Sandia National Laboratories

Introduction to Energy Storage Benefit Cost Analysis

Prepared for the
Illinois Corporation Commission

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U.S. DEPARTMENT OF ENERGY NNSA

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What we will be covering in our presentation today.

1. Context for our discussion
2. Introduction to BCA practices applied toward energy storage.
3. Understanding costs and benefits for energy storage.
4. Summary of existing BCAs available to the ICC
5. What are the key lessons for the ICC?
6. What are key findings specific to regulatory reform?
7. Q&A

Some key points to level-set this discussion.

1. Energy storage is a broad term that describes various technologies, all with different levels of market maturation.

Energy Storage Category	Associated Technologies / (Market Readiness)
Mechanical	• Pumped hydro (commercial) • Compressed air energy storage (commercial) • Gravity-based (pilot phase) • Liquefied air (pilot, with some commercial activity announced) • Liquid CO2 (pilot phase)
Chemical	• Hydrogen (pilot phase) • Synthetic gas (pilot phase)
Thermal/ Thermochemical	• Sensible heat (e.g., molten salts, rock material, concrete) (R&D/pilot phase) • Latent heat (e.g., aluminum alloy) (commercial) • Thermochemical heat (e.g., zeolites, silica gel) (R&D) • Thermochemical heat (e.g., zeolites, silica gel) (R&D)
Electrochemical	• Lead-acid batteries (commercial) • Lithium-ion batteries (commercial) • Zinc alkaline batteries (commercial) • Flow batteries (commercial)

Energy storage cannot be evaluated as just one finite resource.

2. By definition, some ES technologies will have limited viability in specific markets.
   a) Pumped hydro require sites suitable for storage reservoirs, sufficient elevation
   b) Compressed air energy storage is limited by the availability of natural resources.
3. Energy storage can provide multiple services through various applications, sometimes simultaneously.
4. Benefits and costs can be modeled for both wholesale and retail transactions.

Wholesale (Generation) Services	Retail (Distribution) Services

• Peaking capacity
• Time-shifting of generation (energy arbitrage)
• ancillary services such as
  • Frequency regulation
  • Spinning reserves
	• Help manage peak electricity demand
	• Integrate distributed solar
	• Provide voltage or frequency support for weak parts of the system

Most of the current and future BCA analysis of ES will be on batteries.

5. Lead-acid batteries had been the most commonly adopted electrochemical storage technology, with relatively low capital cost, but they suffer from relatively low efficiency and useful life

6. Lithium-ion battery costs have fallen dramatically since their commercial introduction in 1991.

7. Today's lithium-ion batteries offer higher energy density and specific energy than lead-acid batteries.

8. Any modeling effort that analyses costs and benefits will be highly site specific.

Thus, determining which ES technologies to consider will depend on unique factors.

- Batteries, compressed air energy storage (CAES) and pumped storage hydropower historically have been the most common forms of ES to model.
- Batteries in particular can be considered for a multitude of niche services, including system flexibility, peaking capacity, integrating renewables, and ancillary services (regulation, frequency response).
- In addition, three other factors structurally favor the inclusion of batteries over other ES options:

Siting Location Flexibility

Shorter Build Time

Preferred Environmental Profile

Ways in which the ICC can use BCAs.

- Address the following questions:
    - How can BCAs be incorporated into utility **Multi-Year Integrated Grid Plans**?
    - Which **functionalities** of energy storage would be most useful in Illinois?
    - Who could these functionalities benefit?
        - **Use cases** for frequency regulation, energy-time shift, T&D deferral, and reducing carbon emissions
    - Of these functionalities, which has the highest value?
    - What should be the relationship among utilities, customers, and energy storage look like?
    - Under what conditions is energy storage appropriate for **rate base**?
    - How will the determined value of energy storage justify **procurement targets**?

IRP regulations can be coordinated with mandated BCA’s.

- Regulatory commission rejected utility IRPs due to insufficient consideration of energy storage.

- Adopted new IRP policies requiring utilities to identify opportunities for energy storage, energy efficiency, and demand response programs

- State law requires utilities to include energy storage as part of their long-range plans.

- New regulations require the consideration of energy storage in utility IRPs.

- PUC adopted new IRP guidelines requiring utilities to identify flexible capacity needs and how to be meet those needs through DERs (2012)

Storage can be analyzed from various perspectives.

- Sandia National Labs and other national labs, along with industry partners, are working to create tools to analyze energy storage under four distinct but inter-related scenarios:

Storage Operating As A Stand-Alone Resource

Storage Coupled with Another Generation Resource

BTM Storage, Including Aggregated BTM Storage

Storage Within an Organized Energy Market(i.e., ISO/RTO

A comprehensive BCA supports decision-making for ES investments.

- A detailed benefit cost analysis framework can be used to compare storage projects with traditional T&D mitigation solutions
  - Utility view-point (Project cost comparison)
  - Customer view-point (Revenue requirement comparison)

The BCA also supports corporate-level decisions at utility organizations:

- Whether to defer T&D upgrades or not
- Deferral for how many years
- ESS disposition strategy after upgrades

There is inherent value in BCAs for state regulators.

- Where BCAs appear to be most applicable or helpful for state level policymakers are in the following regulatory reform initiatives (branches):
  - Rate design (TOU rates)
  - Approving utility procurement proposals
  - Evaluating specific amounts of energy storage that will be needed.
- Not all BCAs will be applicable or useful. Must be mindful of the underlying objective of each BCA.
- Furthermore, whether the scope is applicable (e.g., distribution/wholesale, technologies included, relevance to regulatory reform).
- Thus, preparation of BCAs at the state level and for application to the retail/distribution market are particularly important and the onus is on state regulators to utilize BCAs for their own unique regulatory purposes.

BCA modeling for ES is both new and fraught with unique challenges.

- There is **no universally agreed upon standard or formula** used to calculate the costs of electricity storage (i.e., a cost metric), given that different metrics highlight different features of storage cost and operation.

- **Examples:** duration, depth-of-discharge, lifetime, and O&M are not always defined in the same way (or even defined at all) for a given set of values.

- Because there are many different technologies and applications now available, Therefore, identifying the storage technology which best matches the application requirements can be a difficult task.

- The most obvious outstanding issue to practitioners of storage economic analysis may be the lack of standardization and challenge of general applicability of storage models.

Traditional economic modeling may lay a foundation but be incomplete.

- Storage economics for ES is still in a phase focused on methodological development rather than methodological refinement or comparison.
- The most common and straightforward approach considers the revenue, benefits, net benefits, or cost-effectiveness of storage for a specific application.
- Progress in storage economics may rely on synthesis and evaluation of existing ideas and methods to provide generally applicable tools.

- However, there has been an attempt to apply basic economic approaches toward energy storage BCA.
  - **Net present value**: the value in the present of a sum of money, in contrast to some future value it will have
  - **Internal rate of return:** annual rate of growth that an investment is expected to generate.
  - **Breakeven period:** the amount of time required for the cash flows generated by a project to equal its initial cost.

Other approaches are emerging as well.

- **Levelized costs:**
  - *Levelized cost of electricity (LCOE)*—Compares different forms of generation against each other. Includes any capital expenses (ES technologies, fuel, purchased electricity, operating expenses). Because fuel costs are included, LCOE is highly variable to local and current prices.
  - *Levelized cost of storage (LCOS)* is basically the ***"all-in"*** cost to design, construct, and utilize the BESS over the course of its useful economic life cycle, including the fixed and variable O&M costs, effects of the battery technology's degradation over time (i.e., decreased output), etc.

Subtracting the benefits of energy storage from the costs of energy storage

Net Cost Analysis

Determines the $/MWh that results in desired internal rate of return (IRR) compared against costs

Levelized Cost Analysis

Marginal cost of grid upgrades required to mitigate overloads and voltage violations in the network

Allocated Cost of Capacity (ACC)

Sum of the marginal value of real power, reactive power and reserve provided by the ESS at any point in time

Locational Marginal Value (LMV)

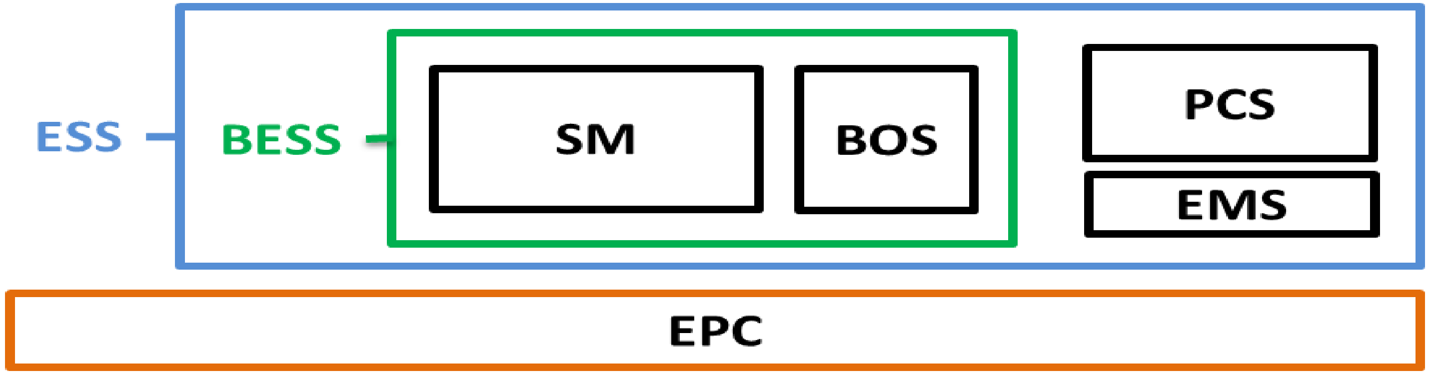
There are standard ES costs that should always be included.

1. The following represent the baseline of **Capital Costs** for various ES technologies:
    a. Storage module
    b. Balance of system
    c. Battery Energy Storage System (BESS)
    d. Power conversion system
    e. Energy management system; and
    f. Engineering, procurement, and construction
2. **O&M Expenses**
    a. Cost for charging the system
    b. Labor associated with plant operation
    c. Plant maintenance
    d. Replacement and repair cost
    e. Decommissioning and disposal cost

Other costs that can be included:

- Thermal management system, which manages heat levels
- Battery management systems
- Fire prevention and suppression technology
- SCADA and metering

Each of these cost components may have additional sub-components.



