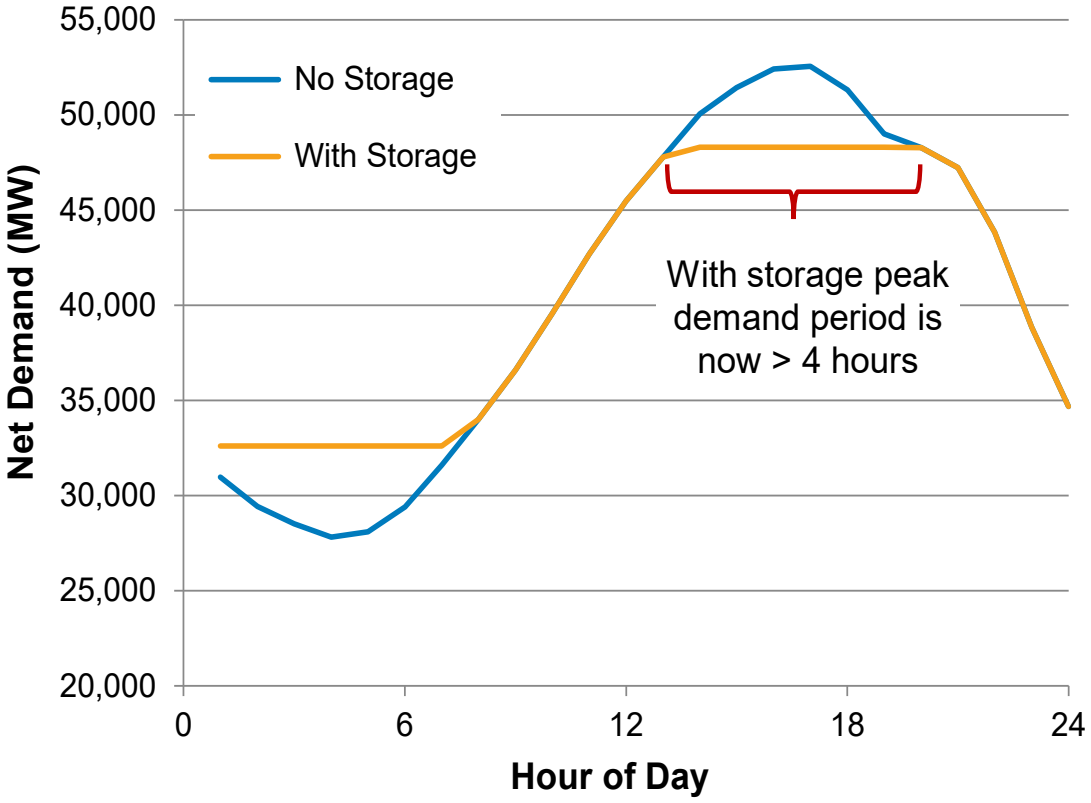
- Perhaps the most likely shift in value will occur due to declining capacity credit for short duration storage.
- Two likely causes:
  - Use of non-linear derates
  - **Shift to longer-duration winter peaks**

ELCC/Non-Linear Derates

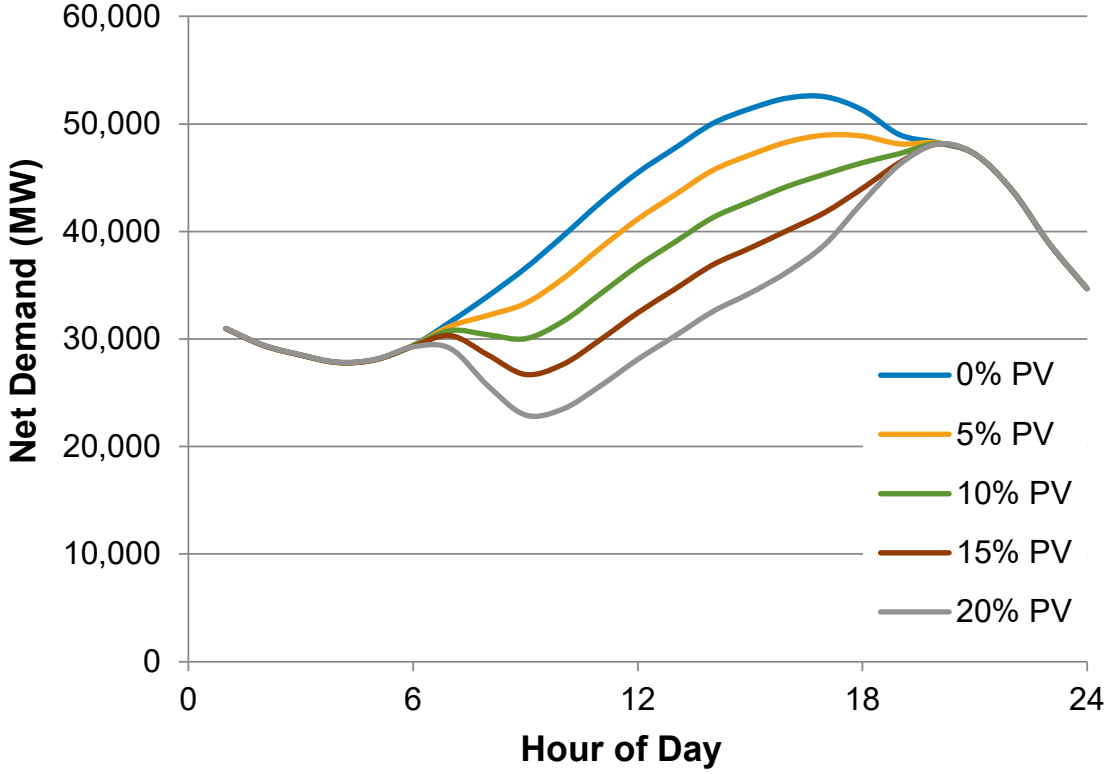




Transition to Longer Duration Peaks? (But Probably Not in the Summer)

