The Evolving Landscape for Storage: Wholesale Market, T&D, and Customer Benefits

PREPARED FOR

The MIT Energy Initiative
Electric Power Systems Center
Spring Workshop

PREPARED BY

Johannes Pfeifenberger
Roger Lueken

May 13, 2020

THE Brattle GROUP

Agenda

I. The Costs and “Value Stack” of Storage

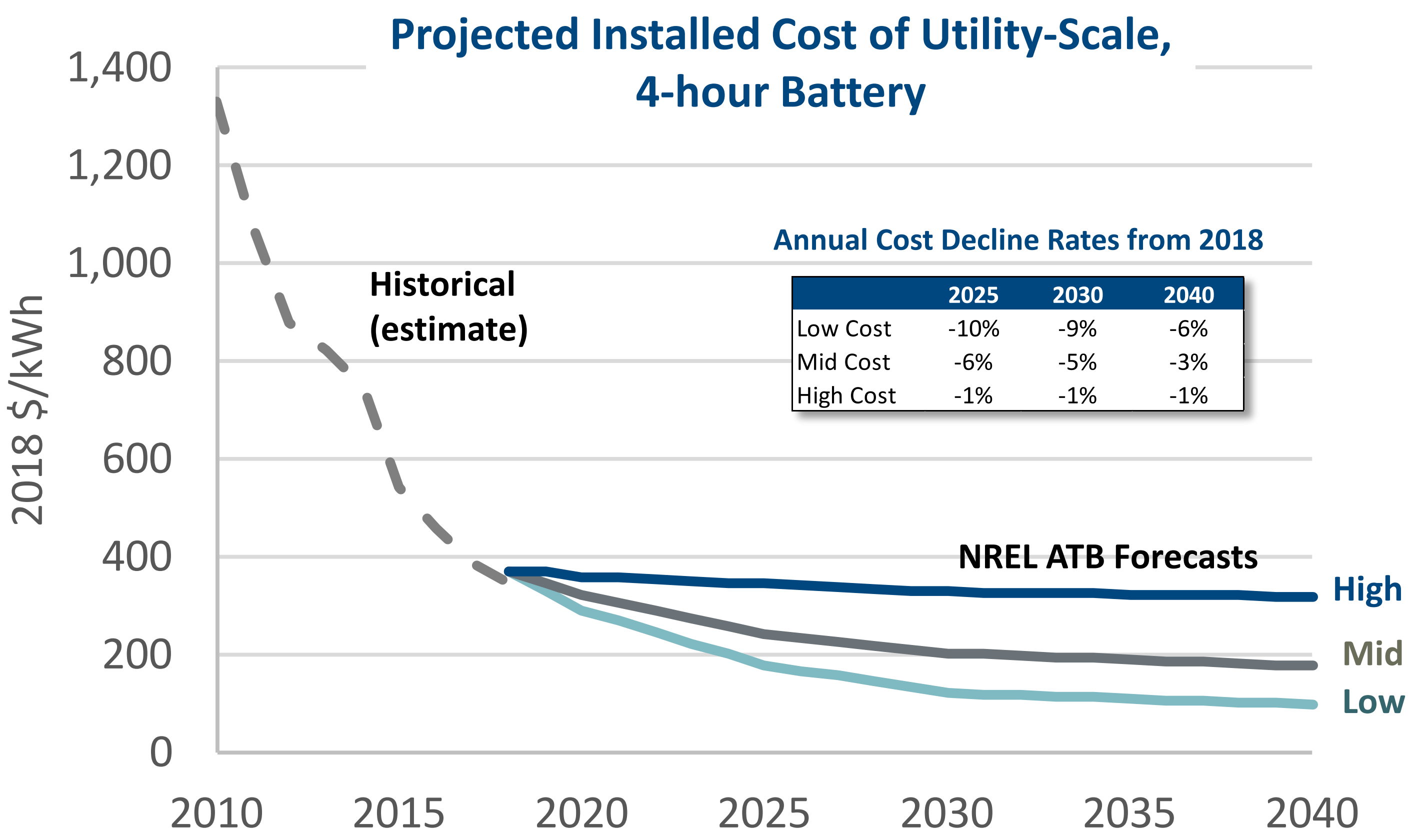
II. Wholesale Market Value of Storage

III. T&D-Deferral and Customer-Reliability Value of Distributed Storage

IV. The Value of Co-locating Solar+Storage

V. Takeaways

Declining Costs of Battery Storage



	2025	2030	2040
Low Cost	-10%	-9%	-6%
Mid Cost	-6%	-5%	-3%
High Cost	-1%	-1%	-1%

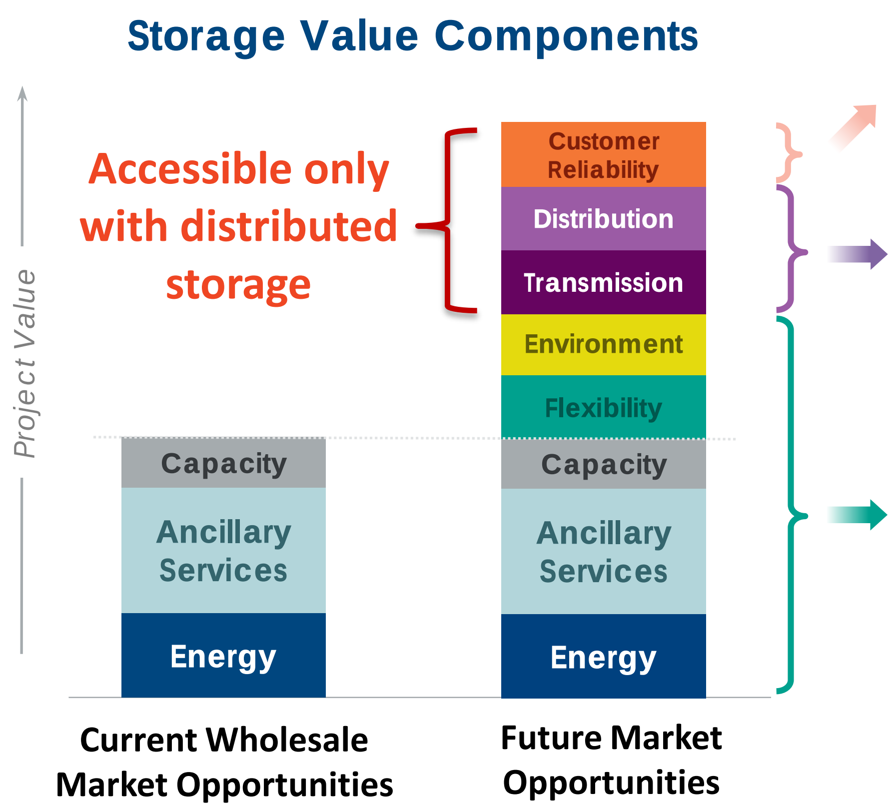
- NREL forecasts costs of ~$300/kWh ($1,200/kW) by the early 2020s are in line with recent solicitations by Xcel and NIPSCO

Source: Bloomberg New Energy Finance (2018) and NREL Annual Technology Baseline with Brattle analysis.
Notes: Historical estimate assumes Bloomberg NEF battery pack cost estimate plus a constant non-pack cost estimate of approximately $170/kWh. NREL costs are for a 4-hour, utility-scale lithium ion battery.

The Multiple Value Streams of Storage

Storage can capture multiple value streams, but the extent is limited by regulatory barriers and operational/locational constraints.

Customer and Distribution = State Regulated
Transmission = FERC Regulated



Customer Value

- Increased reliability (reduced outages)
- Increased engagement in power supply

Utility Infrastructure Value

- Deferred or avoided investments in distribution and transmission infrastructure
- Voltage support & improved power quality