ESS

BESS

SM

BOS

PCS

EMS

EPC

SM	**Storage Module** Rack Level System (DC)
BESS	**Battery Energy Storage System** Containerized System (DC)
ESS	**Energy Storage System** Complete Storage System (AC)

Storage Module (SM)	Balance of System (BOS)	Power Conversion System (PCS)	Energy Management System (EMS)	Engineering Procurement & Construction (EPC)
Racking Frame / Cabinet	Container	Bi-directional Inverter	Application Library	Project Management
Local Protection (Breakers)	Electrical Distribution & Control	Electrical Protection	Economic Optimization	Engineering Studies / Permitting
Rack Management System	Fire Suppression	Connection to Transformer	Distributed Asset Integration	Equipment Procurement / Shipping
Battery Management System	HVAC / Thermal Management		Data Logging	Site Preparation / Construction / Mounting
Battery Module			Communication	Commissioning

Source: 2019 Energy Storage Pricing Survey, Richard Baxter, SANDIA REPORT SAND2021-0831 Printed January 2021

There are numerous services (i.e., benefits) that ES can provide to the grid and customers.

- The DOE/EPRI Electricity Storage Handbook identified distinct values.

Bulk Energy Services (RTO/ISO)	Ancillary Services (RTO/ISO)	Transmission Services (Utility)	Distribution Services (Utility)	Customer Services (Customer)
• Capacity • Arbitrage	• Regulation • Spin / Non-Spin Reserves • Voltage Support • Black Start • Frequency Response	• Transmission Congestion Relief • Transmission Upgrade Deferral	• Distribution Upgrade Deferral • Volt/VAR control • Resource Adequacy	• Power Reliability • Time-of-Use Energy Charge Reduction • Demand Charge Reduction

- Unfortunately, the industry lacks a taxonomy for analyzing these distinct services / benefits.

Traditional BCAs do not reveal energy storage benefits.

- There are three significant gaps that are found in traditional BCA modeling:

Restricted to Hourly Time-Step Modeling

- Most traditional BCA models are based on hourly paradigms. Energy storage can provide services that are temporally and physically more granular (requiring sub-hourly modeling).
- The traditional BCA approach fails to recognize the value of flexible resources that can respond to moment-to-moment changes in generation and load.

Omission of Ancillary Services

- Ancillary services include services such as frequency regulation, regulation and spinning reserves.
- Adding additional variables to solve for various ancillary services needs would significantly increase model complexity and run times.

Discounting of Location-Specific System Effects

- BCA models are designed to balance generation resources and load at the system level.
- Traditional models do not assess benefits that can be achieved by placing resources at specific locations.

How to categorize benefits

- **Merchant Value** – Profits that a private investor could capture in wholesale power markets
  - Frequency regulation
  - Arbitrage
  - Other ancillary services
- **Societal or System-Wide Benefits**
  - Reduced GHGs and other pollutants
  - Reduced peak demand
  - Improved resilience/reliability
- **Customer benefits**
  - Production cost savings and reduced wholesale prices
  - Deferred generation and/or T&D
  - Reduced outages (value of lost load, VOLL; value of avoided outage)
  - Demand or TOU charges

A large benefit to cost ratio (>1) is not as good as a large net benefit ($).

Many attributes are not presently valued—rapidity of output change, ability to reduce emissions, pace of deployment, duration capabilities.

Software for modeling storage as a sub-hourly resource are emerging but are not widely adopted as of yet.

- Offerings from both private and public companies are becoming available.
- Private companies offering tools to model storage at a granular level include:

PLEXOS
BY ENERGY EXEMPLAR

Powersim
the business simulation company™

KEYSCAN
AURORA

Sub-Hourly Modeling

ProSim
Software & Services In Process Simulation

Capacity Modeling

ABB
ABILITY PROMOD

Hourly Modeling with Some Sub-Hourly Modeling

ES BCAs are like everything else in ES – EVOLVING.

- Chemistries, technologies, and applications
- Commissioning, interconnection, decommissioning
- Finance
- Valuation and monetization
- Codes and standards

In the existing, publicly available BCAs. . .

- There are many different methodologies
- The largest portion of current studies show positive net benefits

Energy Storage
Benefit Cost Analysis Studies

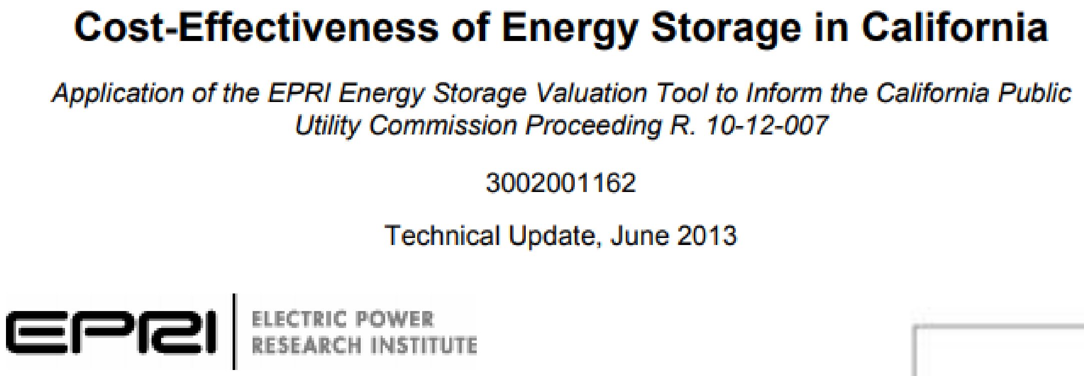
CA, 2013	EPRI ELECTRIC POWER RESEARCH INSTITUTE
TX, 2014	THE Brattle GROUP
MA, 2016	*In house*
NV, 2018	*In house*
NY, 2018	THE Brattle GROUP
CO, 2019	Synapse Energy Economics, Inc.

VA, 2019	STRATEGEN
NC, 2019	*In house*
MN, 2019	Energy+Environmental Economics
NJ, 2019	RUTGERS
ME, 2019	*In house*

Additional Source Material:

2019 Energy Storage Pricing Survey, Richard Baxter, SANDIA REPORT SAND2021-0831 Printed January 2021

Energy Storage Benefits and Market Analysis Handbook: A Study for the DOE Energy Storage Program SAND2004-6177



Cost-Effectiveness of Energy Storage in California

Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007

3002001162

Technical Update, June 2013

ELECTRIC POWER RESEARCH INSTITUTE

- Used the EPRI ES Valuation Tool over ~30 use cases for
  - Bulk storage (peaker substitution)
  - Ancillary services
  - Distributed storage sited at utility substations
- Input data
  - Grid service technical requirements
  - Financial assumptions for storage owner (discount rate, tax assumptions
  - Cost, performance, size, and configuration of ES system

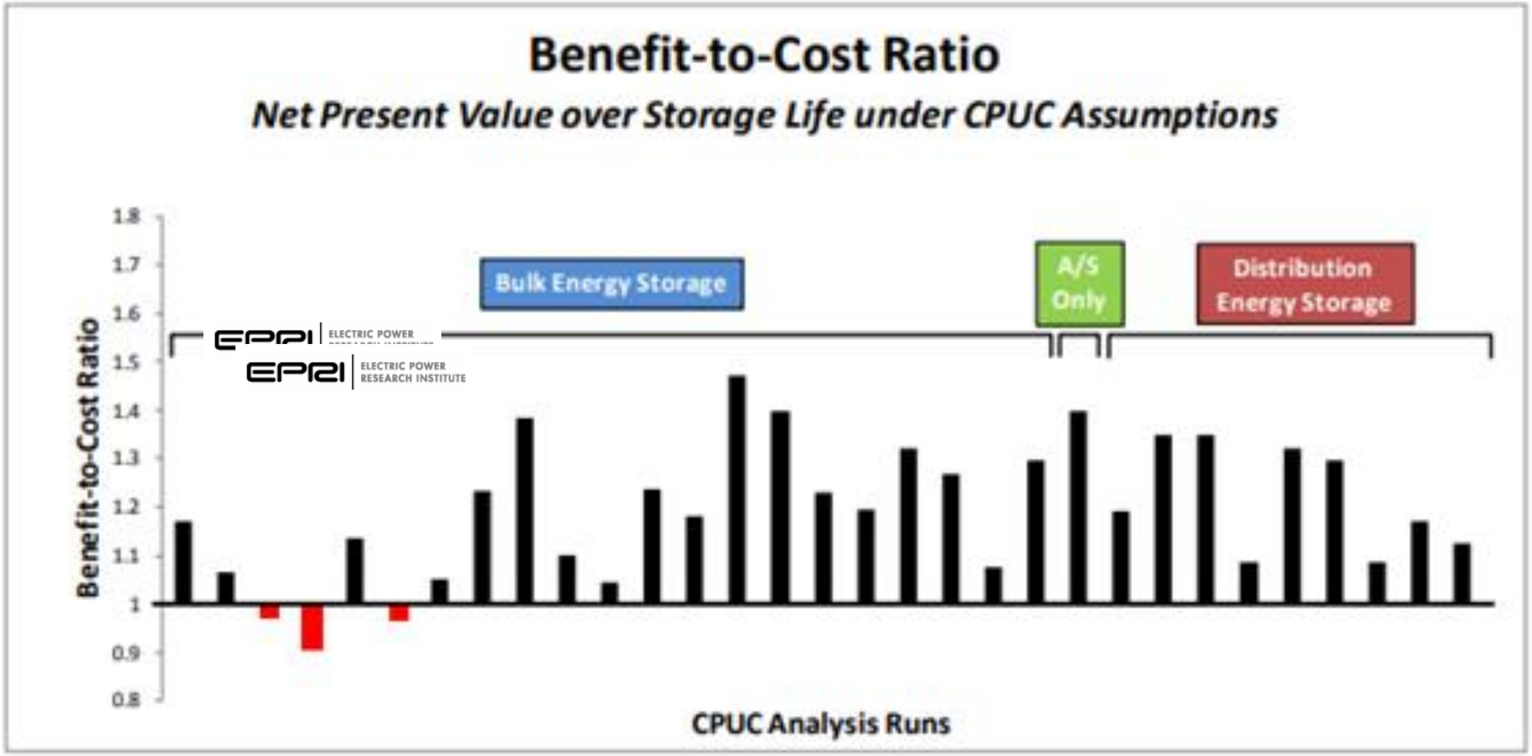
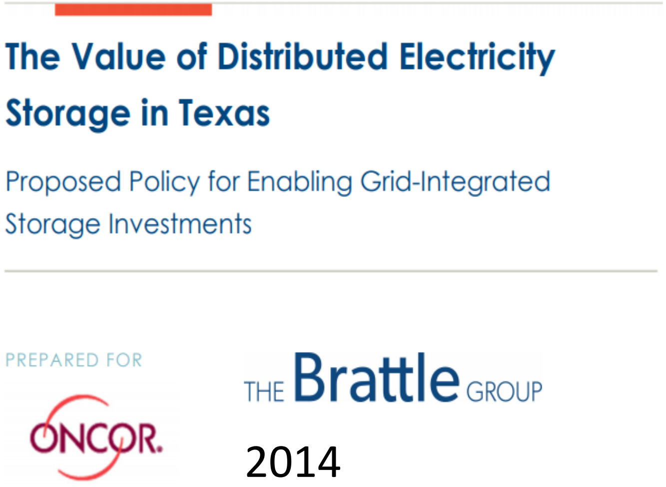