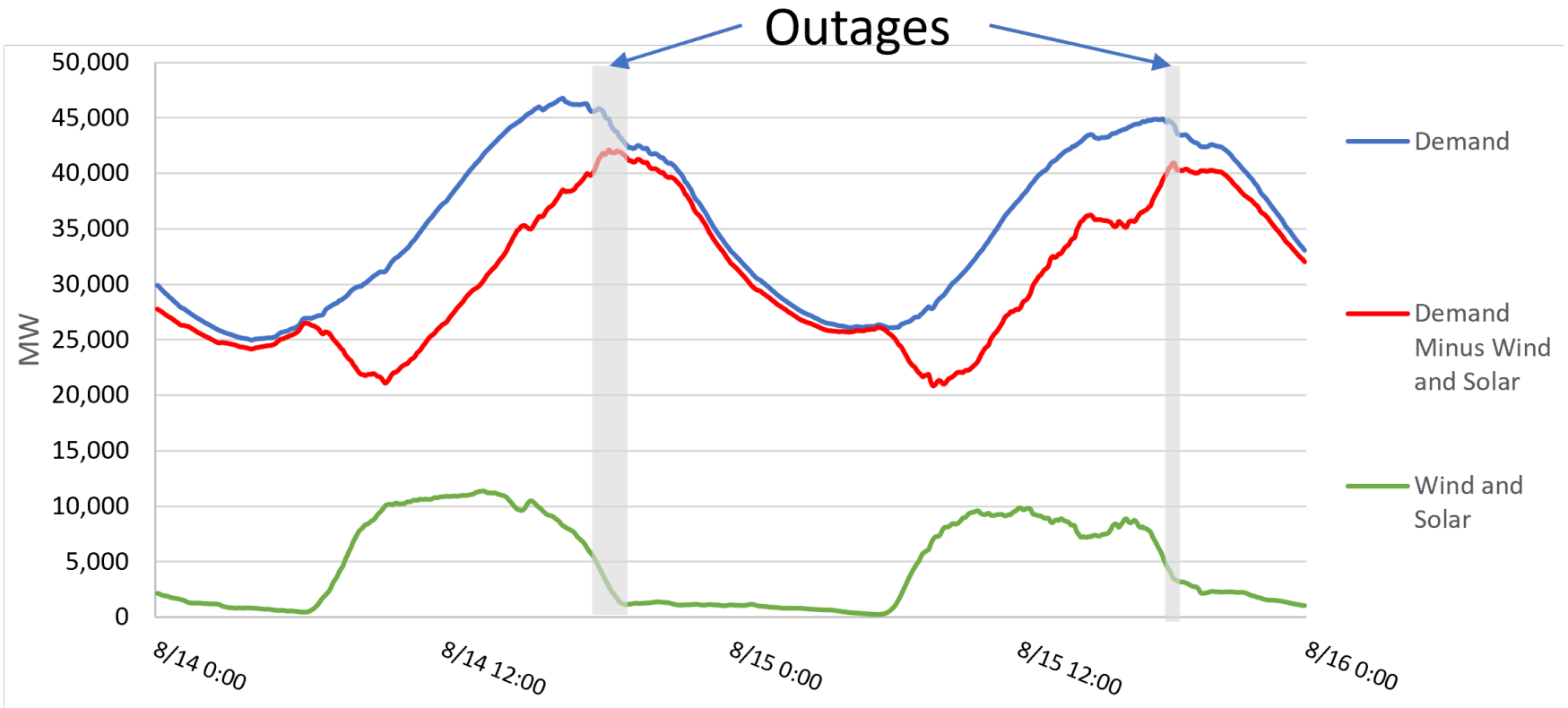


Simulated impact of increased 4-hour storage deployment on net load shape



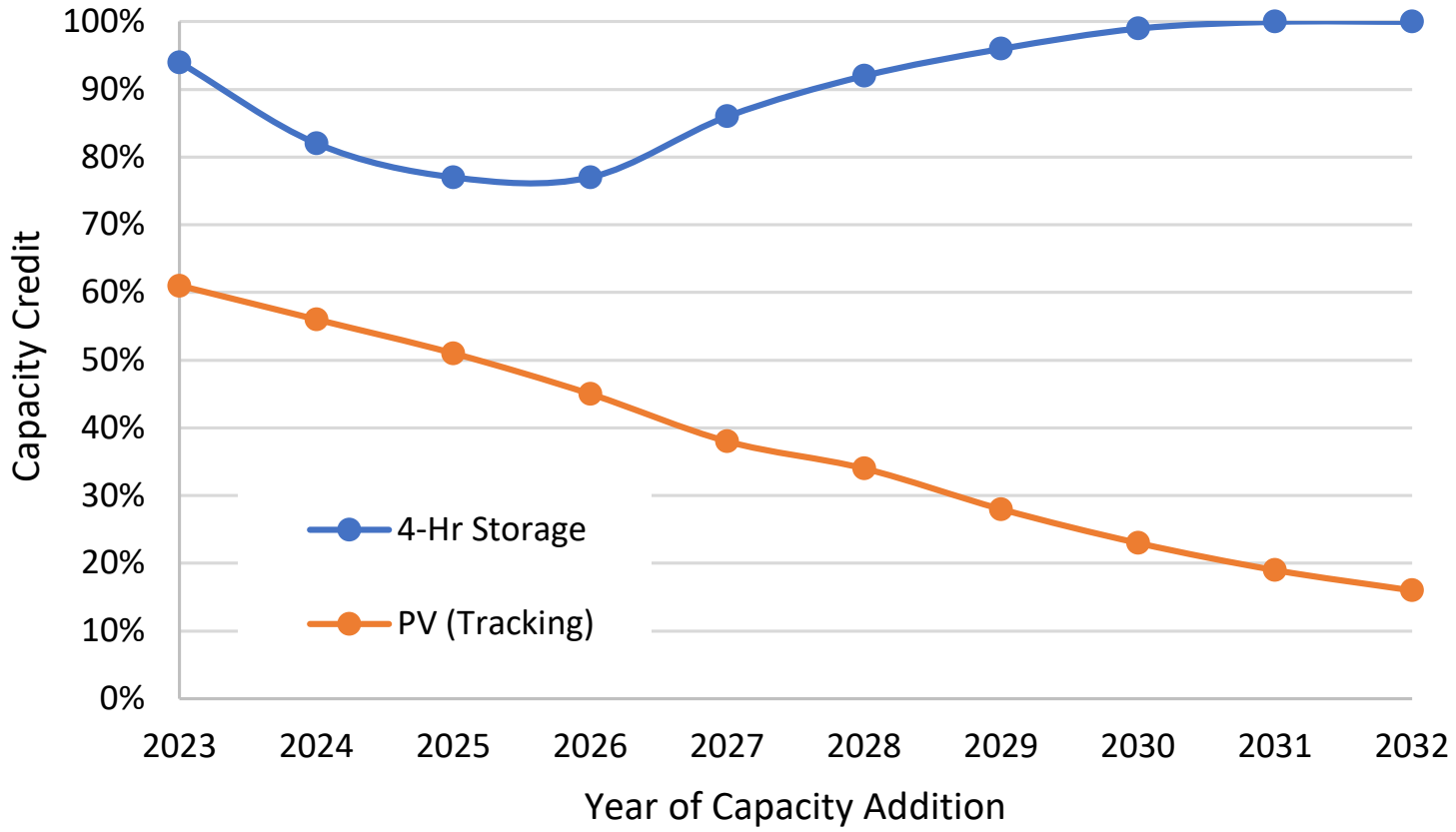
PV increases opportunities for 4-hour storage as peaking capacity – California Example

And Four Hours Should be Enough For Now….