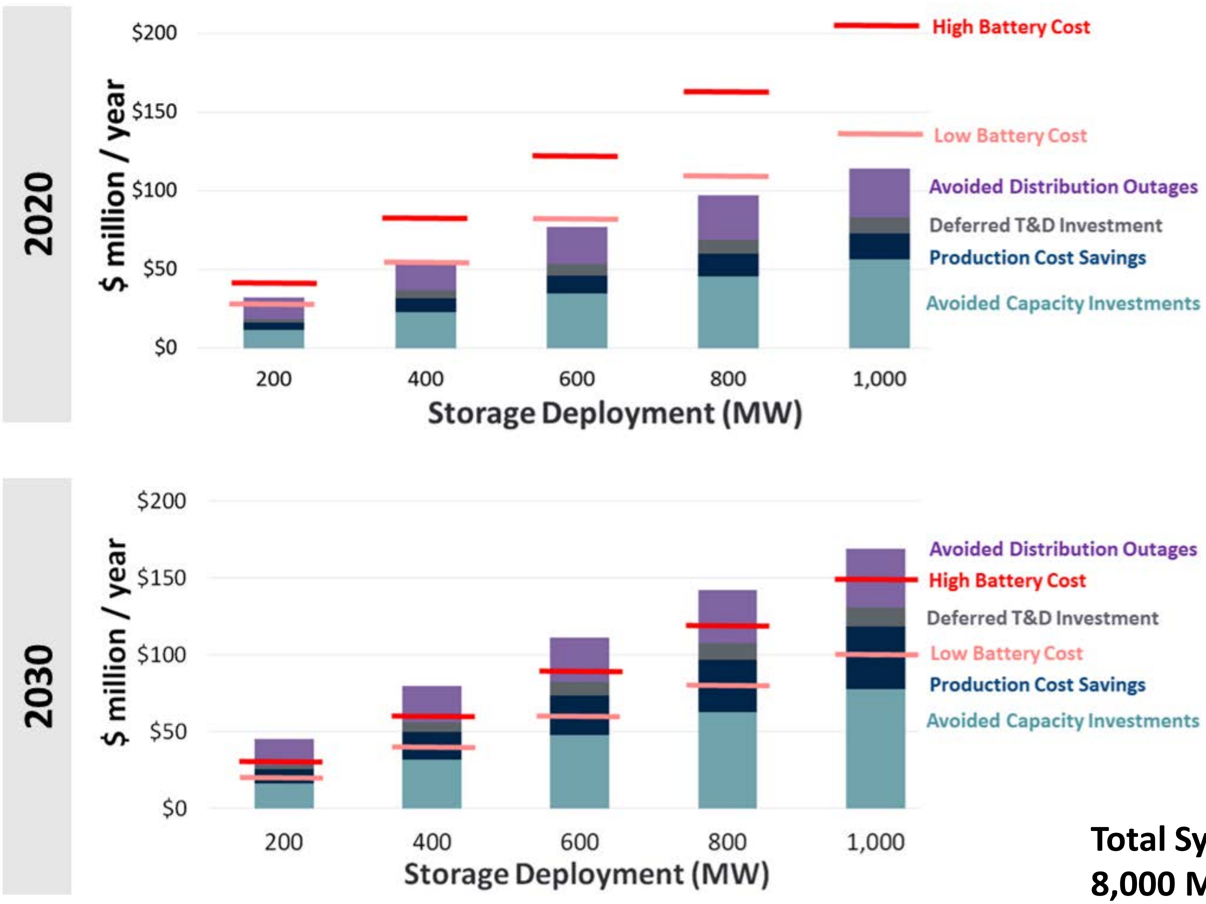
Wholesale Market Value

- Traditional value drivers: energy arbitrage, fast-response capabilities, and avoided capacity
- Realizing additional value due to higher quality A/S and load following reserves
- Flexibility and clean-energy products will provide additional revenue opportunities in the future

Subject of FERC Order 841

Total Benefits and Costs of Storage at Various Deployment Levels: 2020 vs. 2030

Nevada Case Study: modeled benefits and market impact of 4-hour storage for different system conditions and expected changes in the resource mix over time

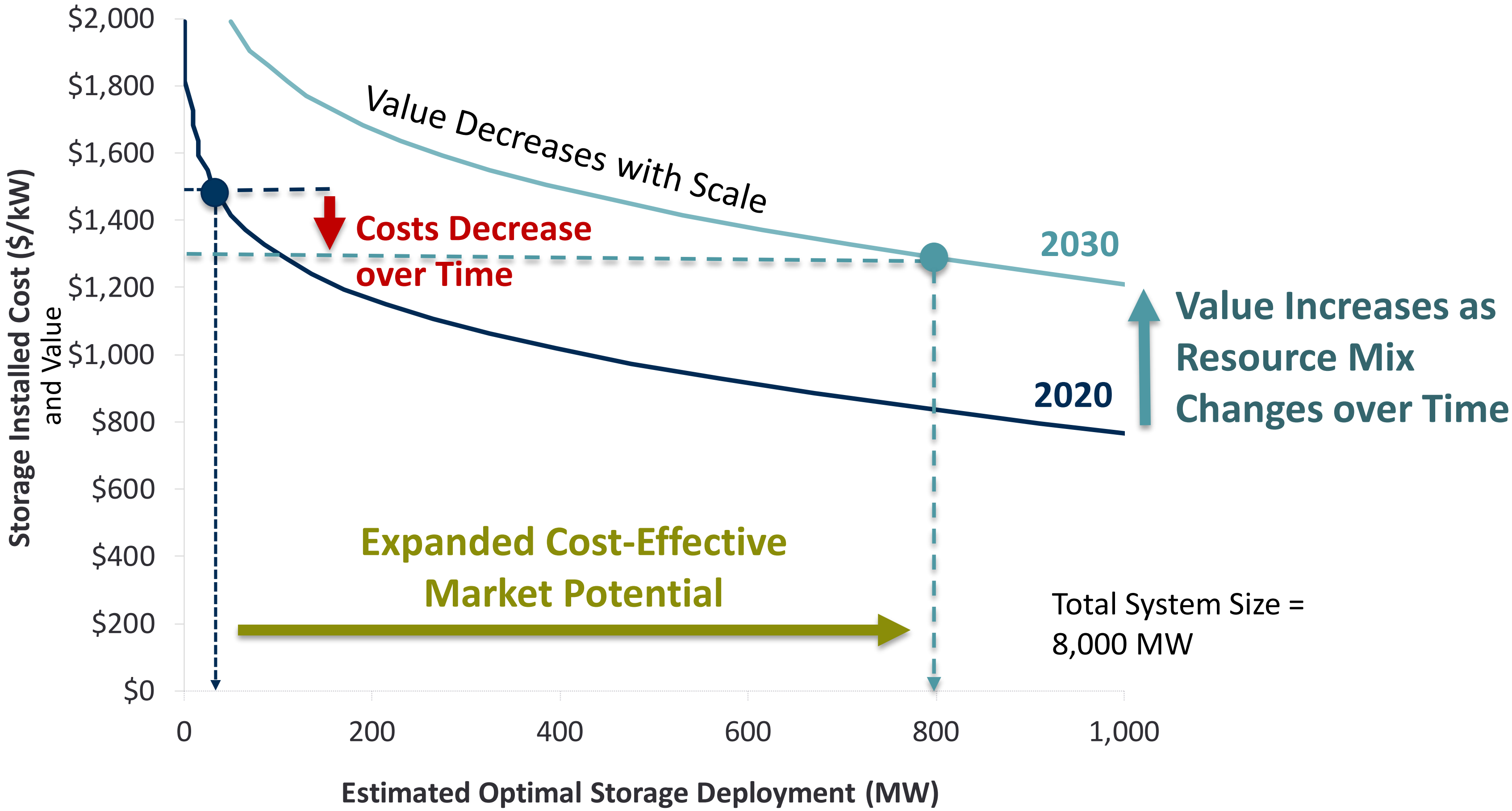


Total System Size = 8,000 MW

Note: All values are in nominal dollars;
Source: Hledik et al. The Economic Potential for Energy Storage in Nevada, October 2018.

Total Cost-Effective Market Potential of Storage: 2020 vs. 2030

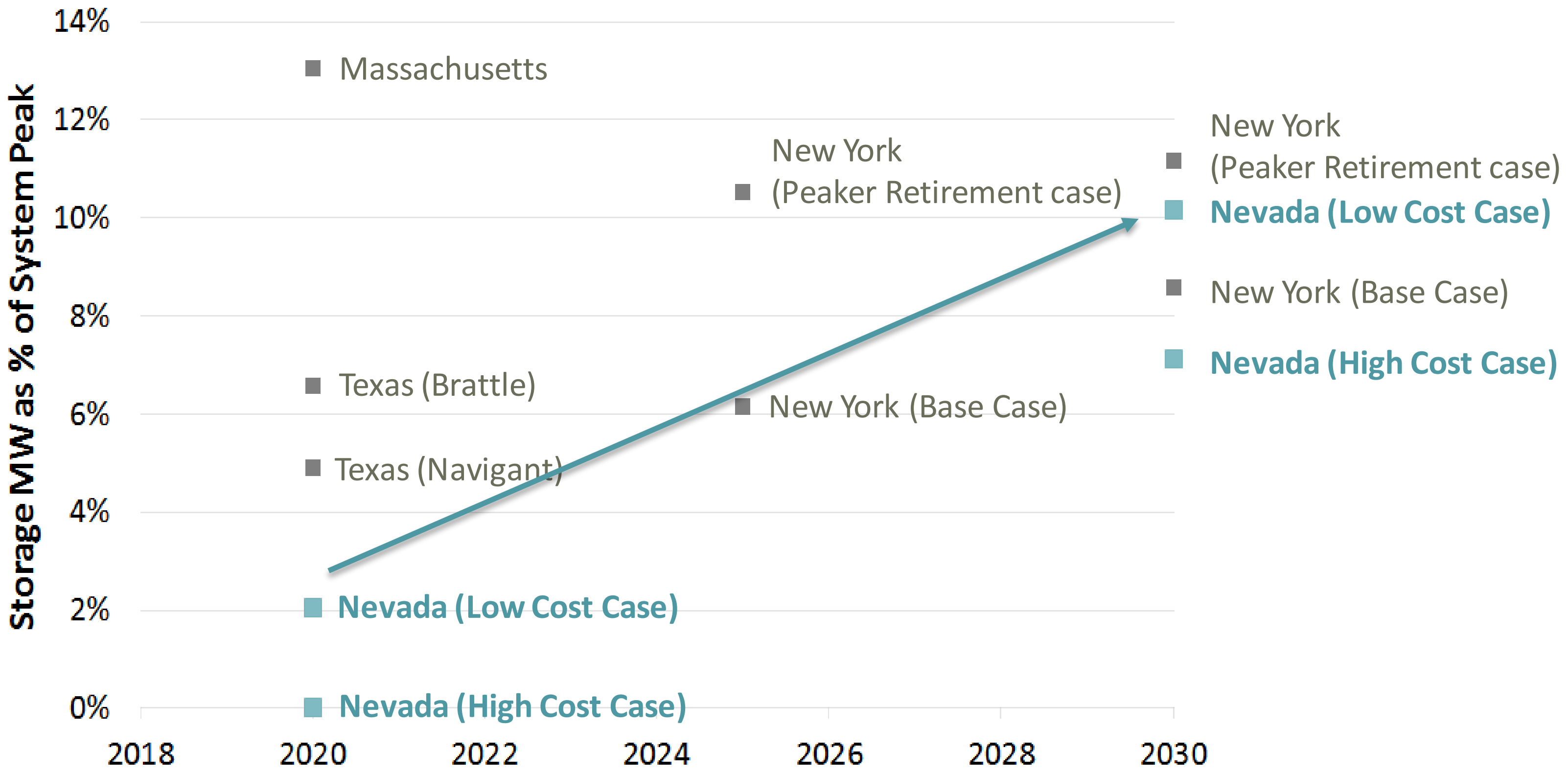
Nevada Case Study: cost-effective market potential of 4-hour storage expands as costs decline and the benefits of storage increase over time



Note: All values are in nominal dollars;
Source: Hledik et al. The Economic Potential for Energy Storage in Nevada, October 2018.