Figure ES-2
Benefit-to-Cost Ratios of All Analysis Runs

Citation: https://www.epri.com/research/products/000000003002001164



The Value of Distributed Electricity Storage in Texas

Proposed Policy for Enabling Grid-Integrated Storage Investments

PREPARED FOR

THE Brattle GROUP

2014

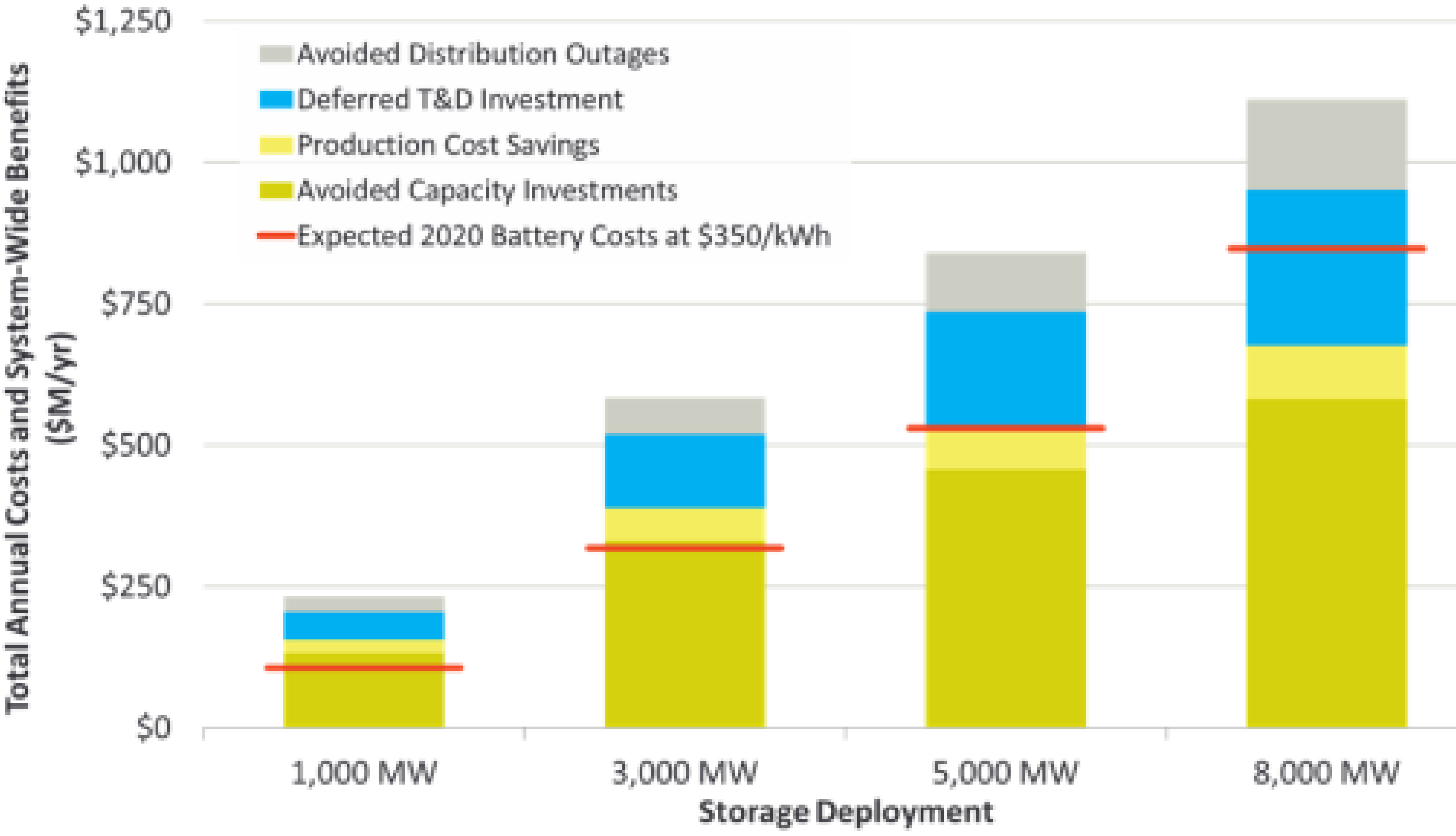
Benefits include:

- Avoided distribution outages
- Deferred T&D investments
- Production cost savings
- Avoided generation or demand-side capacity investments

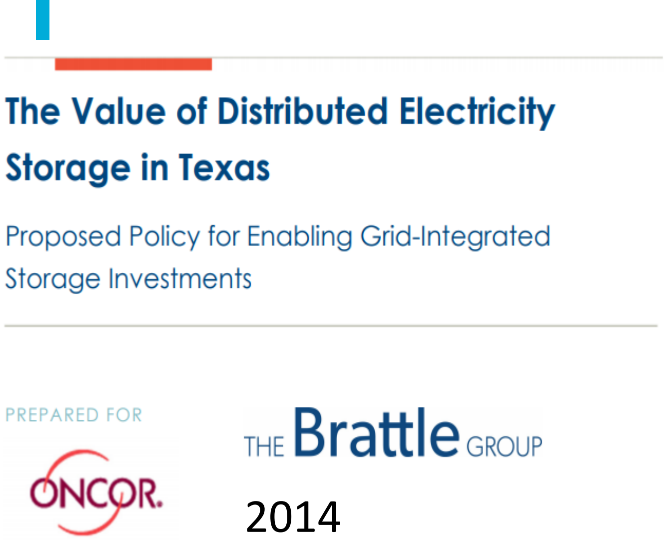
Figure 3

System-Wide Annual Benefits Compared to Expected 2020 Storage Costs

Top: Total Benefits and Costs, Bottom: Net Incremental Benefits



Citation: http://files.brattle.com/files/7589_the_value_of_distributed_electricity_storage_in_texas.pdf



The Value of Distributed Electricity Storage in Texas

Proposed Policy for Enabling Grid-Integrated Storage Investments

PREPARED FOR

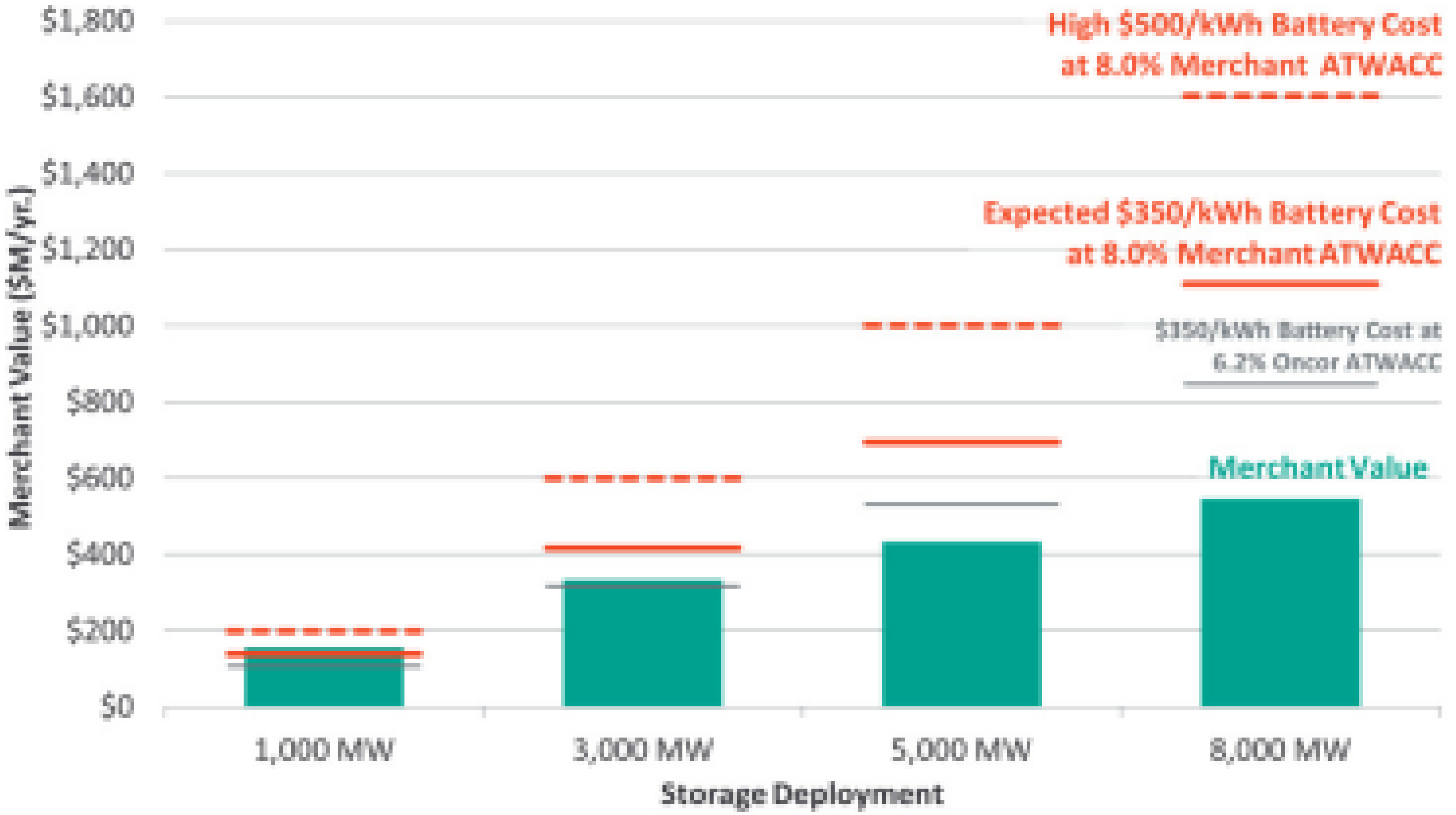
ONCOR

THE Brattle GROUP

2014

Merchant Storage Value Assumptions
- 3 hour discharge capacity
- 85% round trip efficiency
- No other variable O&M costs
- Storage costs of $350/kW
    - $200/kW purchase cost
    - $150/kW installation cost
    - Fixed O&M costs of 1% of investment for “expected” value, and 2% for “high” value

Figure 2
Merchant Storage Value that Could be Captured by Wholesale Market Participants



“Storage investments could not be undertaken at an efficient scale solely by merchant developers in the Texas restructured electricity market because the value that a merchant storage developer can capture and monetize through transacting in the wholesale power market alone is too low compared to costs.”