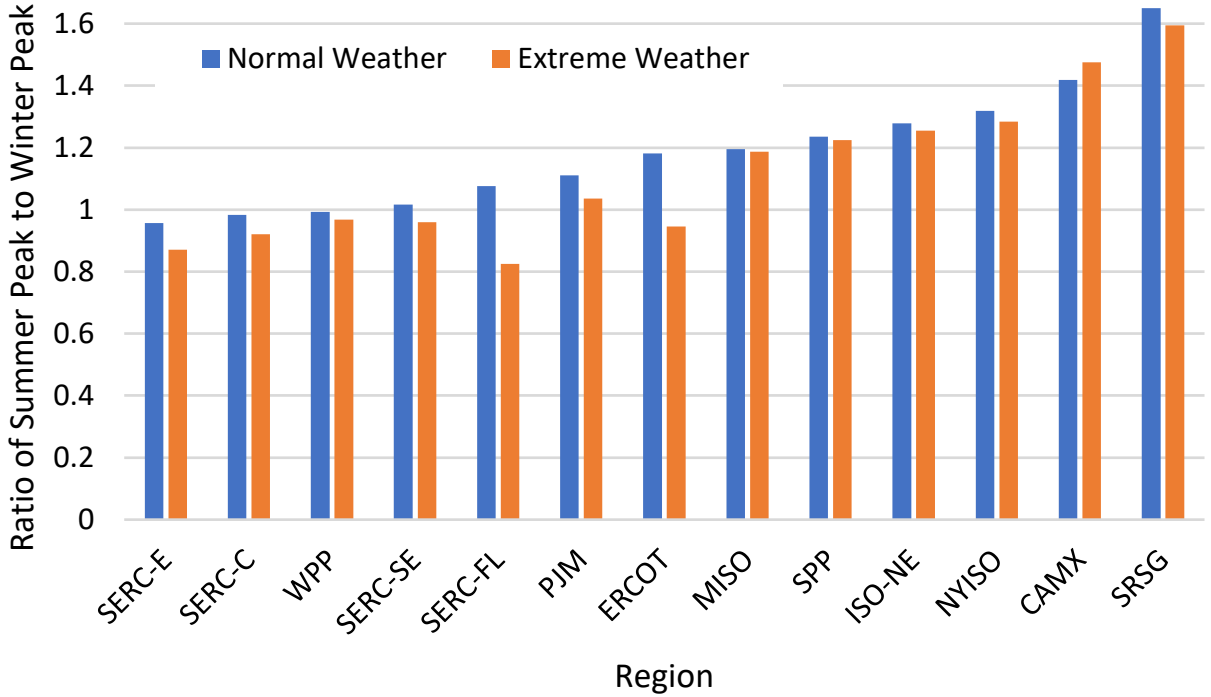
CAISO 2020 outages could have been addressed with 2.5 hours of storage

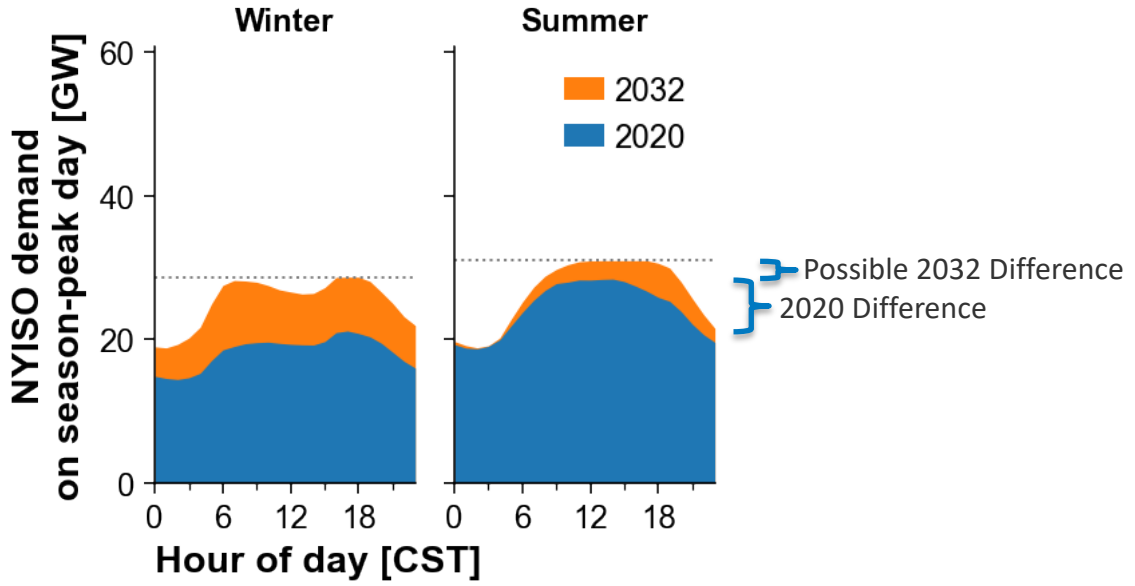
Four Hour Storage Maintains Summer Capacity Value



PJM Analysis by Astrape

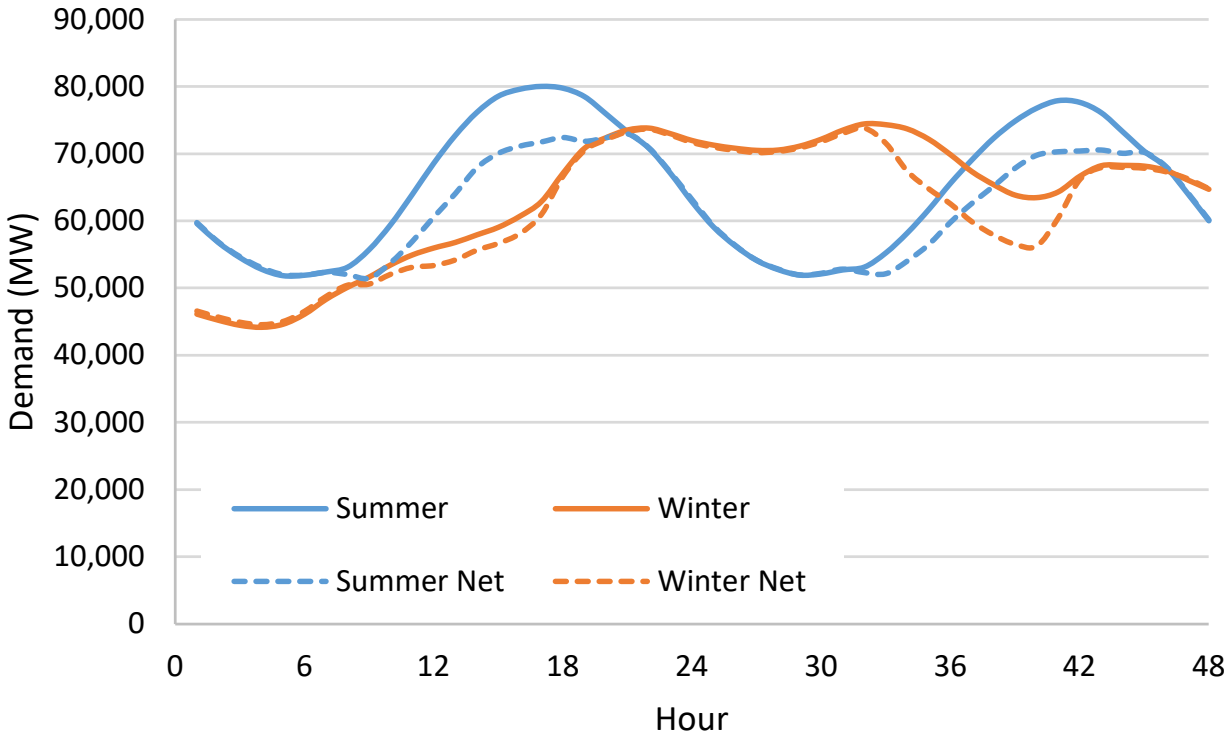
But Winter Peaks are Coming! (or already here…)