Cost-Effective Scale of Storage Deployment: About10% of System Peak

Cost-effective storage levels vary across studies and markets, but generally increase over time as more renewable generation is added to power systems

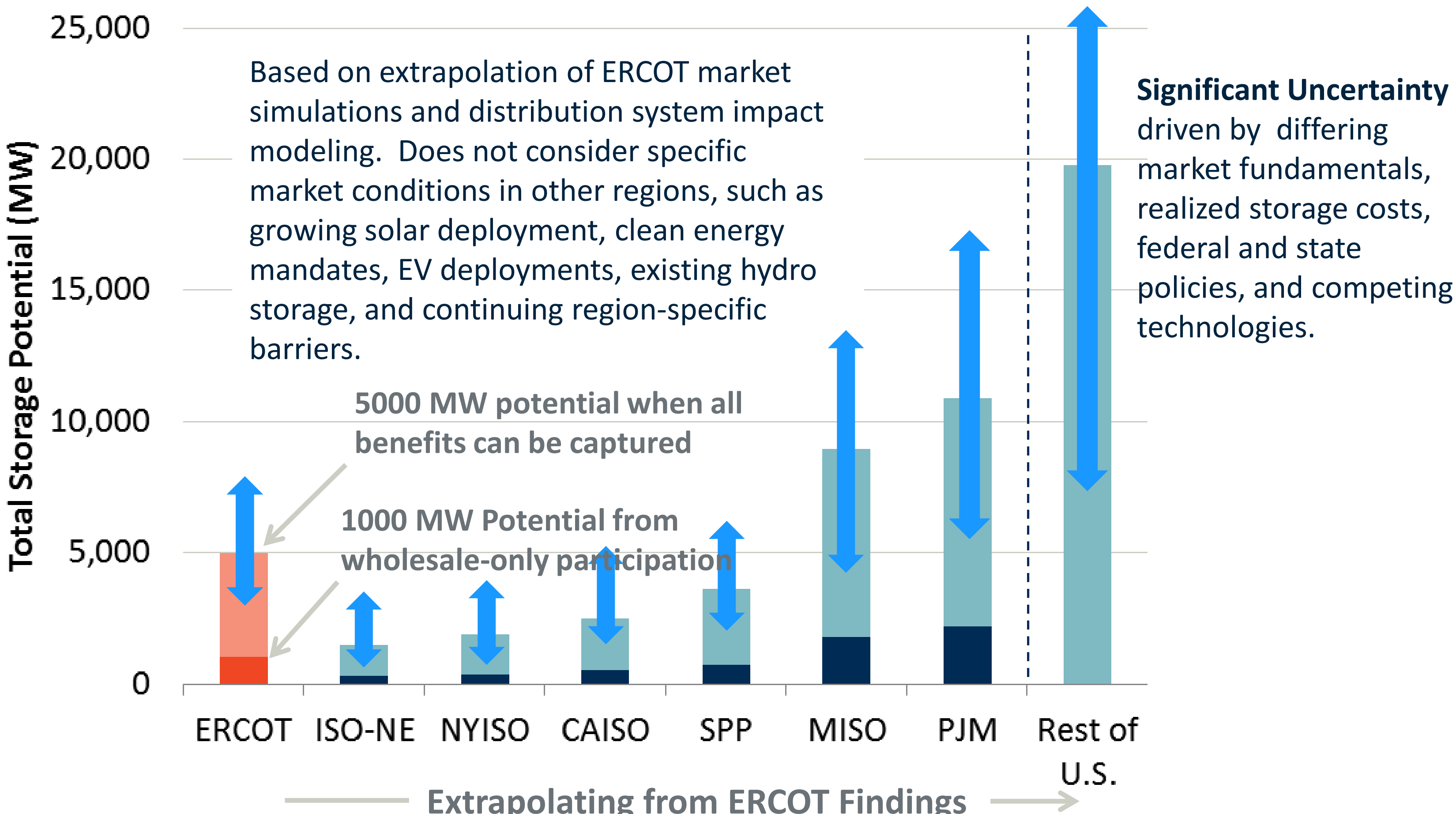


Sources:

Hledik et al. The Economic Potential for Energy Storage in Nevada (2018)
Massachusetts Clean Energy Center and Massachusetts Department of Energy Resources (2016). State of Charge: Massachusetts Energy Storage Initiative.
Chang, J, Pfeifenberger, Spees, Davis, Karkatsouli, Regan, Mashal (2015). The Value of Distributed Electricity Storage in Texas.
NYSERDA and the Department of Public Service (2018). New York State Energy Storage Roadmap

U.S.-Wide Cost-Effective Storage Potential: Getting to 50 GW

At a cost of $350/kWh (installed), **Order 841 could unlock 7,000 MW** based solely on wholesale-market participation in RTOs. This increases to **50,000 MW** US-wide if all benefits can be captured, but **requires states to unlock T&D and customer benefits**.



Notes: Extrapolated from ERCOT study based on average 2016 system load

Limitations to “Value Stacking”

The ability of storage to simultaneously provide multiple value streams is constrained by locational and operational limitations

Locational limitations: Benefits derived from avoided outages and deferred T&D investment tend to be site-specific

Operational limitations: Arise because amount of energy stored is limited

Example modeling assumptions to account for constraints in “value stacking”:

- **T&D deferral:** Assume storage deployed for T&D deferral prioritizes reducing <u>local peak</u> load over all other services
- **Capacity:** Assume storage must fully charge in advance of <u>system peak</u> load hours
- **Energy:** Dispatch is affected by T&D deferral and capacity requirements; cannot simultaneously provide energy and certain ancillary services
- **Customer outage reduction value:** Assume outages cannot be anticipated and have 50% SOC at time of event; but in reality storage operators can chose to be at full charge in anticipation of outage events (e.g., forecast storms). Assumes microgrid islanding capabilities.

Our simulations show that these limits do not substantially reduce the joint value relative to sum of individual value streams

State Regulatory Example: California's Multiple-Use Applications (MUA)

The California Public Utilities Commission (CPUC) has adopted 11 stacking rules to govern multiple-use distributed and utility-scale storage applications

1. Customer-side storage can provide all services
2. Distribution-system storage can provide all services <u>except</u> the customer-side services
3. Transmission-system storage can provide all <u>except</u> customer-side and distribution-system services
4. All storage resources can provide: resource adequacy, transmission, and wholesale-market services
5. Reliability services must have priority
6. Reliability services provided must not be in conflict or mutually exclusive
7. Different portions of capacity can be dedicated to perform different services
8. Provision of each service must be enforceable, including through penalties for non-performance
9. In response to a utility request for offer, storage providers must list (and update over time) any services provided outside of the solicitation
10. The storage resource must comply with all specified availability and performance requirements
11. Compensation is permitted only for measurable services which are incremental and distinct; the same service can be counted and compensated only once

Source: CPUC 2018. [Decision 18-01-003 in Rulemaking 15-03-011]

Agenda

I. The Costs and “Value Stack” of Storage

II. Wholesale Market Value of Storage

III. T&D-Deferral and Customer-Reliability Value of Distributed Storage

IV. The Value of Co-locating Solar+Storage

V. Takeaways

Storage Participation in Existing and Future Wholesale "Product Markets"

Storage resources are well positioned to compete in the emerging products-based wholesale power markets

Resources/Technologies (Existing and New)