STATE OF CHARGE

Massachusetts Energy Storage Initiative

2016

- Modeling results show that up to 1766 MW of new ES would result in $2.3B in benefits by:
  - Reducing the price paid for electricity
  - Lowering peak demand by nearly 10%
  - Deferring transmission and distribution investments
  - Reducing GHG emissions (and reducing the effective cost of compliance)
  - Reducing the cost to integrate renewable energy generation
  - Deferring capital investment in new capacity
  - Increasing the grid’s overall flexibility, reliability, and resiliency

[Citation: https://www.mass.gov/doc/state-of-charge-report/download](https://www.mass.gov/doc/state-of-charge-report/download)

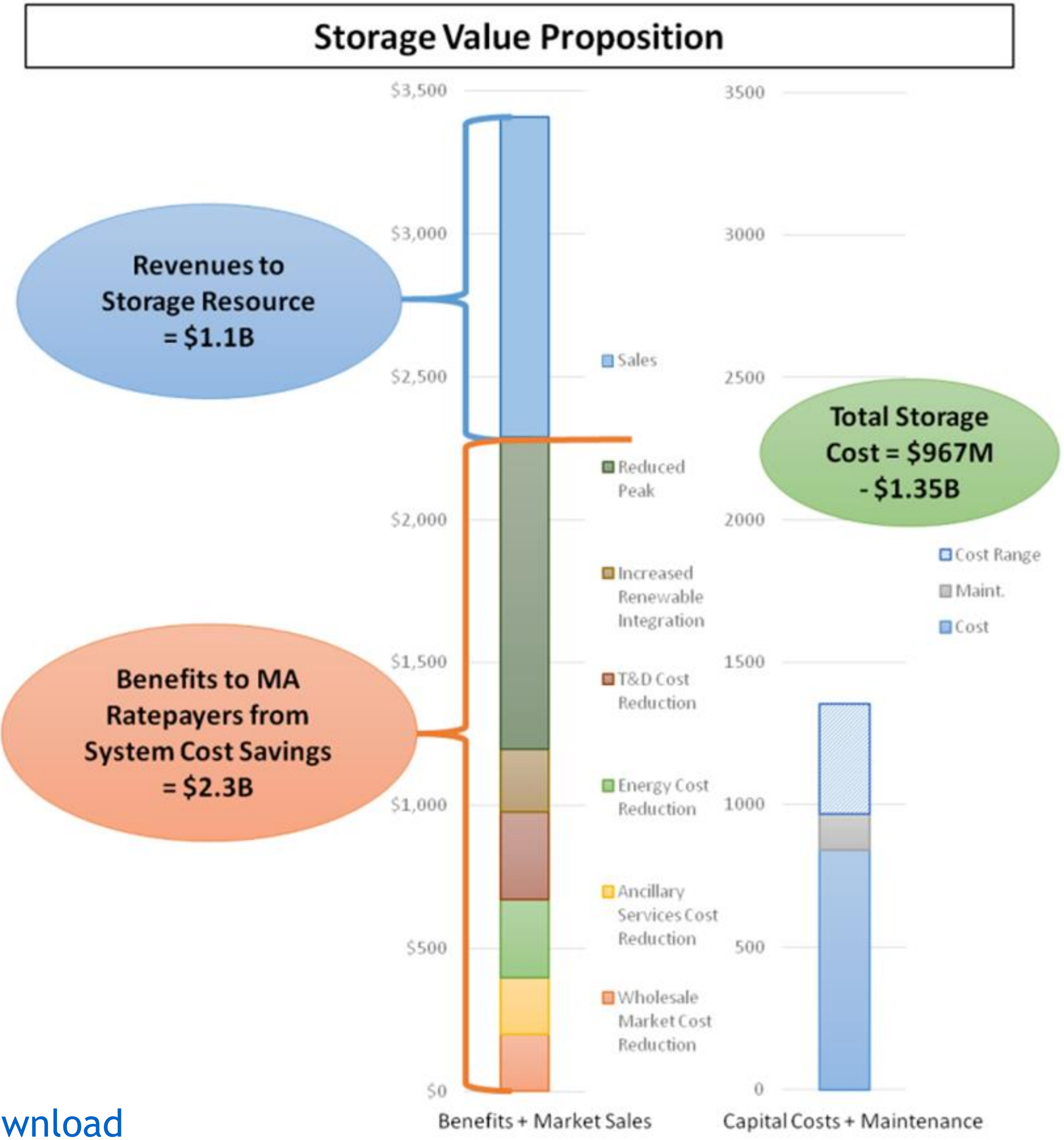


Figure 12: Storage Value Proposition

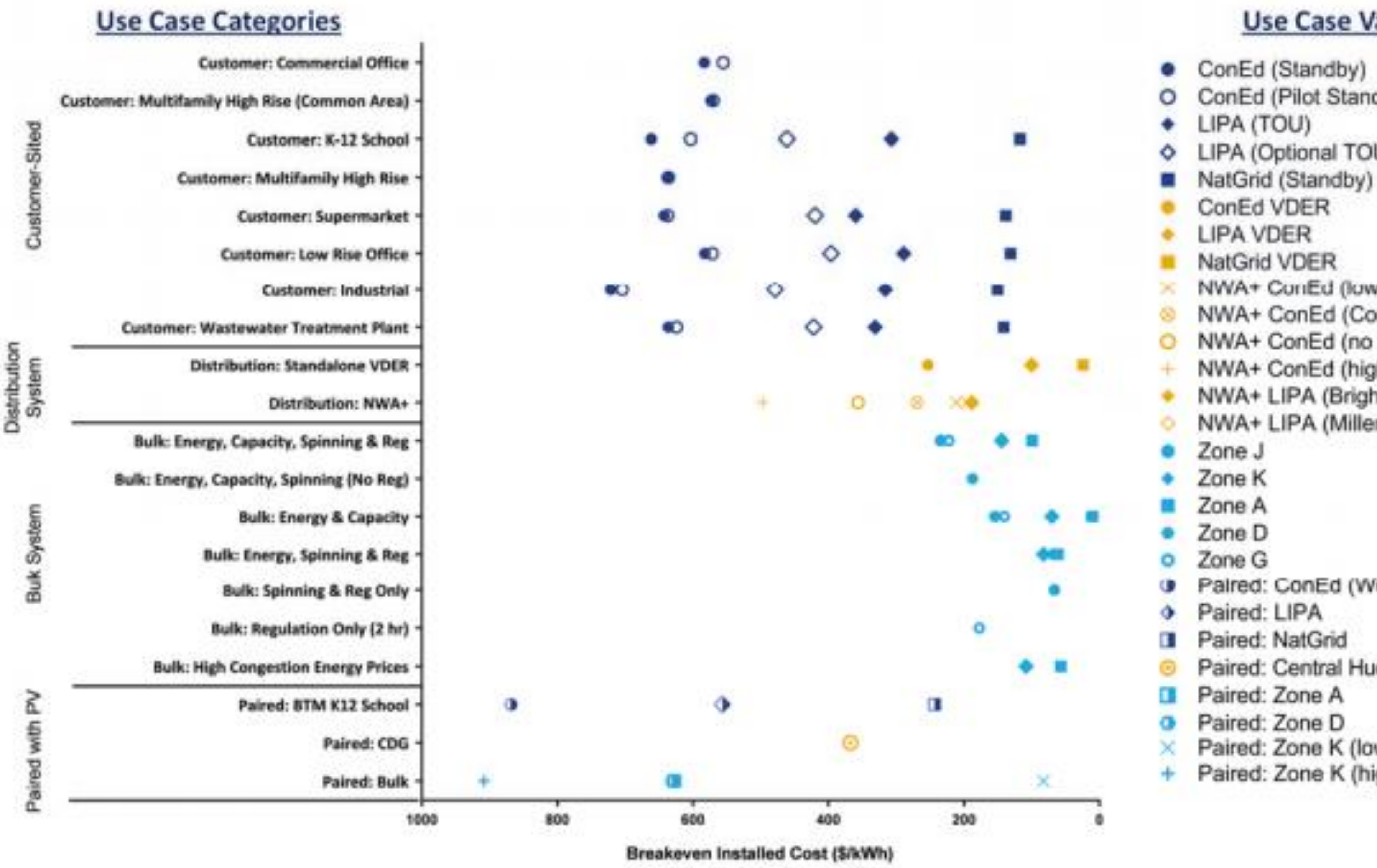
New York State Energy Storage Roadmap

2018

BICOS – Breakeven Installed Cost of System

- Breakeven Capital Cost – the estimated up front capital cost of a storage system with certain defined performance characteristics which would result in a **B/C ratio of 1**.