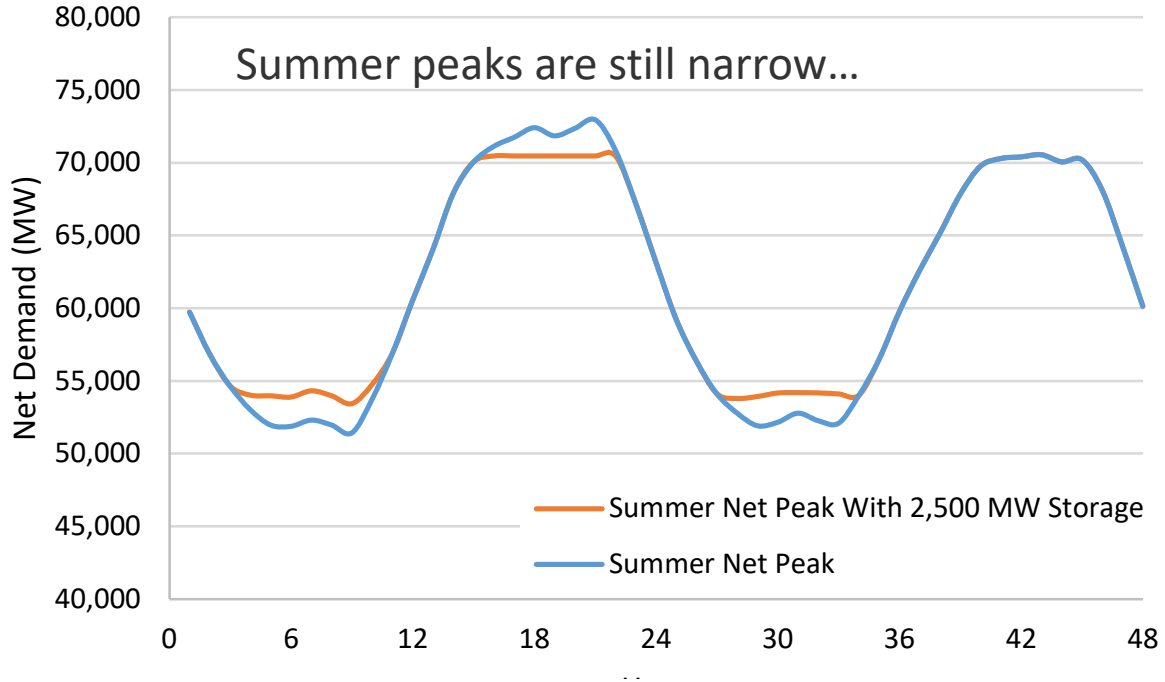


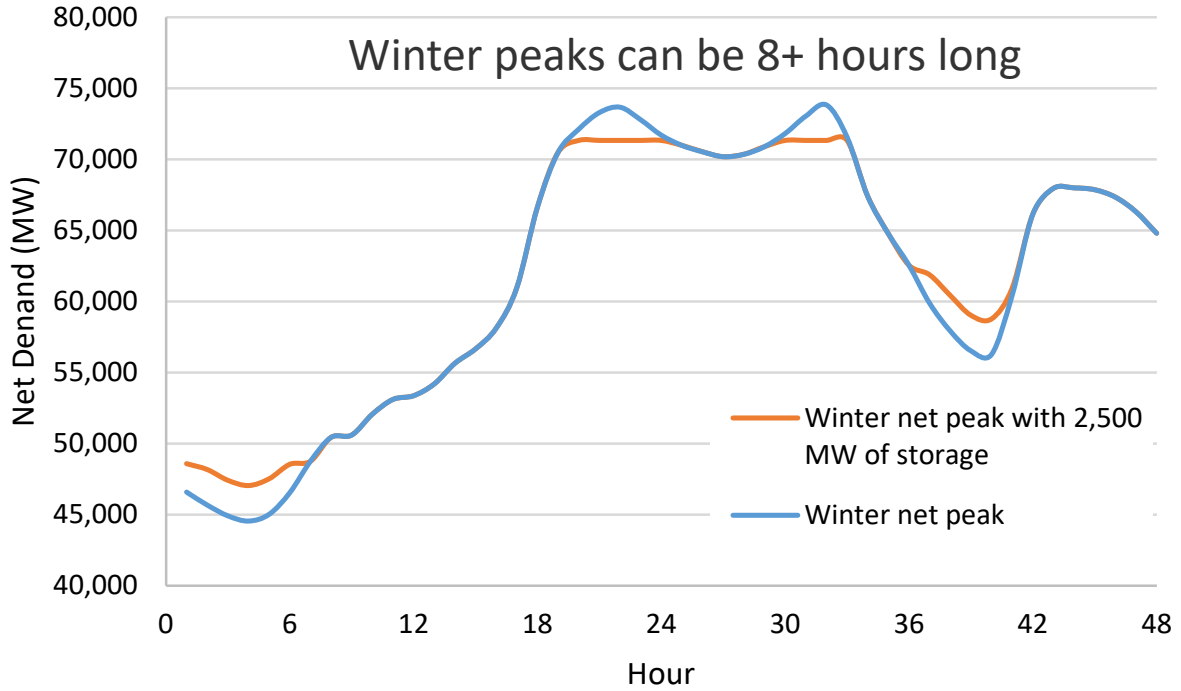
The Southeast is now winter peaking !!