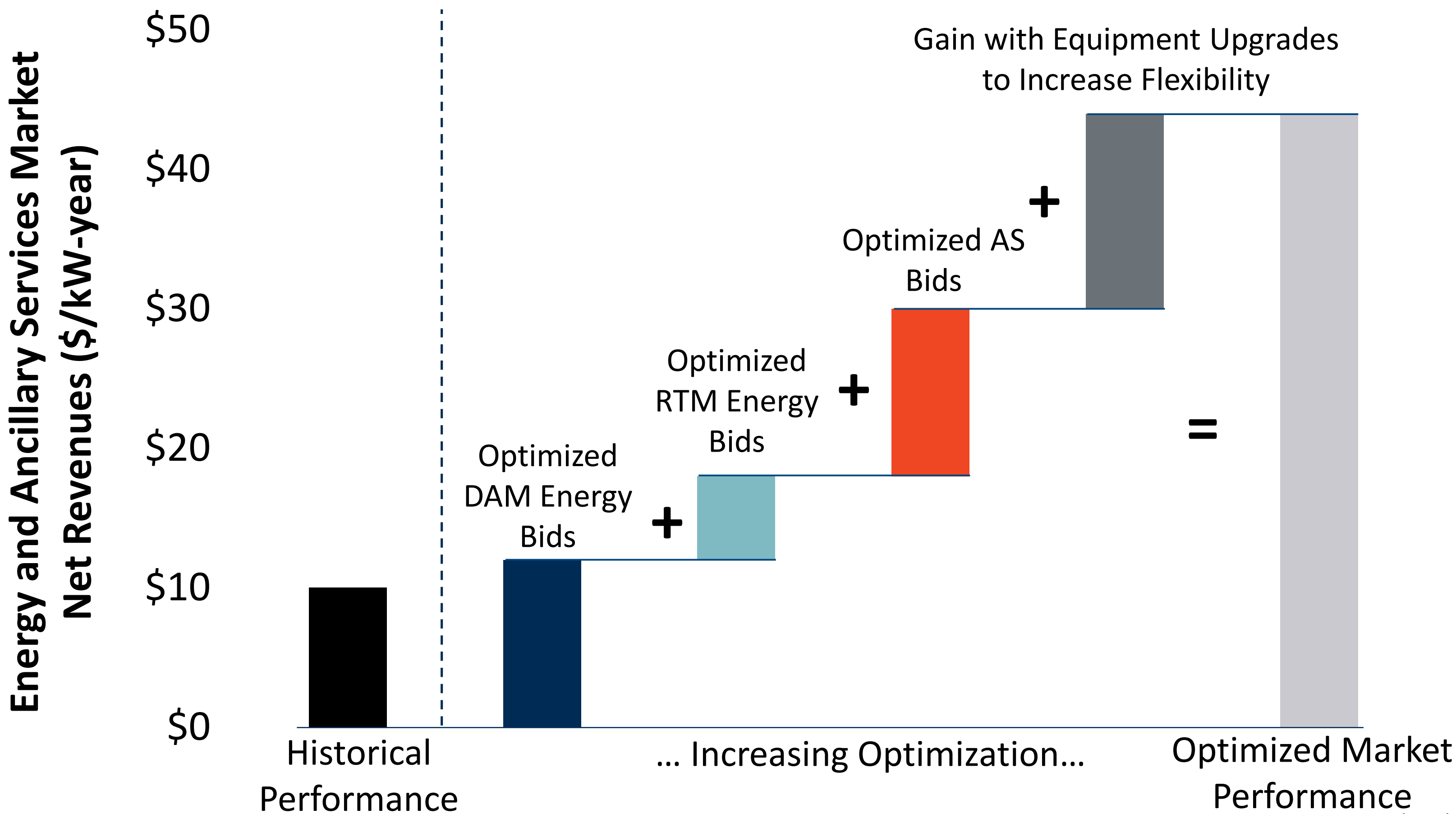
Products	Nuclear	RoR Hydro	Hydro w/ Storage	Coal	CC	CT	Wind	Solar	Battery Storage	DR	EE	Imports	Number of Competing Technologies
DA Energy	✓	✓	✓	✓	✓	O	✓	✓	✓	O	O	✓	10.5
RT Energy (5 min)	O	✓	✓	✓	✓	O	✓	✓	✓	O	O	O	9.5
Regulation	X	✓	✓	✓	✓	O	O	O	✓	O	X	O	7.5
Spinning Reserves	X	O	✓	✓	✓	✓	X	X	✓	O	X	O	6.5
Non-Spinning Reserves	X	X	✓	X	✓	✓	X	X	✓	O	X	O	5
Load following / Flexibility	O	O	✓	O	✓	✓	O	O	✓	O	X	O	7.5
Capacity / Res. Adequacy	✓	O	✓	✓	✓	✓	O	O	O	✓	✓	✓	10
Clean Energy	✓	✓	✓	X	O	O	✓	✓	O	O	✓	✓	9
Reactive / Voltage Support	✓	✓	✓	✓	✓	✓	O	O	✓	X	X	O	8.5
Black Start	X	✓	✓	O	✓	✓	X	X	O	X	X	O	5.5
Inertia	✓	✓	✓	✓	✓	✓	O	X	O	X	X	O	6.5

Legend — **Technical Capability to Provide Service**

- ✓ Well Suited (1.0)
- O Neutral (0.5)
- X Not / Poorly Suited (0)

Increasing the Wholesale Market Value: Pumped Hydro Storage

Optimized operating strategies, accounting for existing market rules and **DA/RT/AS+uncertainties**, can increase storage revenues 2–5 times.



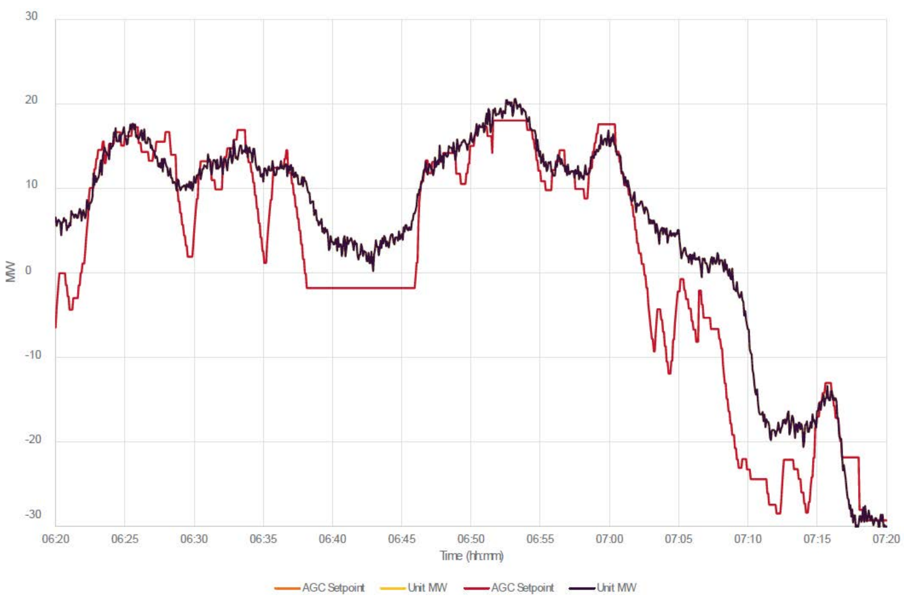
Source: Based on analysis with Brattle's bSTORE modeling platform.

Energy Arbitrage and Ancillary Service: Australia's "Big" Battery

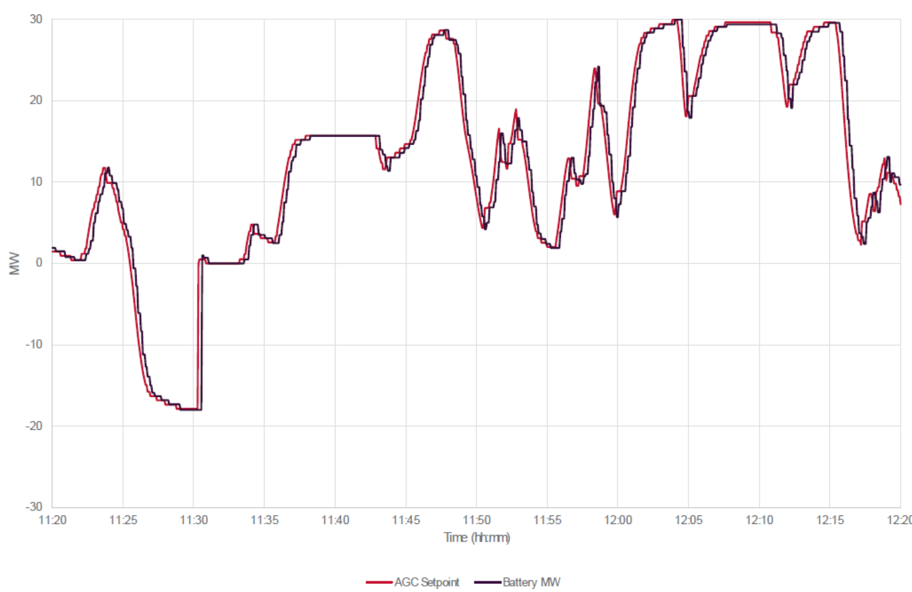
Tesla's Hornsdale battery in S. Australia illustrates the real-world benefits of using batteries to provide both energy and ancillary services value

- Battery size: 100 MW discharge, 80 MW charge. Storage capacity of 129 MWh
- 30 MW and 119 MWh dedicated to **energy arbitrage**
- 70 MW of 10 MWh dedicated to **ancillary services** (grid support)**:**

Accuracy and speed of regulation FCAS response
Large conventional steam turbine



Accuracy and speed of regulation FCAS response
Hornsdale Power Reserve (battery)

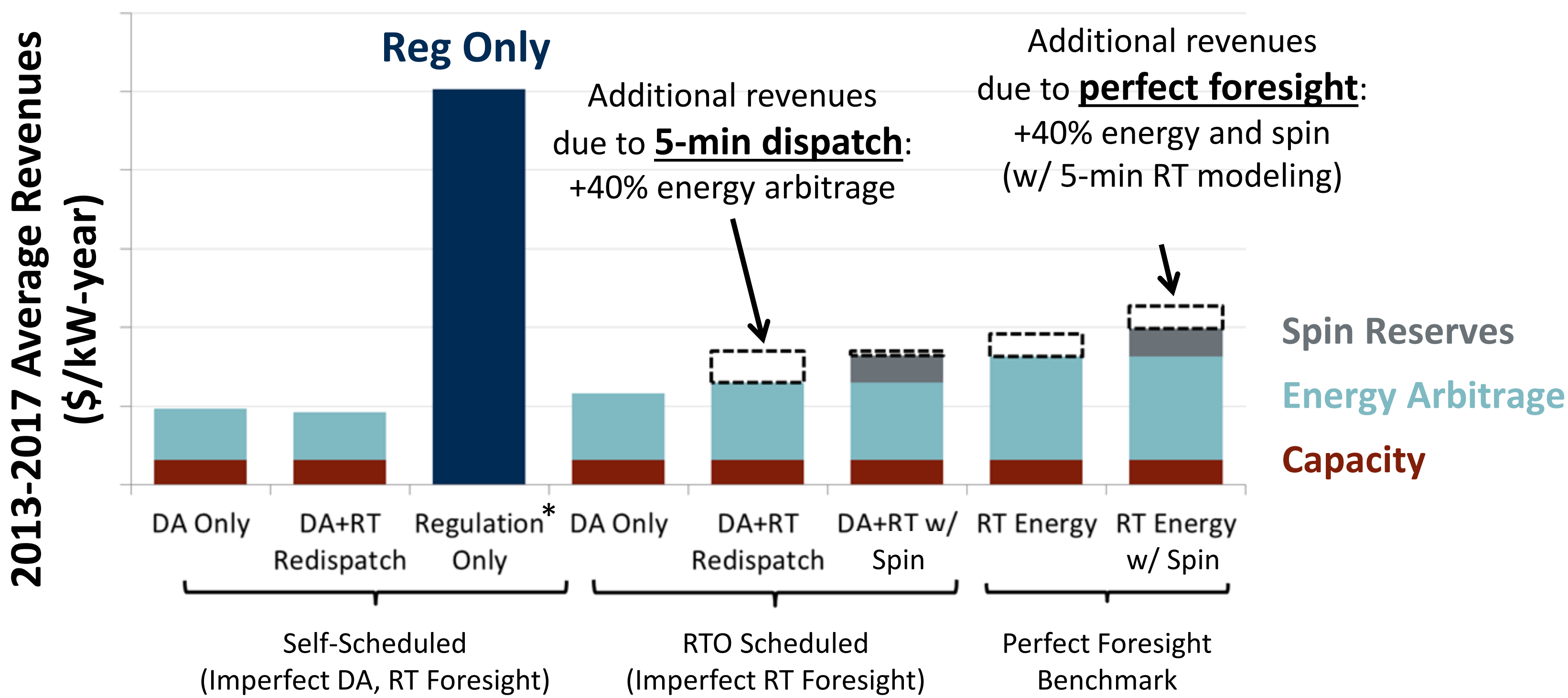


Source: AEMO. Initial operation of the Hornsdale Power Reserve Battery Energy Storage System. April 2018.