Figure ES2. Economics (BICOS) of Various Storage Use Cases Comparing Revenue Streams to Total Over System Lifetime[12]



https://documents.dps.ny.gov/public/MatterManagement/MatterFilingItem.aspx?FilingSeq=209590&MatterSeq=55960

The Economic Potential for Energy Storage in Nevada

PREPARED FOR
Public Utilities Commission of Nevada
Nevada Governor's Office of Energy

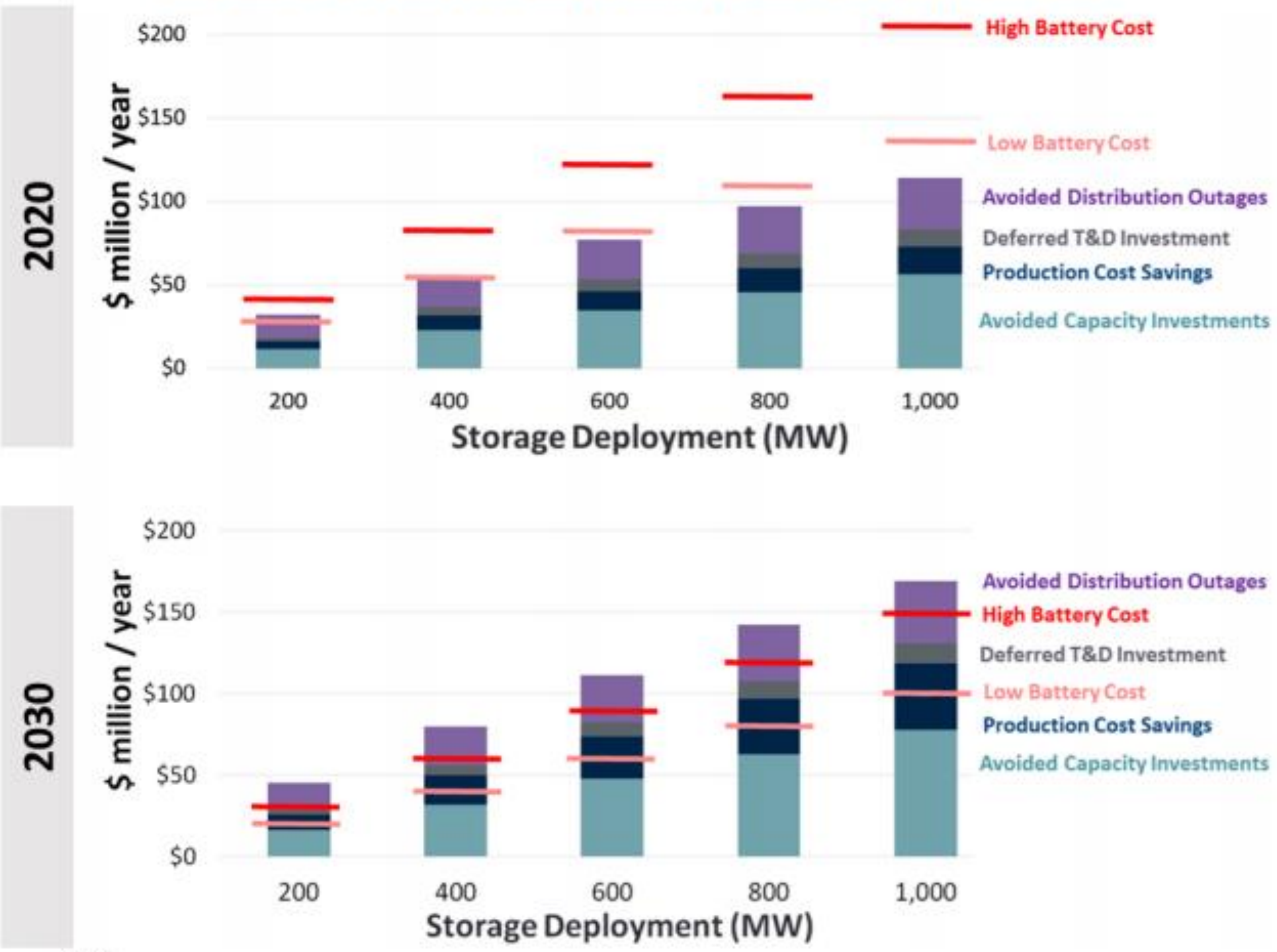
THE Brattle GROUP

2018

Highlights

- By 2020 175 MW of FTM ES (4-hour) could be cost effective.
- By 2030 700-1000 MW could be cost effective
- By 2030 BTM ES could add 30 -- 40 MW with proper incentives

Figure 1
Total System Benefits and Costs of Storage at Various Deployment Levels



Note:
All values are in nominal dollars.

Citation: https://energy.nv.gov/uploadedFiles/energynvgov/content/Home/Features/EconomicPotentialForStorageInNV.pdf

The Future of Energy Storage in Colorado

Opportunities, Barriers, Analysis, and Policy Recommendations

Prepared for the Colorado Energy Office

June 28, 2019

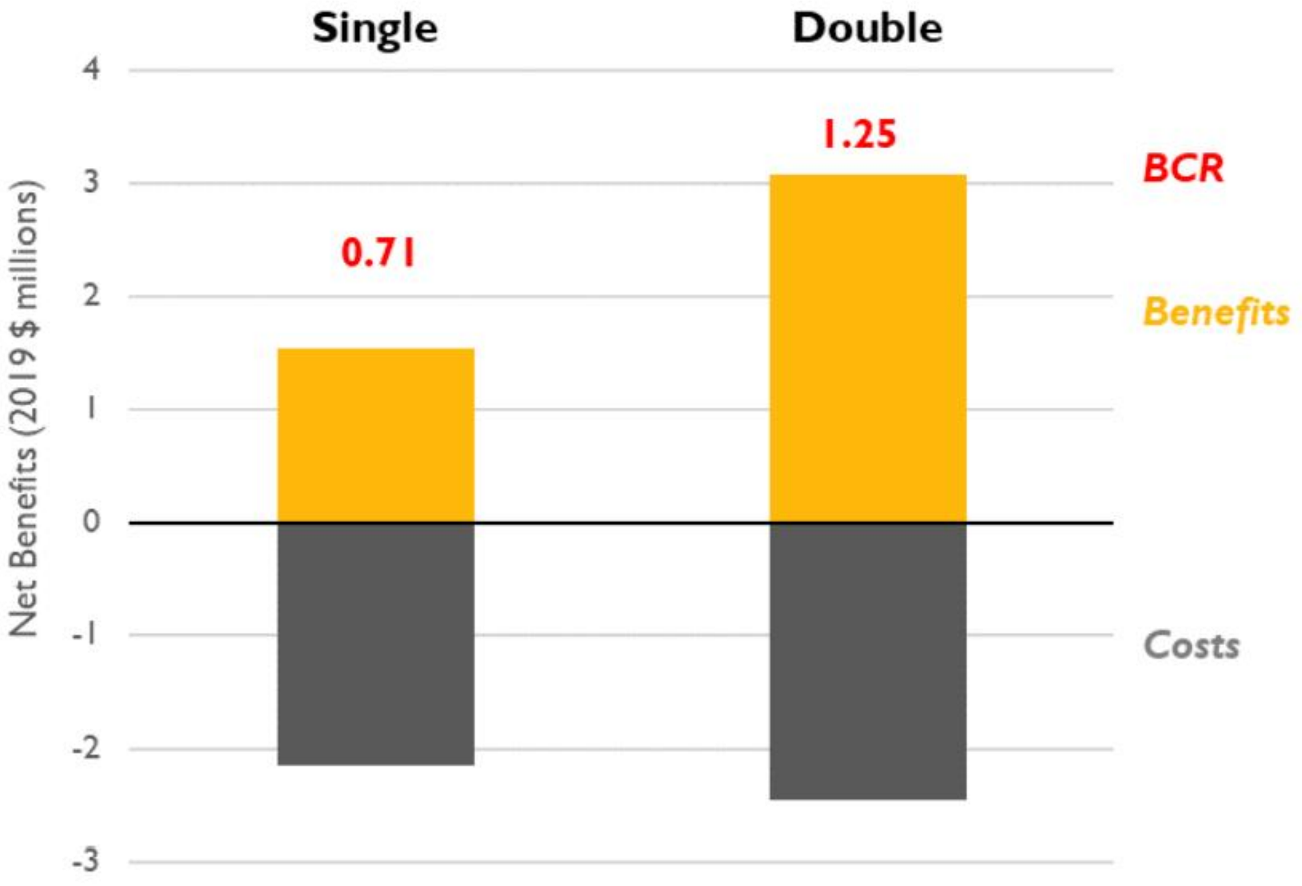
Synapse
Energy Economics, Inc.

485 Massachusetts Avenue, Suite 2
Cambridge, Massachusetts 02139

617.661.3248 | www.synapse-energy.com

2-hr, BTM pilot, single or double 5 kW systems modeled over 10 years and including avoided energy, capacity, T&D costs over four scenarios

Figure 4. Benefits, costs, and benefit-cost ratio (BCR) of a single- vs double-battery system



Source: Synapse calculations.

Citation: https://energy.nv.gov/uploadedFiles/energynvgov/content/Home/Features/EconomicPotentialForStorageInNV.pdf


Commonwealth of Virginia Energy Storage Study

Final Report

August 2019

STRATEGEN

Prepared by Strategen for the Virginia Department of Mines, Minerals and Energy. © 2019.

Citation: https://www.strategen.com/strategen-blog/commonwealth-of-virginia-energy-storage-study

The cost components and their values are summarized below, assuming an annual cost decline of 5% (CAGR).

	2019		2029	
	Low	High	Low	High
Storage Module ($/kWh)	$205	$350	$123	$210
Balance of System ($/kWh)	$27	$48	$16	$29
Power Conversion System ($/kW)	$49	$61	$29	$37
Engineering, Procurement & Construction (%)	16.7%	16.7%	16.7%	16.7%
Annual O&M				
O&M (% of Storage Module and BoS Equipment)	1.3%			
O&M (% of Power Conversion System)	1.7%			
Warranty (% of Storage Module and BoS Equipment)	1.5%			
Warranty (% of Power Conversion System)	2.0%			
Augmentation (% of Storage Module and BoS Equipment)	4.2%			

Figure 19. Storage Cost Assumptions

This study also includes jobs and end-of-life and environmental considerations.