Transition to Longer Winter Peaks

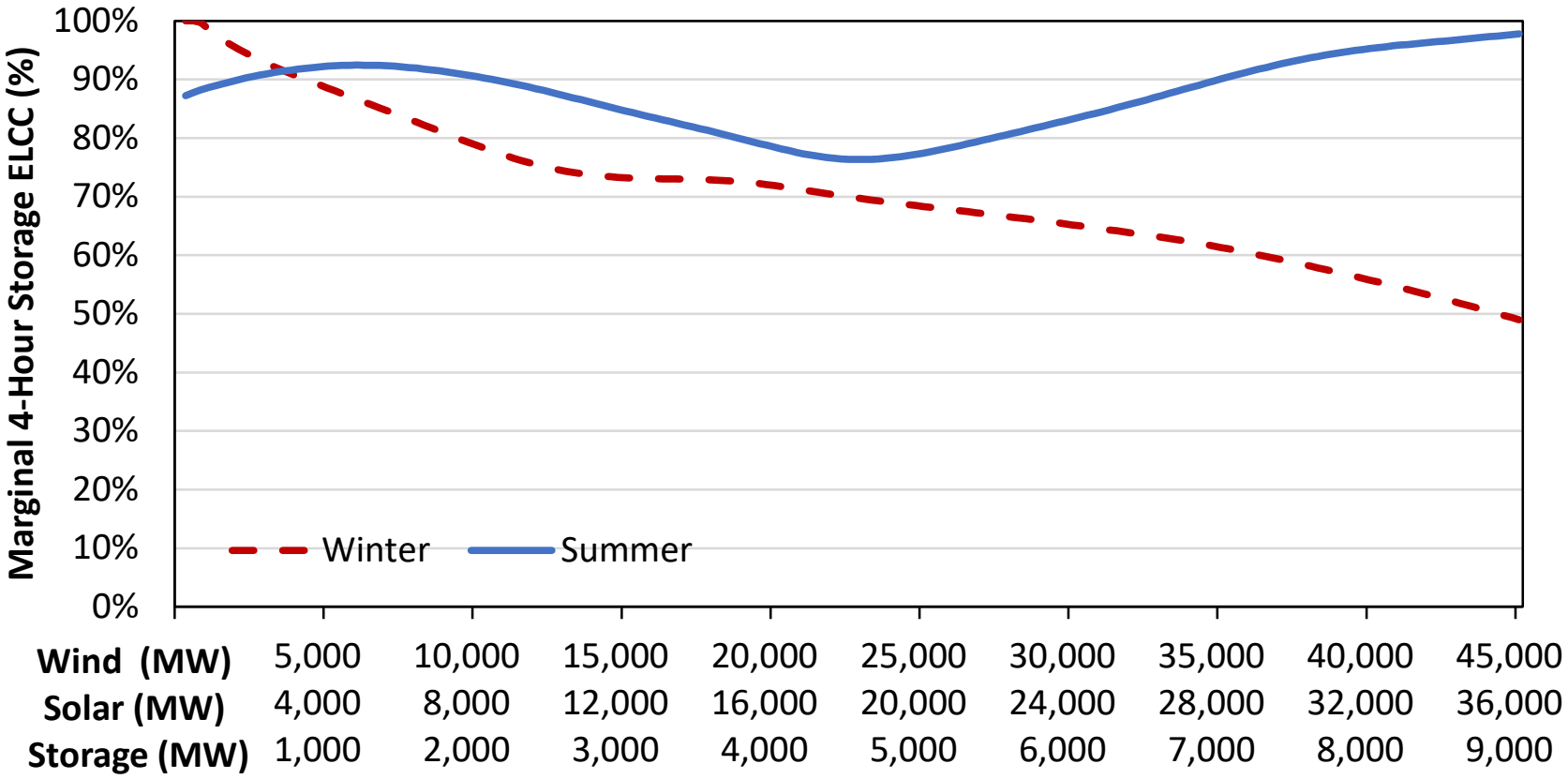


2022 ERCOT load data – net winter peak with the impact of PV





Decline in Winter Capacity Value – ERCOT Example

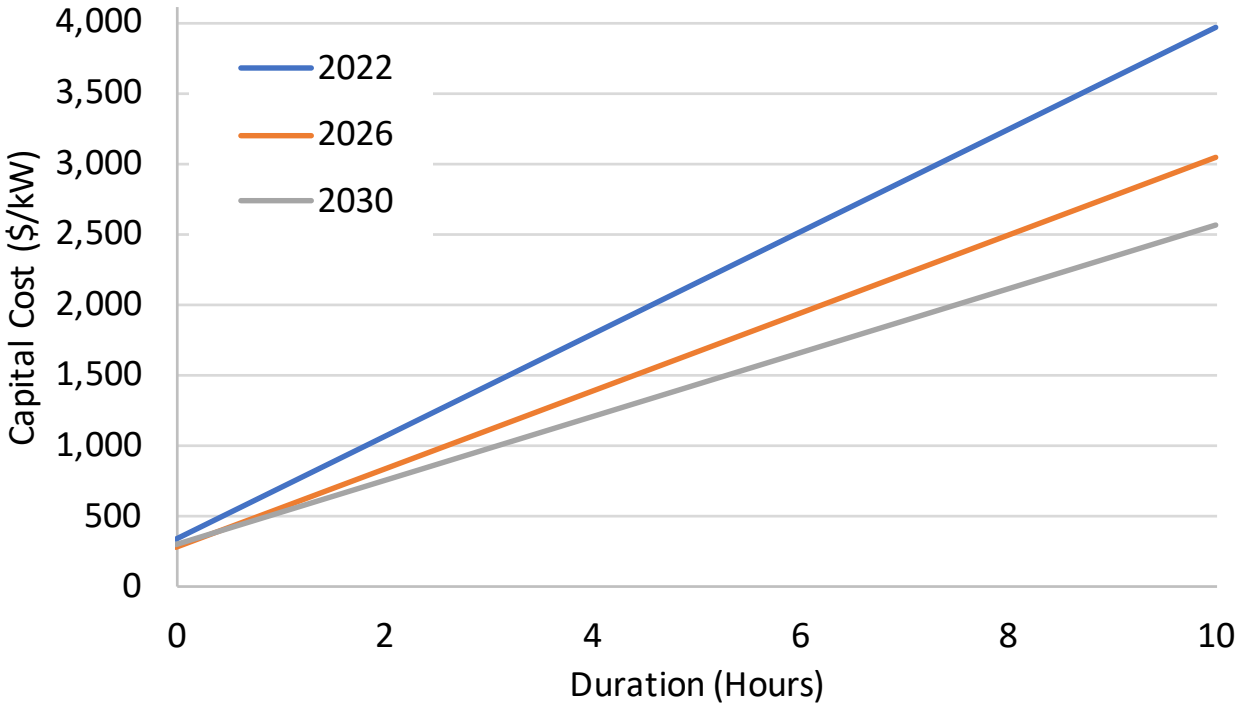


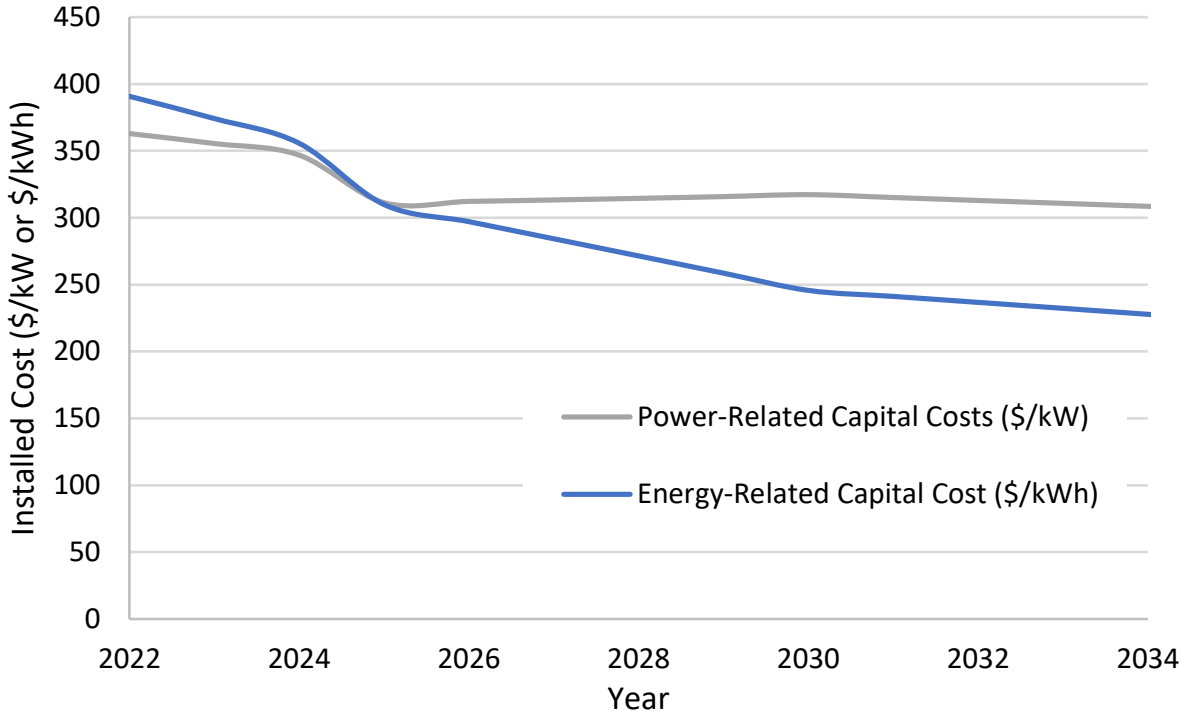
ERCOT will be here soon!

How to Beat Li-Ion….

- What happens when the capacity credit of a 4-hour device falls to ~50%?