Impacts of RT Markets and Uncertainties

The impacts of uncertainty modeling and 5-min RT modeling can be very significant, e.g., +/- 25-50% changes in E&AS performance.

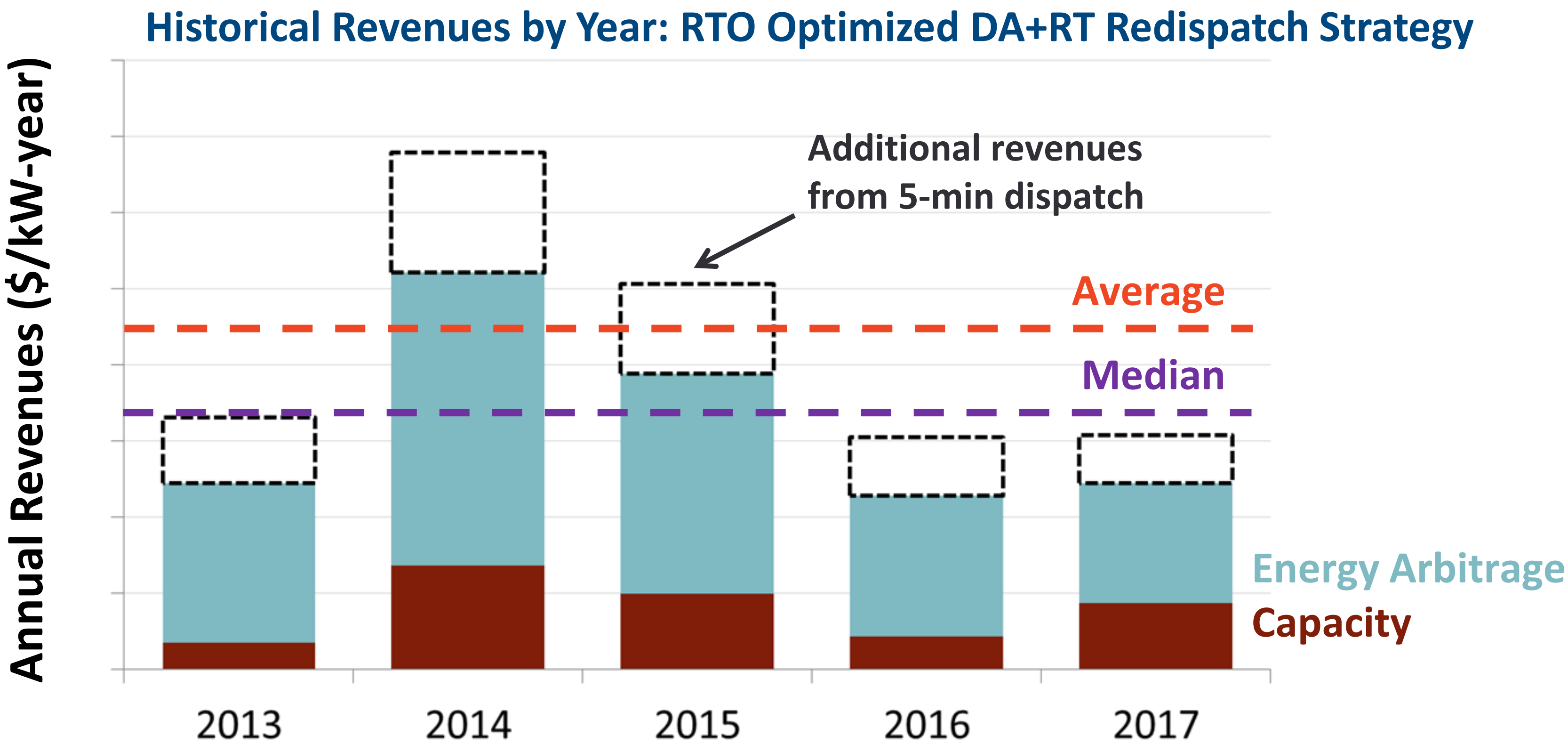
PJM Annual Revenues, 2013–2017, for a 1 MW, 4-hour Battery in an RTO Market



Note: Assumes 90% efficient battery with 4-hour duration.
*Regulation is based on PJM's "Reg D" (a thin market that is rapidly declining in value)

How Much Do Energy and Capacity Value Change over Time?

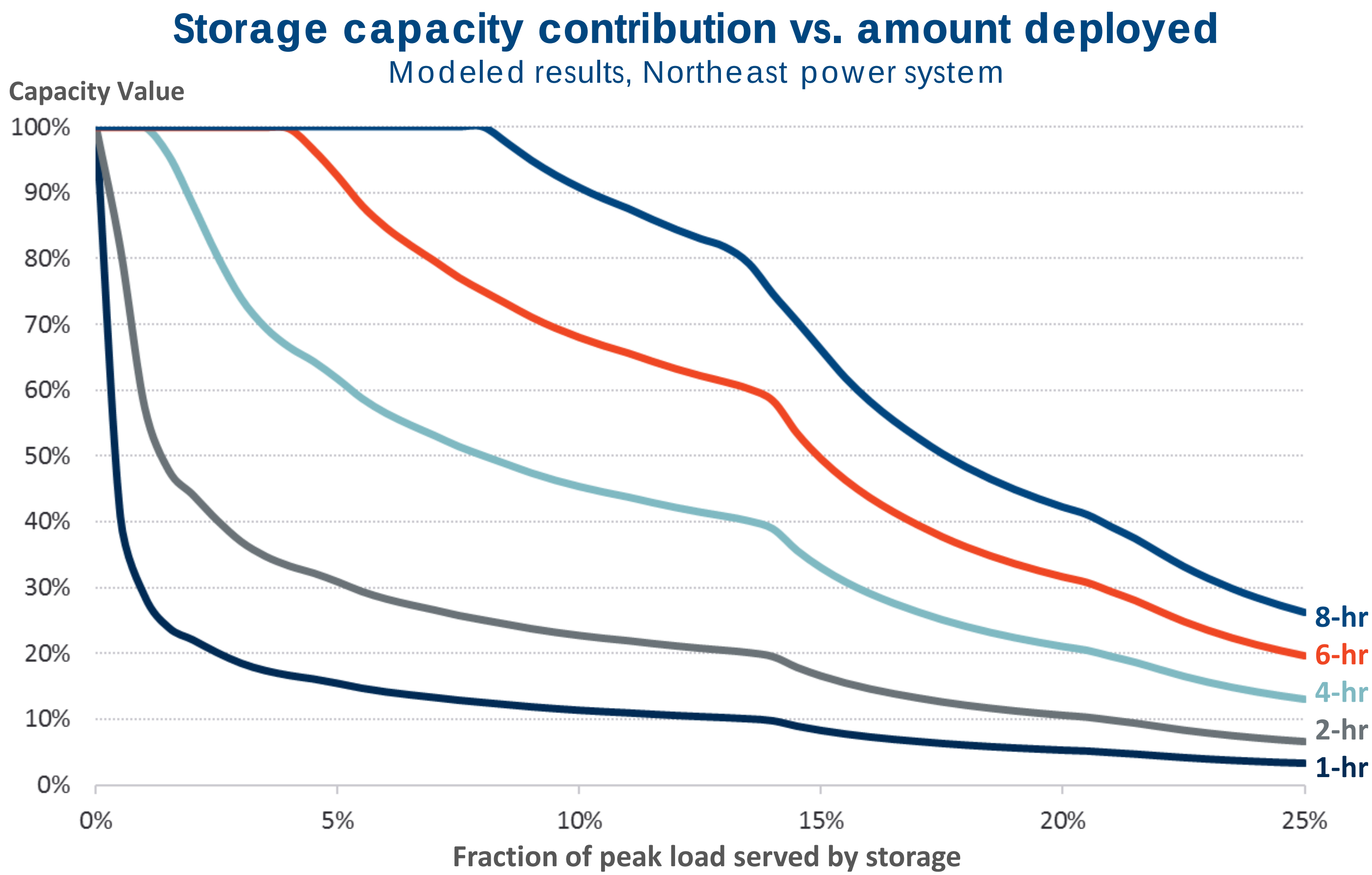
Annual revenues vary by a factor of 2x across 2013 – 2017. Price-taker modeling is especially sensitive to too-short simulation periods.



Notes: Assumes 90% efficient battery with 4 hour duration, 24 hr foresight over DA prices, 1 hr foresight over hourly RT prices, and 15 minute foresight over 5-min RT prices .