Brattle results →

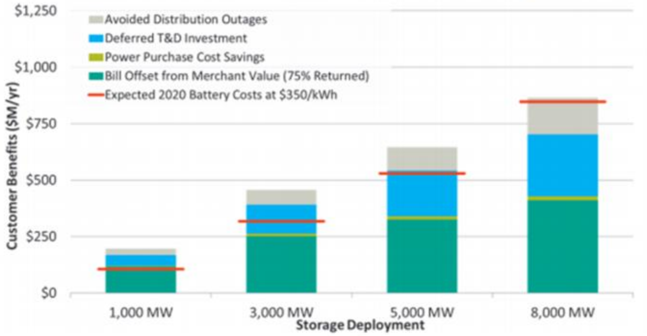
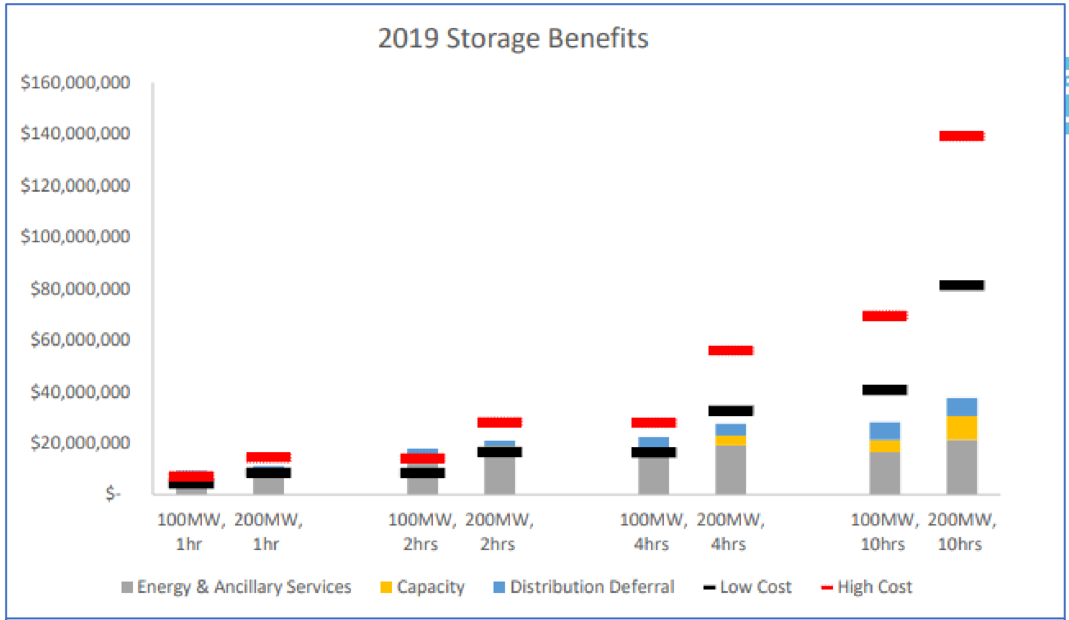
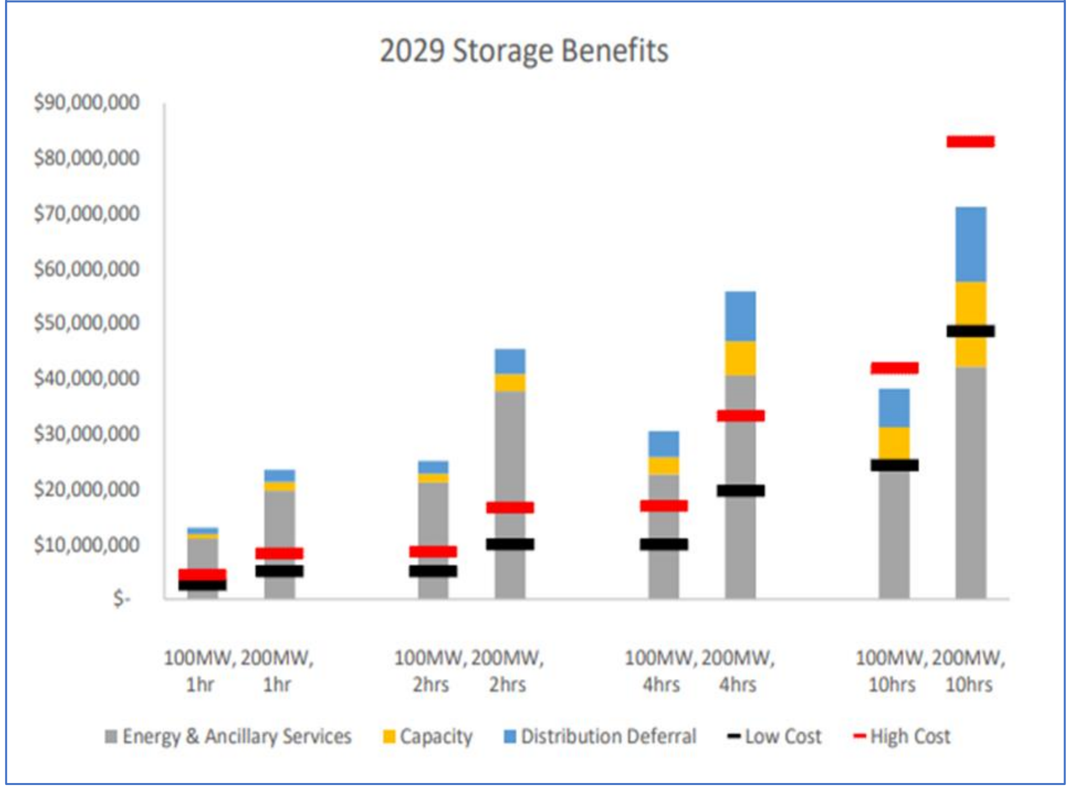


Figure 4
Estimated 2020 ERCOT-Wide Customer Benefits and Storage Costs

Sources and Notes:

The expected 2020 battery costs are annualized based on Oncor's 6.3% ATWACC, with 15- and 30-year assumed lifetime for the battery and balance of plant respectively.


2019 Storage Benefits


2029 Storage Benefits

Energy Storage Options for North Carolina

PREPARED BY
NC State Energy Storage Team

PREPARED FOR
Energy Policy Council
Joint Legislative Commission on Energy Policy

2019

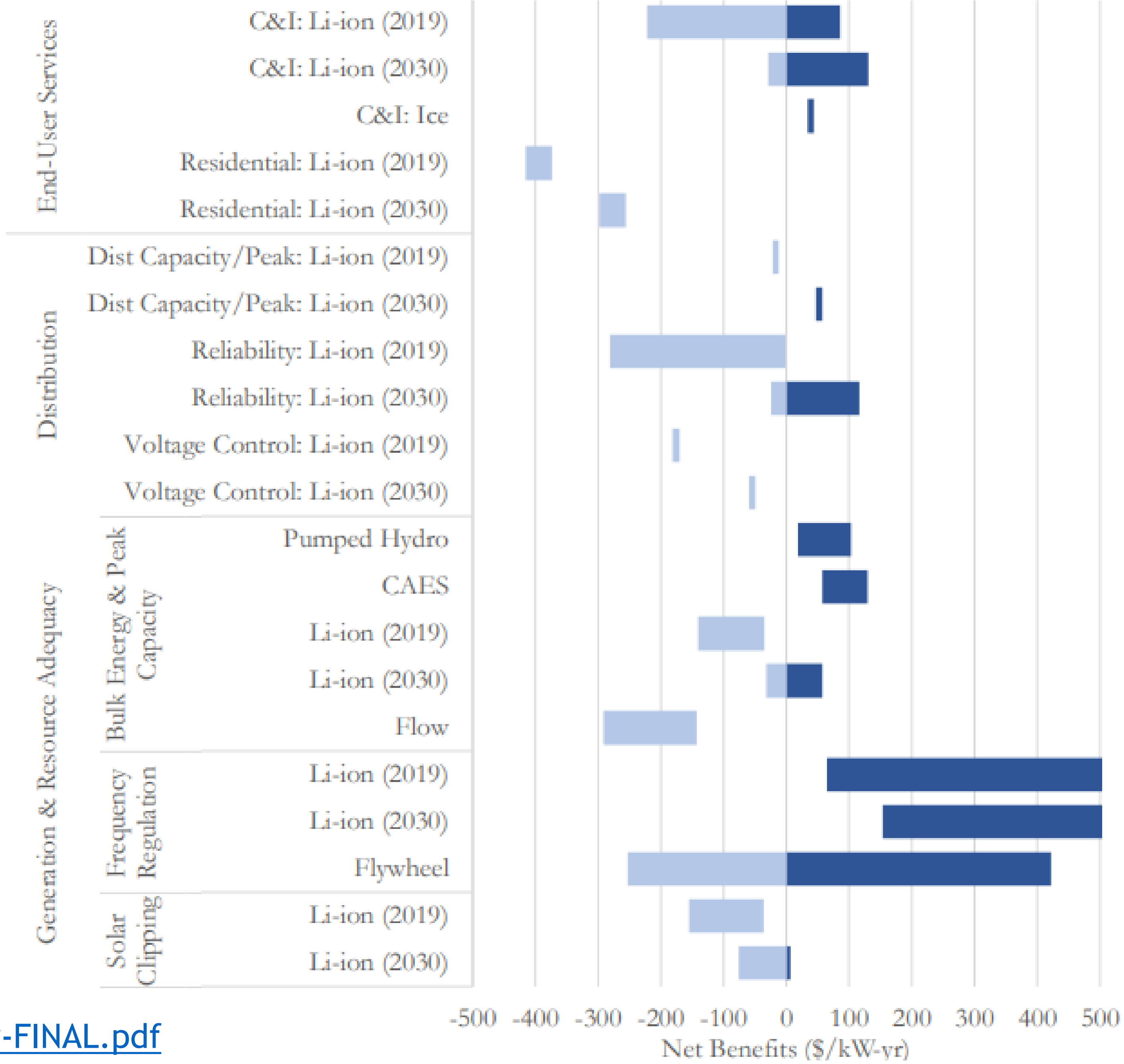


Figure 2. Range of net benefits ($/kWyr) for each technology and service category analyzed. Light blue bars represent negative net benefits (i.e., costs exceed benefits), while dark blue bars represent positive net benefits (i.e., benefits exceed costs). Results assuming current Li-ion battery costs in 2019 and projected 2030 costs are presented separately. Note that Li-ion battery benefits for frequency regulation exceed $500/kWyr, but are truncated for readability.