- Just build an eight hour li-ion battery?
- Or something else?

Beyond Li-Ion? Declining costs and potential longer duration



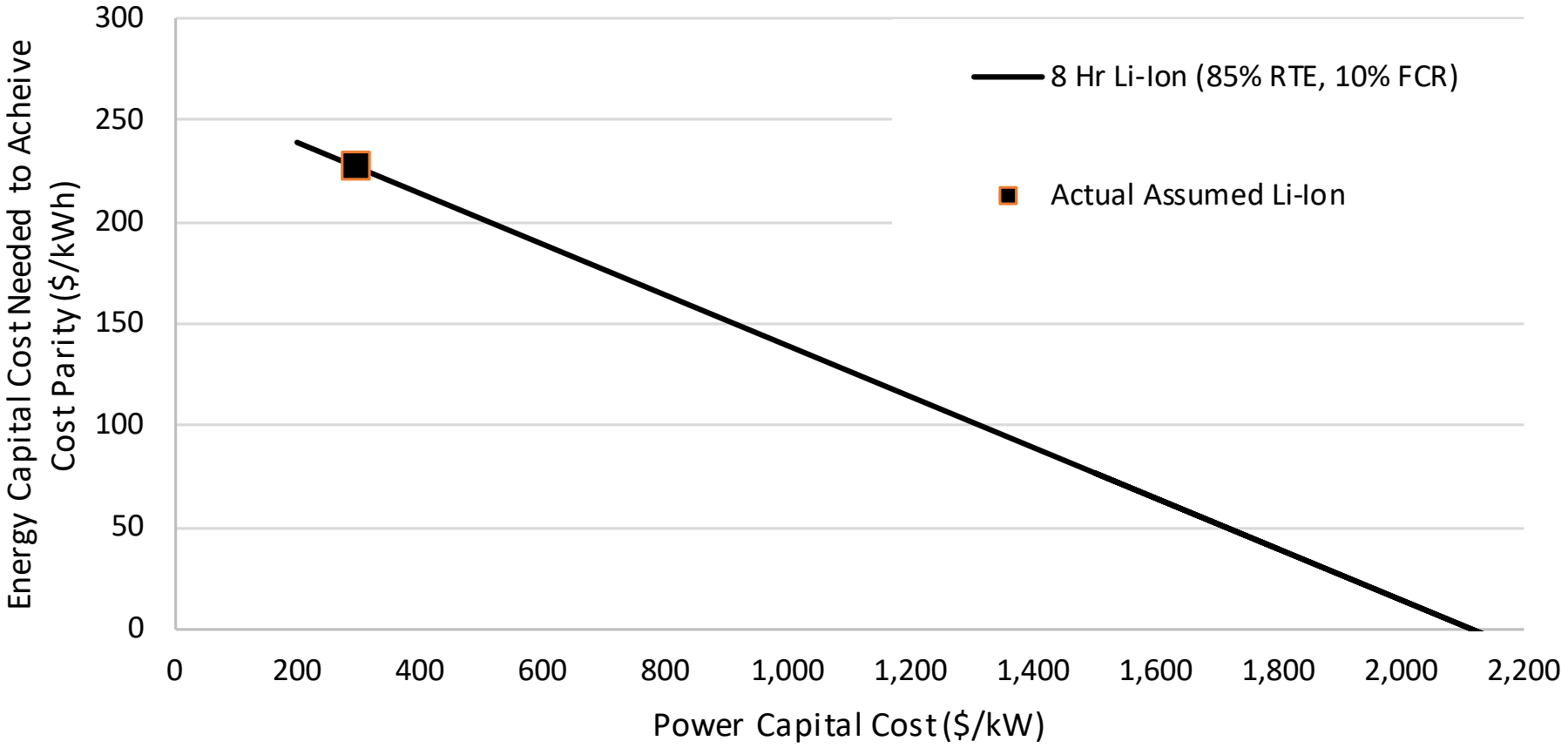


ATB mid-case estimates for Li-Ion

Four Parameters to Consider

- Power component cost ($/kW)
- Energy component cost ($/kWh)
- Round-trip efficiency
- Life