Resource Adequacy: Capacity Value of Storage by Duration

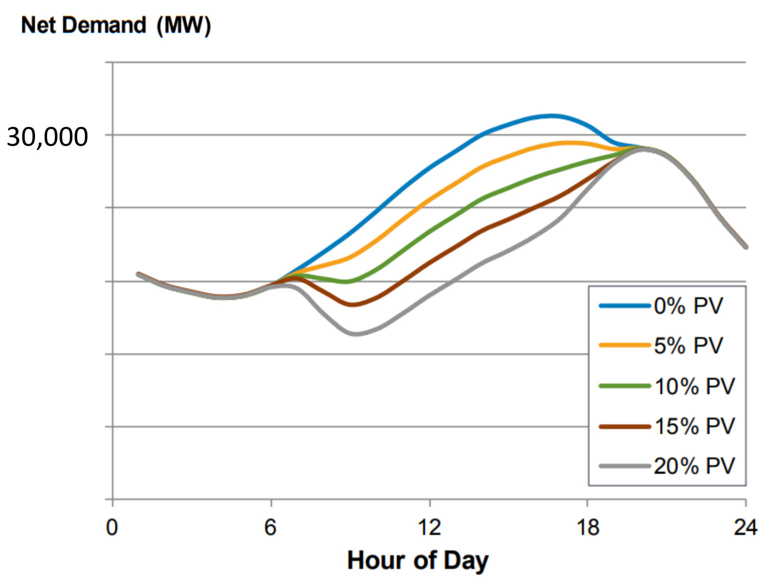
The **capacity contribution** of storage depends on the **type of storage**, the **nature of peak load events**, and the **amount of storage deployed**.



Resource Adequacy: Capacity Value of Storage with Solar

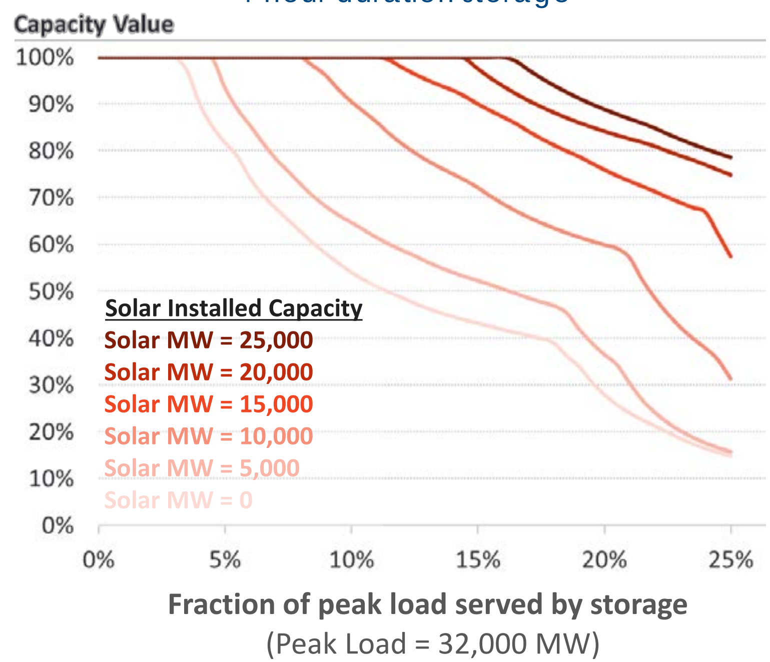
The **capacity contribution of storage** is **higher** in systems with **significant solar deployments**, as solar tends to compress peak load events into fewer hours.

Effect of PV on peak load shape



Effect of PV on storage capacity contribution

4-hour duration storage



Sources:

Brattle analysis.

NREL (2018) The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics

Agenda

I. The Costs and “Value Stack” of Storage

II. Wholesale Market Value of Storage

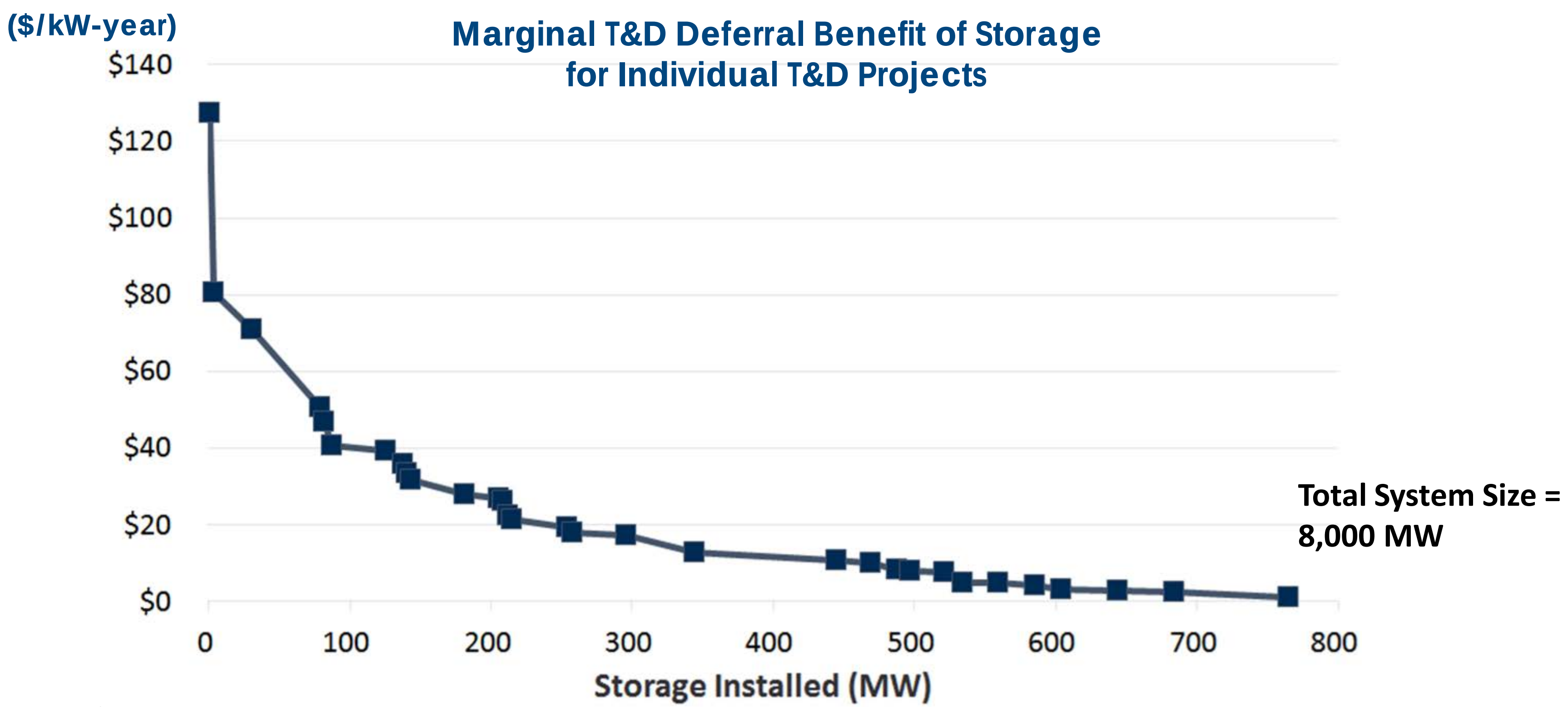
III. T&D-Deferral and Customer-Reliability Value of Distributed Storage

IV. The Value of Co-locating Solar+Storage

V. Takeaways

Transmission & Distribution Deferral Value

Our Nevada study showed there is a limited number of **high-value opportunities** to **defer specific T&D investments**

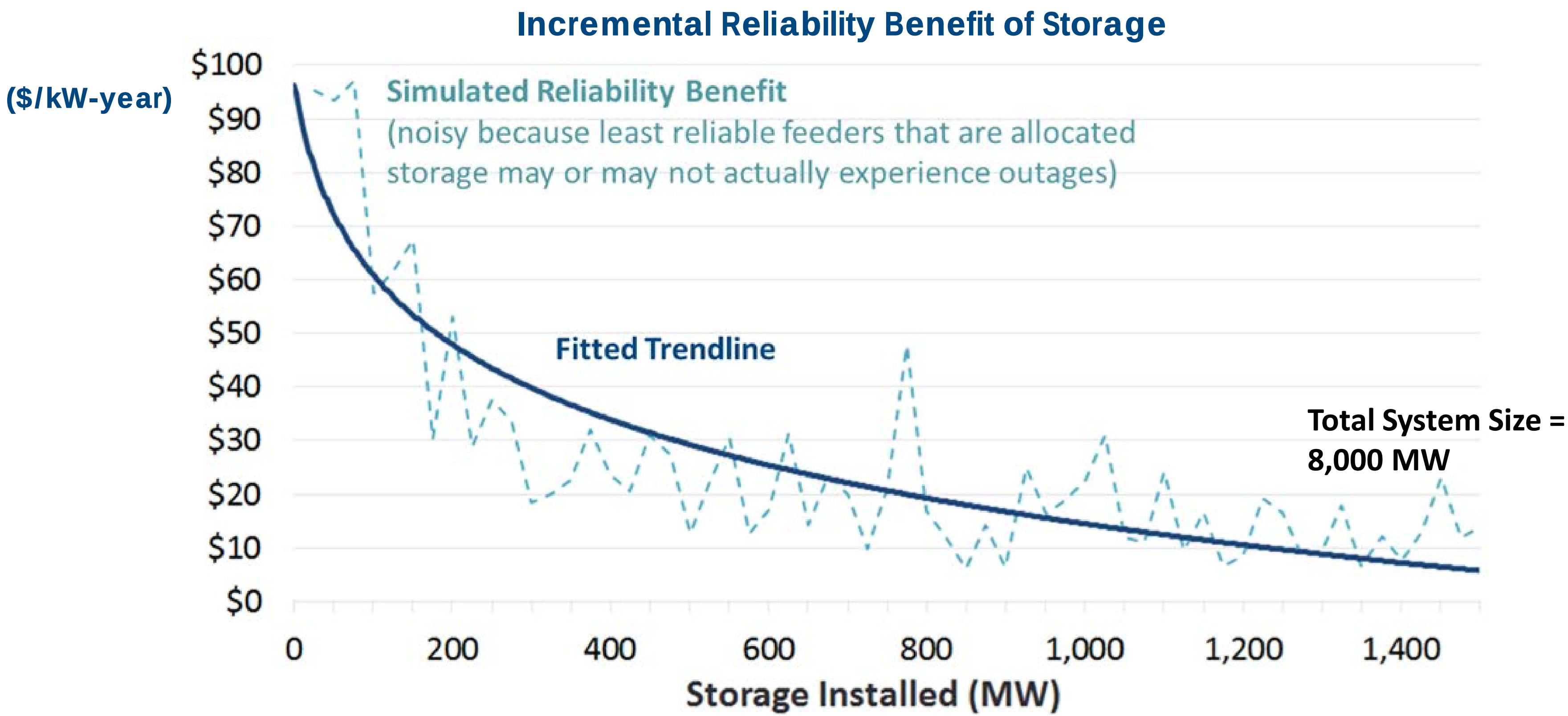


Sources and Notes:

Hledik et al. (2018). The Economic Potential for Energy Storage in Nevada. Points reflect individual projects from NV Energy's 2018 transmission and distribution capital expenditure outlook identified as deferrable by storage. Although NV Energy's outlook is over a 10-year span, we annualize the size and value of opportunities. We order projects by $/kW-year value, and plot to estimate the marginal benefit for storage from T&D investment deferral. Values in nominal dollars.

Customer Reliability Value

We found the **marginal reliability benefit of distributed storage** is **initially high**, but **falls off relatively rapidly** as storage is deployed to least reliable feeders



Sources and Notes:
Hledik et al. (2018). The Economic Potential for Energy Storage in Nevada
All values in nominal dollars.

Agenda

I. The Costs and "Value Stack" of Storage

II. Wholesale Market Value of Storage

III. T&D-Deferral and Customer-Reliability Value of Distributed Storage

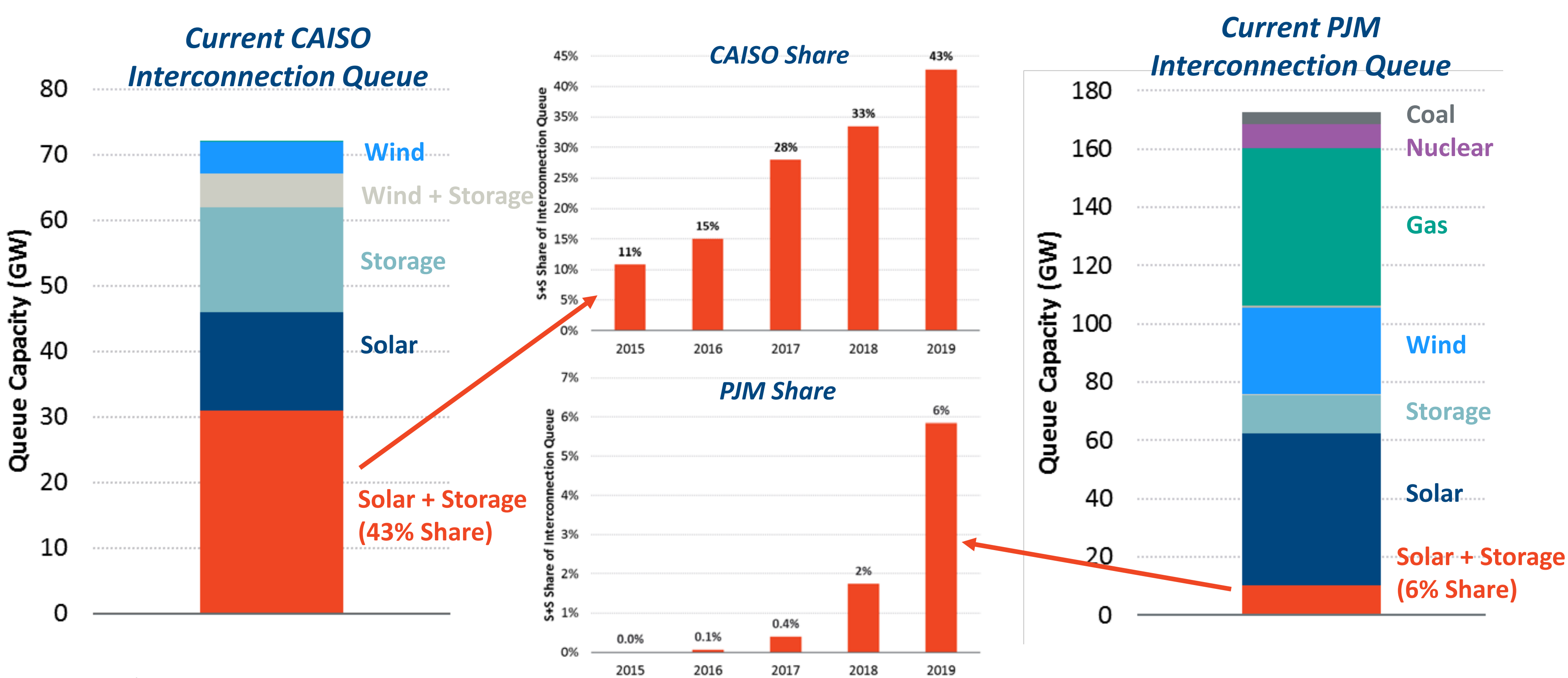
IV. The Value of Co-locating Solar+Storage

V. Takeaways

Solar+Storage Deployments will Increase Dramatically in Next Years Coming Years

Solar+storage accounts for over 40% of all capacity in the California ISO interconnection queue. PJM also has seen sizeable growth in applications.

Capacity in ISO Generation Interconnection Queues



Source: RTO websites.

Notes: PJM data downloaded 11/27/2019. Counts Maximum Facility Output; CAISO data as of 11/27/2019. Counts Net MW Total. PJM and CAISO report hybrid solar+storage projects independently; projects including other resources (e.g. gas + solar + storage) are excluded. Queues are filtered to include generation resources only (no transmission resources).

Solar and Storage are Complementary Resources

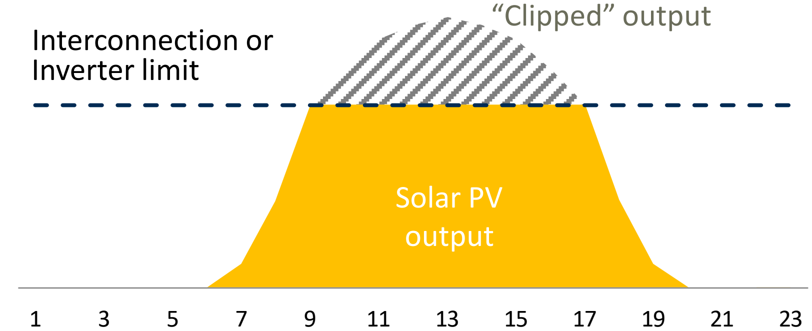
Co-locating storage with solar facilities (i.e., "solar+storage") allows valuable features of both resources to be captured at a single site

Attribute	Standalone Solar PV	Standalone Storage	Solar+Storage
Zero-carbon energy	✓		✓
Eligible for Federal Investment Tax Credit	✓		✓
Flexible/dispatchable		✓	✓
Firm capacity		✓	✓
Co-location efficiencies (cost savings)			✓

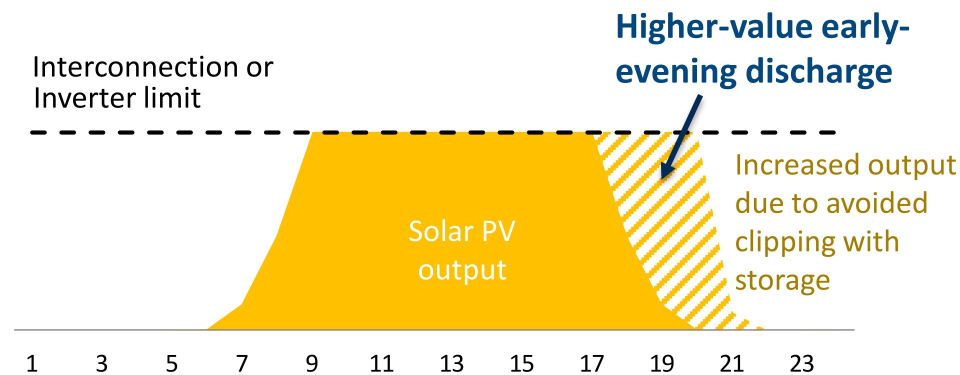
Benefit of Upsized Solar and Avoided "Peak Clipping"

Storage can charge from solar PV output that would be wasted due to inverter or interconnection capacity limits. **Energy can be discharged at <u>higher value</u> later.**

- Solar PV facilities are typically developed with solar panel capacity that exceeds the capacity of the inverter
- Transmission interconnection limits may impose similar constraints
- At times when the output of the panels exceeds the limit, that energy is "clipped" (i.e. unused)