Citation: https://energy.ncsu.edu/storage/wp-content/uploads/sites/2/2019/02/NC-Storage-Study-FINAL.pdf

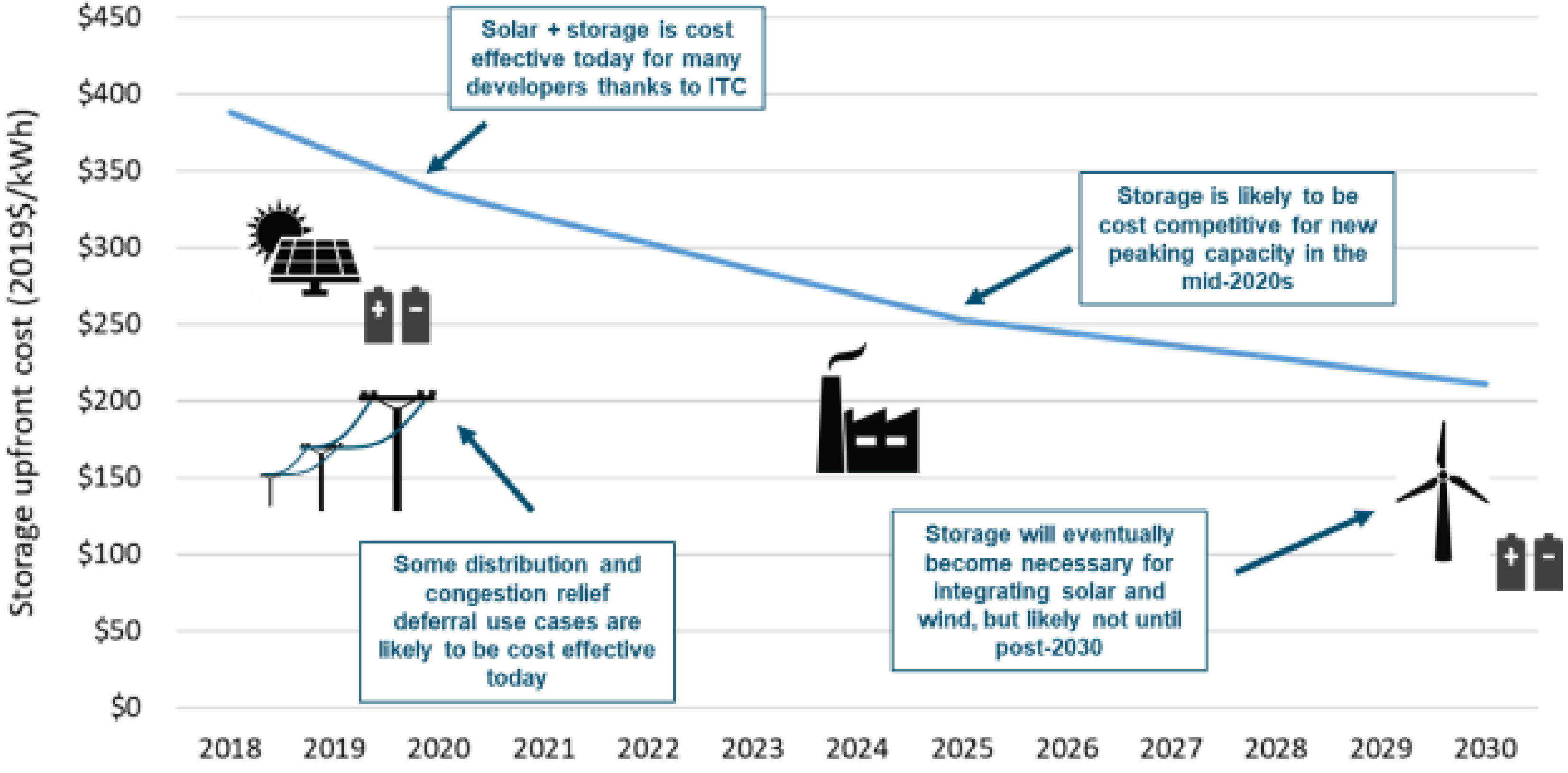
Minnesota Energy Storage Cost-Benefit Analysis

Prepared for: Minnesota Department of Commerce, Division of Energy Resources
Prepared by: Energy and Environmental Economics, Inc. (E3)

Energy+Environmental Economics

2019

Figure 1. Energy storage value transition



Solar + storage is cost effective today for many developers thanks to ITC

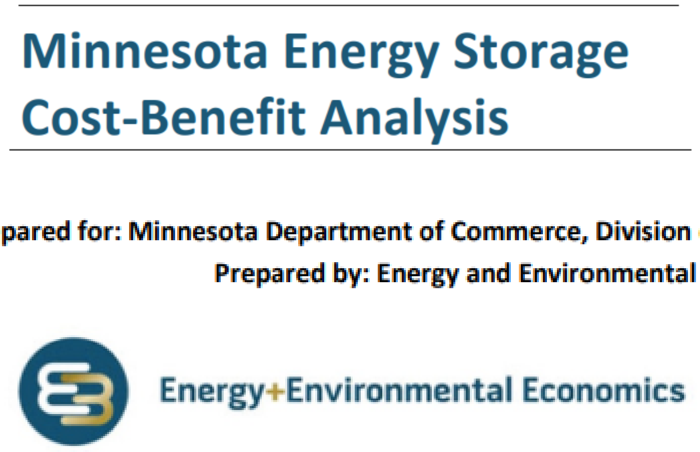
Storage is likely to be cost competitive for new peaking capacity in the mid-2020s

Some distribution and congestion relief deferral use cases are likely to be cost effective today

Storage will eventually become necessary for integrating solar and wind, but likely not until post-2030

Storage upfront cost is based on the NREL "Mid" Case projection (NREL, 2019)

Citation: https://mn.gov/commerce/policy-data-reports/energy-data-reports/?id=17-415938



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Energy+Environmental Economics

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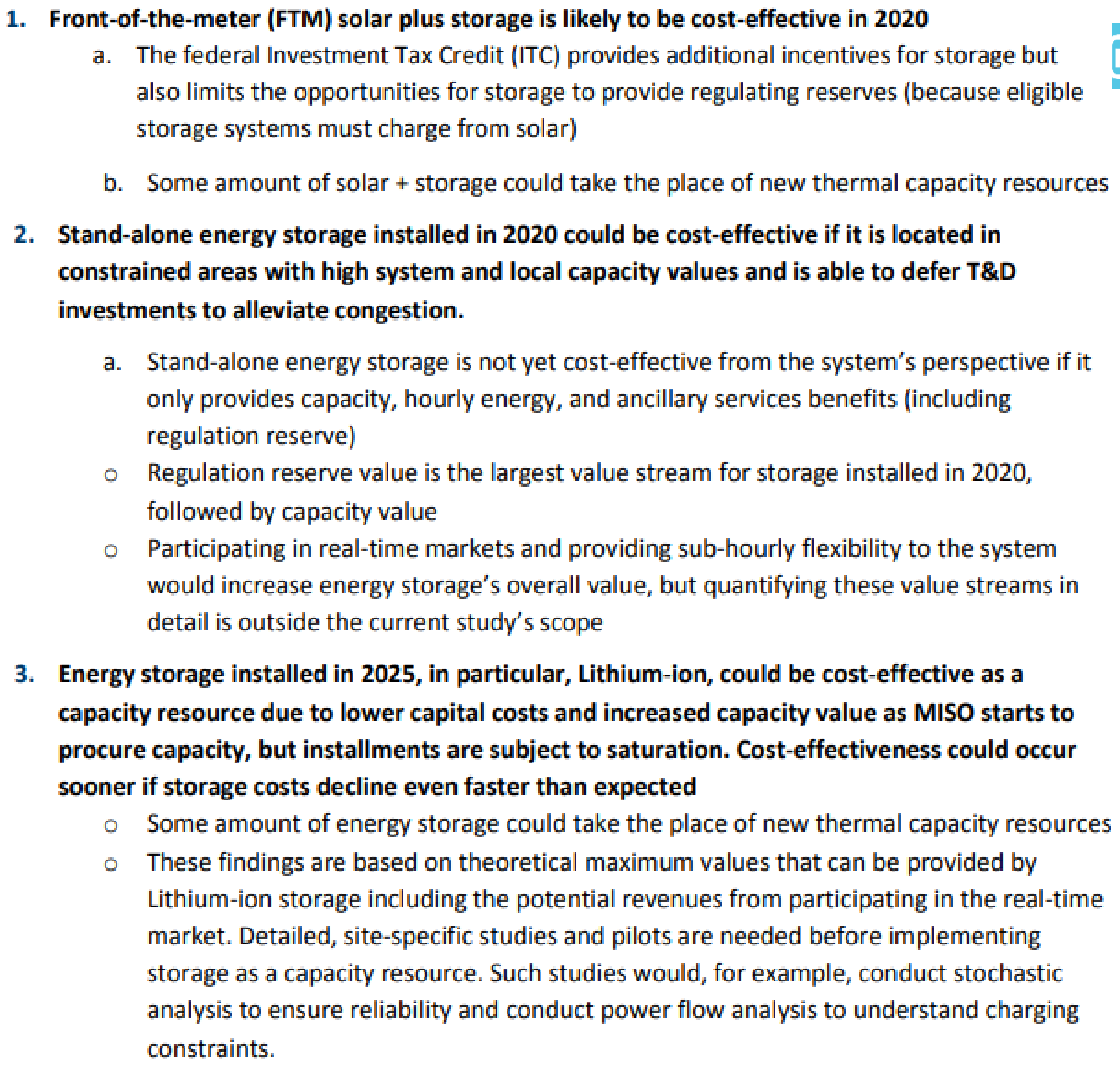
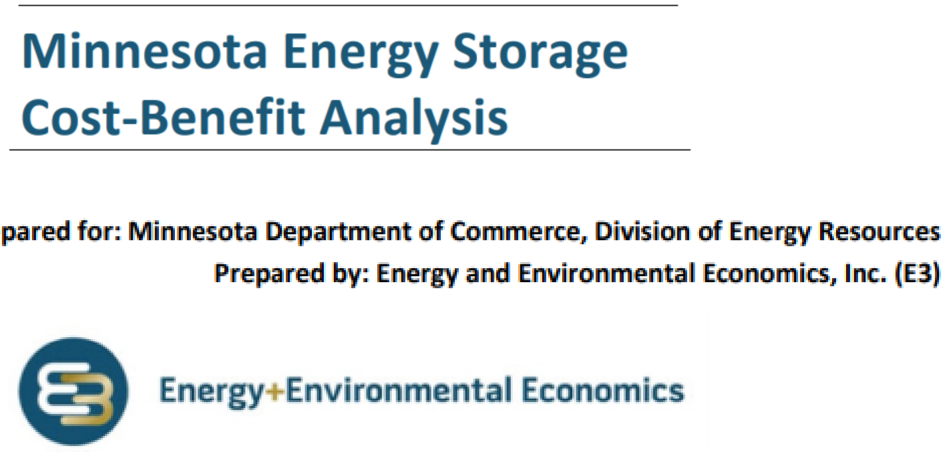


1. **Front-of-the-meter (FTM) solar plus storage is likely to be cost-effective in 2020**
    a. The federal Investment Tax Credit (ITC) provides additional incentives for storage but also limits the opportunities for storage to provide regulating reserves (because eligible storage systems must charge from solar)
    b. Some amount of solar + storage could take the place of new thermal capacity resources
2. **Stand-alone energy storage installed in 2020 could be cost-effective if it is located in constrained areas with high system and local capacity values and is able to defer T&D investments to alleviate congestion.**
    a. Stand-alone energy storage is not yet cost-effective from the system's perspective if it only provides capacity, hourly energy, and ancillary services benefits (including regulation reserve)
    - Regulation reserve value is the largest value stream for storage installed in 2020, followed by capacity value
    - Participating in real-time markets and providing sub-hourly flexibility to the system would increase energy storage's overall value, but quantifying these value streams in detail is outside the current study's scope
3. **Energy storage installed in 2025, in particular, Lithium-ion, could be cost-effective as a capacity resource due to lower capital costs and increased capacity value as MISO starts to procure capacity, but installments are subject to saturation. Cost-effectiveness could occur sooner if storage costs decline even faster than expected**
    - Some amount of energy storage could take the place of new thermal capacity resources
    - These findings are based on theoretical maximum values that can be provided by Lithium-ion storage including the potential revenues from participating in the real-time market. Detailed, site-specific studies and pilots are needed before implementing storage as a capacity resource. Such studies would, for example, conduct stochastic analysis to ensure reliability and conduct power flow analysis to understand charging constraints.