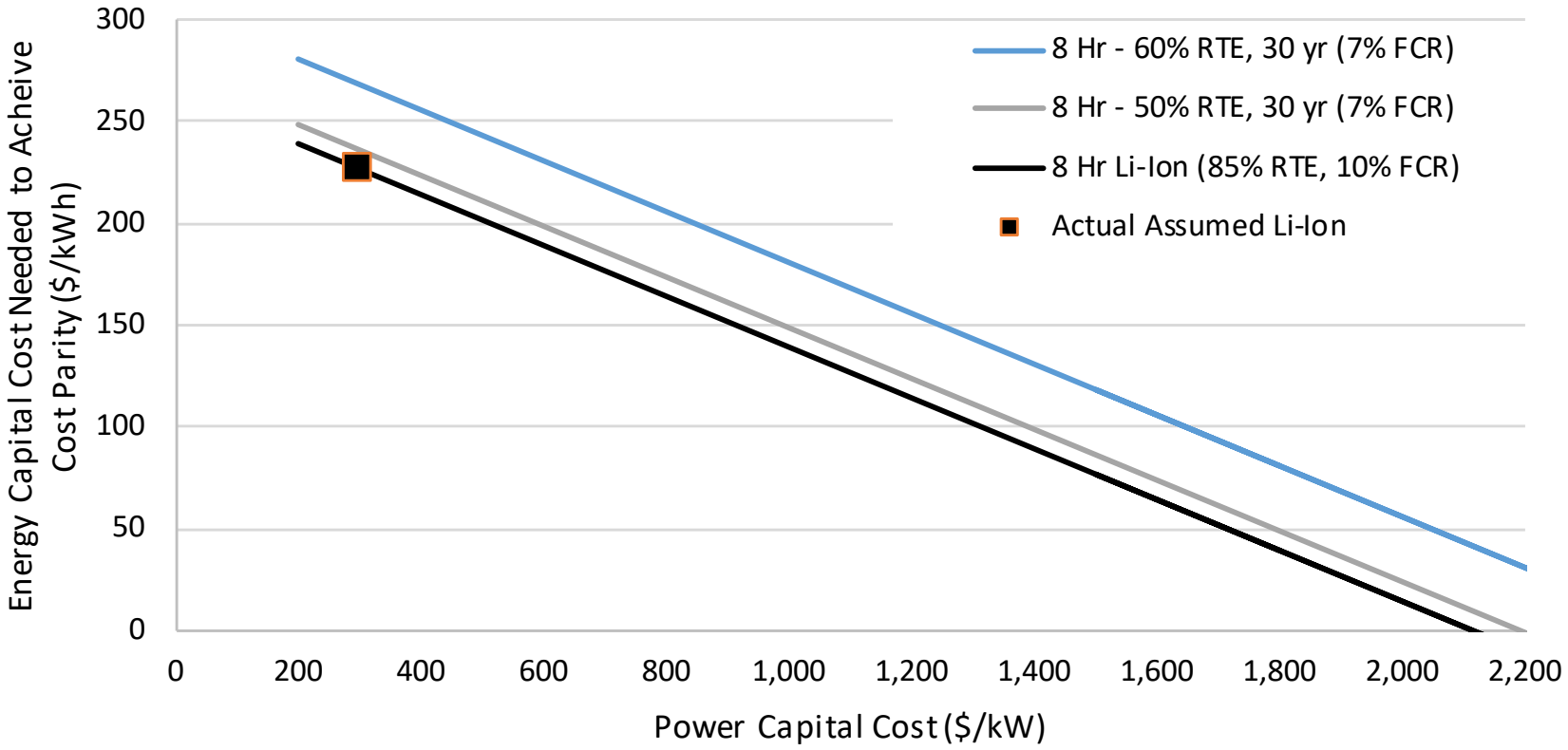
Breakeven Conditions for 8-Hour Devices in 2030



Assuming same life and efficiency as Li-Ion

Many longer-duration storage technologies are based on higher power-related costs, but lower energy related costs, creating a crossover point at a certain duration

Other Key Drivers – Life and Efficiency



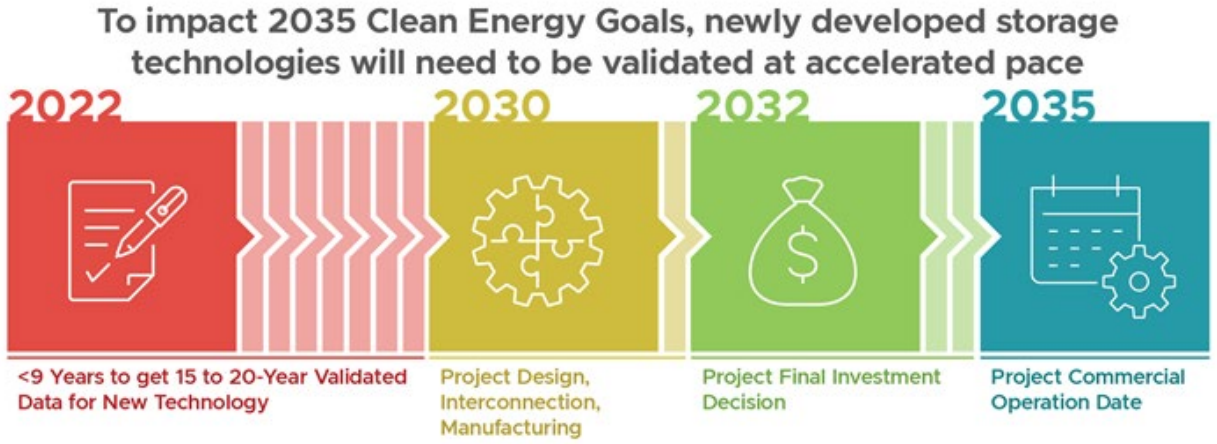
1) Lower efficiency requires a lower capital cost
2) Longer life allows for a higher capital cost