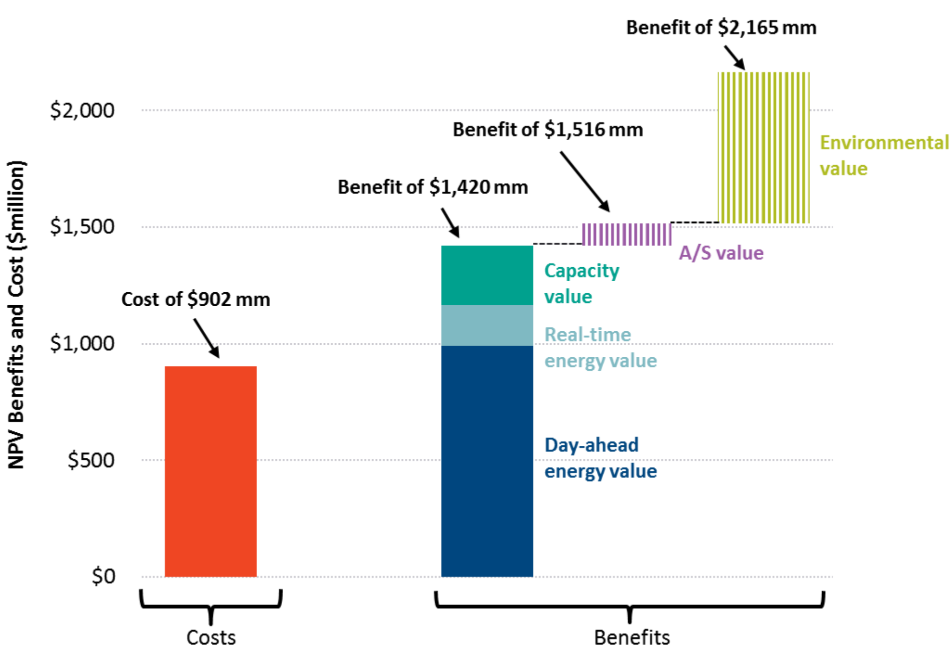
- Batteries behind the solar PV facility's inverter (i.e., DC-coupled) or constrained interconnection point are able to charge from the output that otherwise would be "clipped"
- **Peak clipping can significantly decrease the facility's average costs and increase its energy and capacity revenues**
- This finding is highly dependent on the sizing of the battery, solar array, inverter, and transmission interconnection limits



Case Study: Nevada Solar+Storage

The Nevada PUC just approved the largest solar+storage facility in the U.S. (690 MW solar, 380 MW/1,416 MWh storage)

Benefits and Costs of "Gemini" Solar+Storage



Source: Direct Testimony of Ryan Hledik on Behalf of Arevia, PUCN Docket No. 19-06039, September 26, 2019.

Key Findings

- Net benefits to customers of the Gemini solar+storage project range between $500 million and $1.3 billion (present value)
- Benefit-cost ratio of between 1.6 and 2.4, depending on which value streams are counted as benefits
- Energy value alone exceeds the costs of the project
- Significant storage capacity provides ability to respond to real-time fluctuations in supply and demand, resulting in operational flexibility that will "future proof" the resource as market conditions evolve

Agenda

I. The Costs and “Value Stack” of Storage

II. Wholesale Market Value of Storage

III. T&D-Deferral and Customer-Reliability Value of Distributed Storage

IV. The Value of Co-locating Solar+Storage

V. Takeaways

Main Takeaways

- Battery storage will undoubtedly become an increasingly important part of power systems as costs continue to decline
- **Deployment of battery storage is growing rapidly**
  - Interconnection queues indicate growing interest in storage by developers
  - Renewable+storage becoming increasingly competitive even with new gas plants, particularly in the Southwest
  - Increasing need for flexibility due to growing renewable energy development will increase the value of storage
- Overall, we anticipate that battery storage will add **significant value** to power systems, but new tools will be needed to ensure its grid visibility and controllability
- Market operators, resource planners, transmission and distribution system planners, and regulators all need to learn to utilize storage as a new technology option

Challenges of Operating a System with Significant Storage

- How to **reliably operate** many small and distributed battery storage systems across all wholesale market products?
- How to evaluate the **capacity value** of storage as increasing amounts of storage is deployed on the system?
- How to ensure sufficient **visibility** into operations and control?
- How to **monitor and mitigate** offers from storage?
- How to **coordinate control** across wholesale and non-wholesale uses?
- What are storage's **interconnection** rules?
- How to integrate storage into **transmission and distribution** system planning and operations?

Further actions by FERC, states, and system operators are needed to unlock storage's full value and manage planning/operational/coordination challenges

PRESENTER BIO & CONTACT INFORMATION

Johannes Pfeifenberger

Principal, Boston
+1.617.234.5624 (Direct)
Hannes.Pfeifenberger@brattle.com

Mr. Johannes (Hannes) Pfeifenberger is an economist with a background in power engineering and over 25 years of experience in the areas of public utility economics and finance. He has published widely, assisted clients and stakeholder groups in the formulation of business and regulatory strategy, and submitted expert testimony to the U.S. Congress, courts, state and federal regulatory agencies, and in arbitration proceedings.

Hannes has extensive experience in the economic analyses of wholesale power markets and transmission systems. His recent experience includes the analysis of hydro and battery storage economics, transmission benefits, reviews of wholesale power market designs, testimony in contract disputes, cost allocation, and rate design. He has performed market assessments, market design reviews, asset valuations, and cost-benefit studies for investor-owned utilities, independent system operators, transmission companies, regulatory agencies, public power companies, and generators across North America.

Hannes received an M.A. in Economics and Finance from Brandeis University and an M.S. (Dipl. Ing.) in Power Engineering and Energy Economics from the University of Technology in Vienna, Austria.

CO-AUTHOR BIO & CONTACT INFORMATION

Roger Lueken

Senior Associate, Washington DC
+1.202.955.5050 (Direct)
Roger.Lueken@brattle.com

Dr. Roger Lueken is a Senior Associate at *The Brattle Group* with expertise in the economics of energy storage and wholesale market design. Dr. Lueken has worked with clients throughout the U.S. and internationally, including market operators, investors, regulated utilities, and other market participants. Energy storage assignments include using Brattle's bSTORE model to perform benefit cost analyses of distributed and utility-scale storage in California, PJM, and the Midcontinent ISO (MISO). Dr. Lueken has provided due diligence support on behalf of investors and technology firms evaluating specific storage and solar+storage projects.

Dr. Lueken earned his Ph.D. in Engineering and Public Policy from the Carnegie Mellon Electricity Industry Center at Carnegie Mellon University, and a Masters of Engineering and Public Policy from the University of Maryland. He received a B.S. in Mechanical Engineering from Purdue University.

Additional Reading

Direct Testimony of Ryan Hledik on Behalf of Arevia. Public Utilities Commission of Nevada Docket No. 19-06039, September 26, 2019.

"Solar-Plus-Storage: The Future Market for Hybrid Resources," Ryan Hledik et al. December 2019.

"The Economic Potential for Energy Storage in Nevada," Ryan Hledik et al., Prepared for the Public Utilities Commission of Nevada and Governor's Office of Energy. October 3, 2018.

"Getting to 50 GW? The Role of FERC Order 841, RTOs, States, and Utilities in Unlocking Storage's Potential," Roger Lueken, Judy Chang, Johannes P. Pfeifenberger, Pablo Ruiz, and Heidi Bishop, February 22, 2018

"Battery Storage Development: Regulatory and Market Environments," Michael Hagerty and Judy Chang, Presented to the Philadelphia Area Municipal Analyst Society, January 18, 2018

"U.S. Federal and State Regulations: Opportunities and Challenges for Electricity Storage," Romkaew P. Broehm, Presented at BIT Congress, Inc.'s 7th World Congress of Smart Energy, November 2, 2017

"Stacked Benefits: Comprehensively Valuing Battery Storage in California," Ryan Hledik, Roger Lueken, Colin McIntyre, and Heidi Bishop, Prepared for Eos Energy Storage, September 12, 2017

"The Hidden Battery: Opportunities in Electric Water Heating," Ryan Hledik, Judy Chang, and Roger Lueken, Prepared for the National Rural Electric Cooperative Association (NRECA), the Natural Resources Defense Council (NRDC), and the Peak Load Management Alliance (PLMA), February 10, 2016

"Impacts of Distributed Storage on Electricity Markets, Utility Operations, and Customers," Johannes P. Pfeifenberger, Judy Chang, Kathleen Spees, and Matthew Davis, Presented at the 2015 MIT Energy Initiative Associate Member Symposium, May 1, 2015

"The Value of Distributed Electricity Storage in Texas - Proposed Policy for Enabling Grid-Integrated Storage Investments," Ioanna Karkatsouli, James Mashal, Lauren Regan, Judy Chang, Matthew Davis, Johannes P. Pfeifenberger, and Kathleen Spees, Prepared for Oncor, March 2015

About The Brattle Group

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies worldwide.

We combine in-depth industry experience and rigorous analyses to help clients answer complex economic and financial questions in litigation and regulation, develop strategies for changing markets, and make critical business decisions.

Our services to the electric power industry include:

- Climate Change Policy and Planning
- Cost of Capital
- Demand Forecasting Methodology
- Demand Response and Energy Efficiency
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Environmental Compliance
- Fuel and Power Procurement
- Incentive Regulation
- Rate Design and Cost Allocation
- Regulatory Strategy and Litigation Support
- Renewables
- Resource Planning
- Retail Access and Restructuring
- Risk Management
- Market-Based Rates
- Market Design and Competitive Analysis
- Mergers and Acquisitions
- Transmission

Brattle's Storage Experience

Asset Valuation	• Valuing and sizing renewables + storage facilities • Valuing storage across multiple value streams • Developing bid/offer strategies to maximize value • Accommodating storage into IRPs • Supporting due diligence efforts of investors
Market Intelligence	• The state and federal policy landscape • Electricity market fundamentals and opportunities • Storage cost and technology trends • Current and emerging business models
Policy, Regulatory, and Market Design	• Wholesale market design • Market and regulatory barriers • Utility ownership and operation models • Retail rate implications of distributed storage • Implications of storage on wholesale markets

www.brattle.com/storage

Our Offices


BOSTON


BRUSSELS


CHICAGO


LONDON


MADRID


NEW YORK


ROME


SAN FRANCISCO


SYDNEY


TORONTO


WASHINGTON