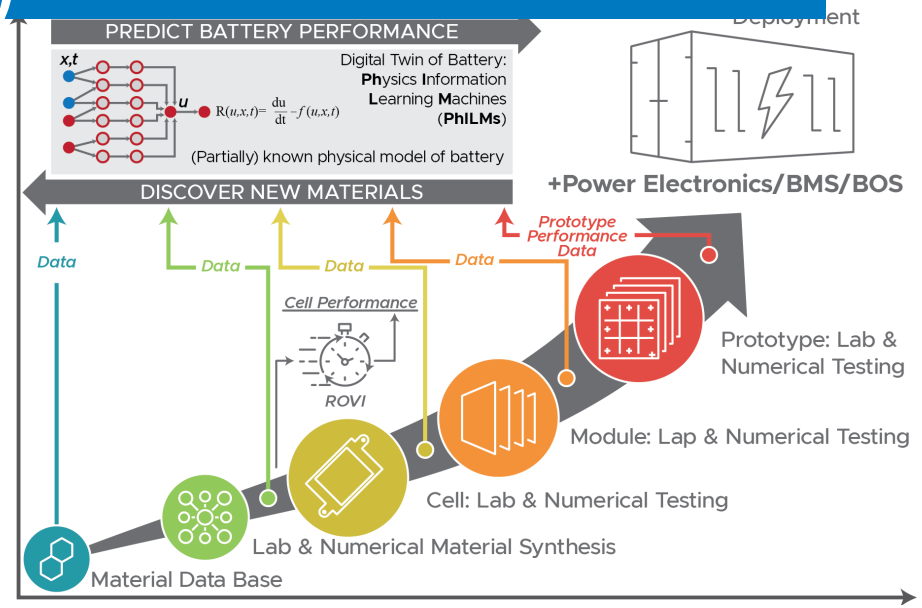
Many longer-duration storage technologies are based on higher power-related costs, but lower energy related costs, creating a crossover point at a certain duration

Other caveats

- Competition for materials
- The normal issues of scaling…

Getting there faster: Rapid Operational Validation Initiative (ROVI)

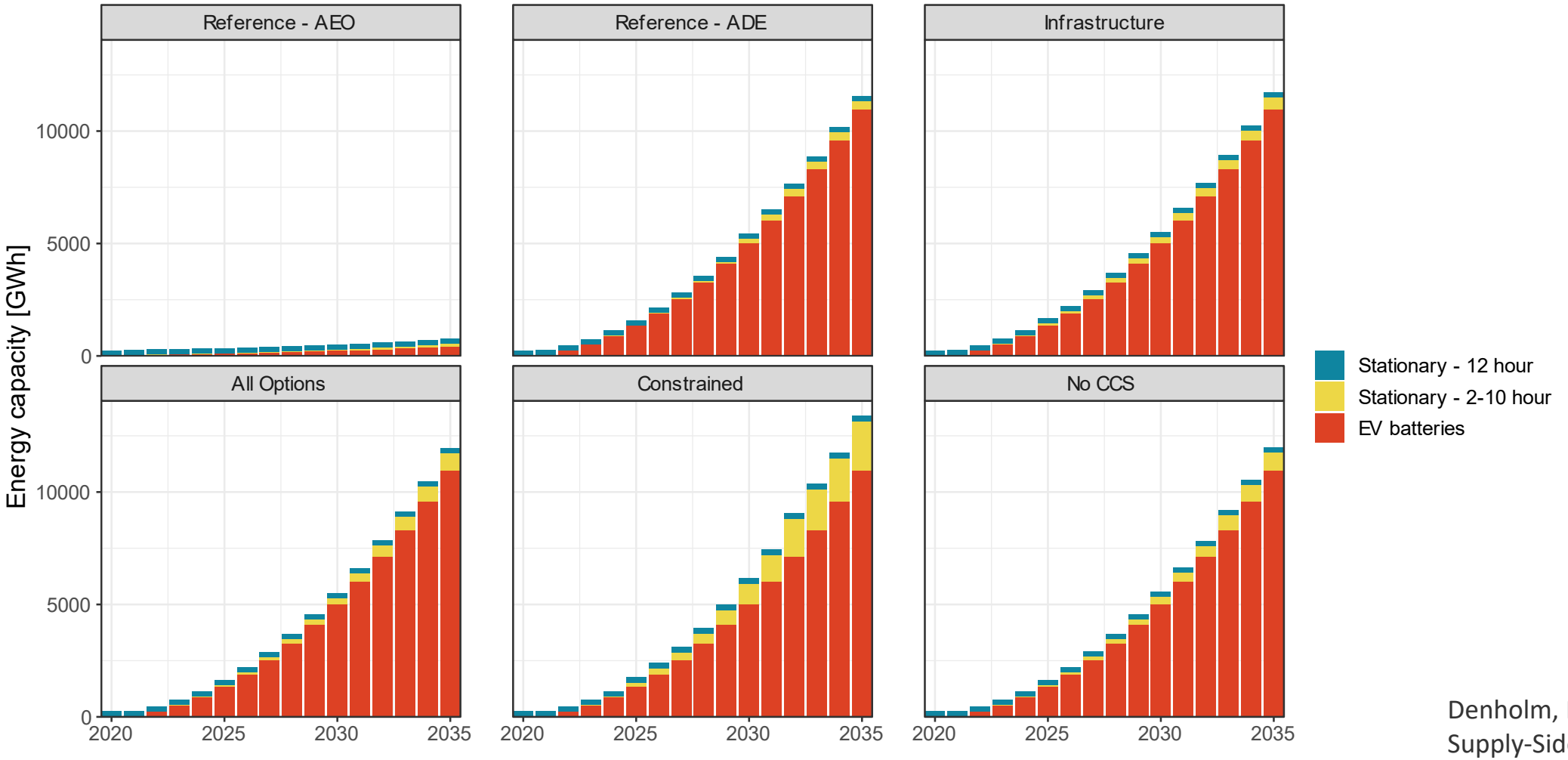




- Accelerate time from lab to market for new LDES technologies via accelerated life prediction tools based on laboratory testing and field deployments
  - 15-year investment-grade prediction from 1-year data
  - Evolving grid use scenarios impact value generation
- Track OE and OCED LDES technologies

Pacific Northwest National Laboratory · Sandia National Laboratories · Argonne National Laboratory · INL Idaho National Laboratory · Oak Ridge National Laboratory · NREL

Actual storage capacity driven by electric vehicles



Reference-AEO uses low demand growth. Reference-ADE assumes a path towards economy-wide decarbonization

Denholm, P., et al. (2022). Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035. Golden, CO: National Renewable Energy Laboratory. NREL/TP6A40-81644.

Conclusions

- The opportunity is very large
- Li-Ion is winning for now because the market opportunities driven by summer peaks and limited incentives for longer duration
- Opportunities for longer duration will grow
- There is a large surface space of power- and energy-related costs combinations that could beat Li-Ion, especially considering the potential for longer life, which tends to offset the lower RTE (up to a point)

Thank you

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