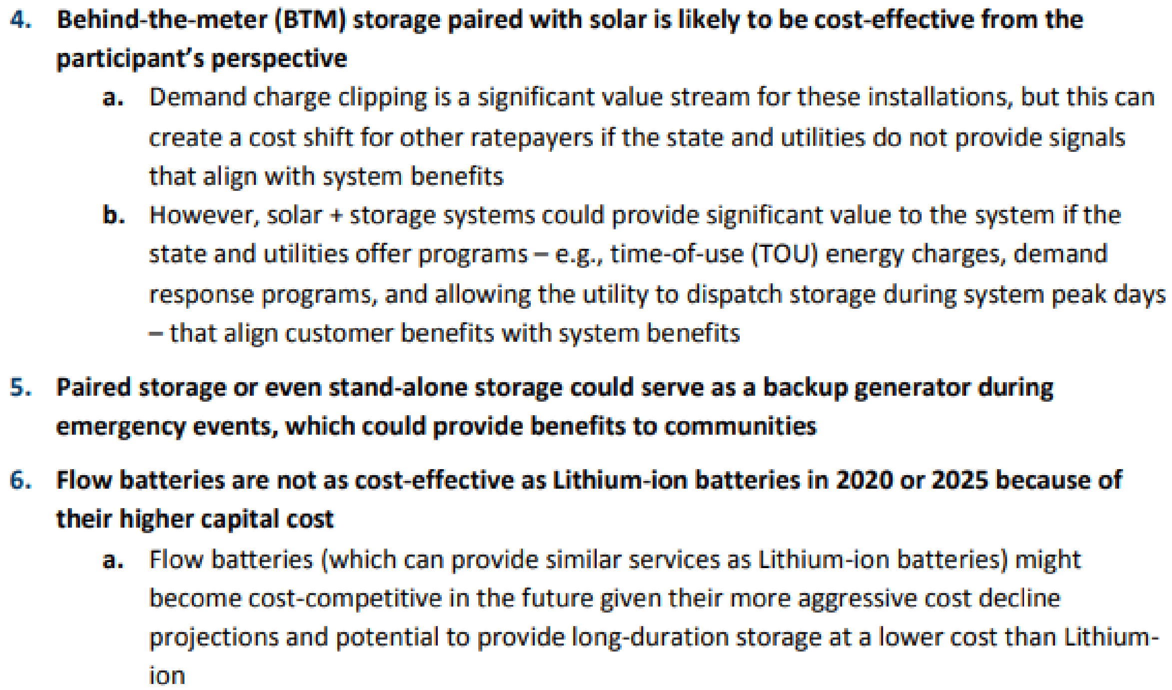


Minnesota Energy Storage Cost-Benefit Analysis

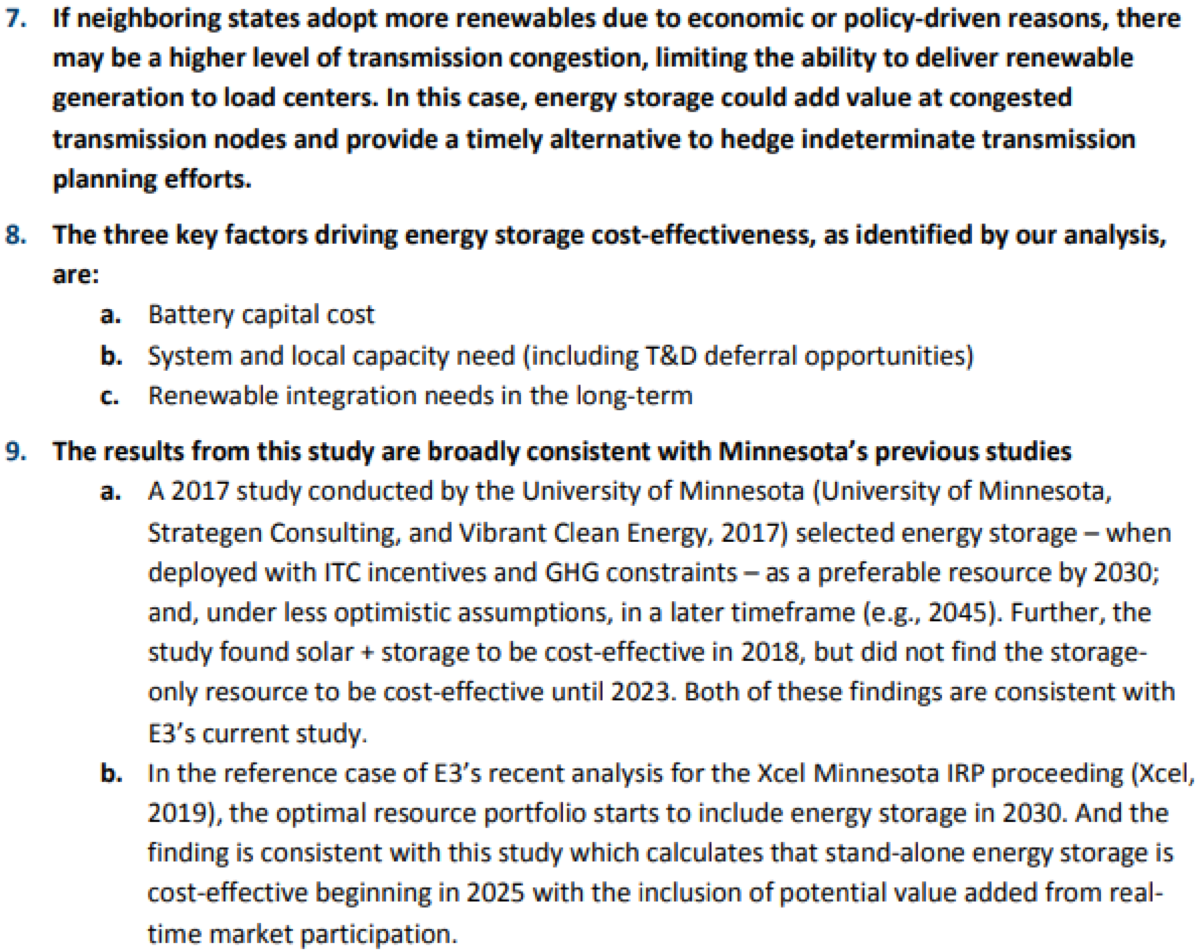
Prepared for: Minnesota Department of Commerce, Division of Energy Resources
Prepared by: Energy and Environmental Economics, Inc. (E3)

Energy+Environmental Economics

2019

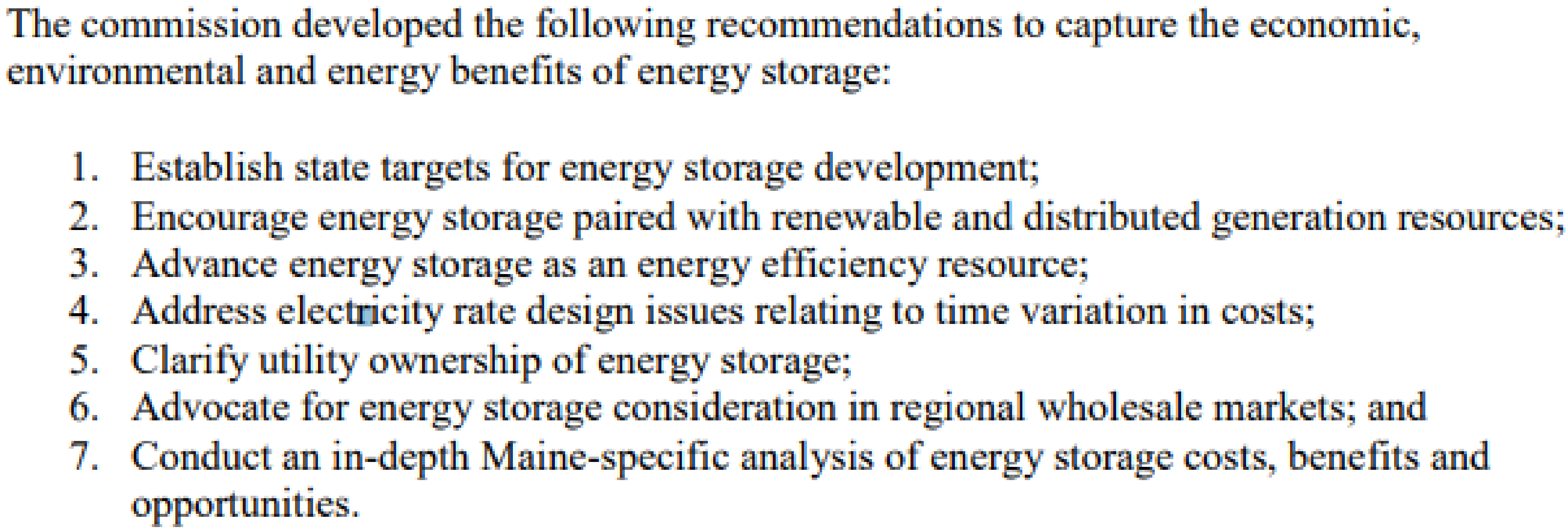


4. **Behind-the-meter (BTM) storage paired with solar is likely to be cost-effective from the participant's perspective**
    a. Demand charge clipping is a significant value stream for these installations, but this can create a cost shift for other ratepayers if the state and utilities do not provide signals that align with system benefits
    b. However, solar + storage systems could provide significant value to the system if the state and utilities offer programs – e.g., time-of-use (TOU) energy charges, demand response programs, and allowing the utility to dispatch storage during system peak days – that align customer benefits with system benefits
5. **Paired storage or even stand-alone storage could serve as a backup generator during emergency events, which could provide benefits to communities**
6. **Flow batteries are not as cost-effective as Lithium-ion batteries in 2020 or 2025 because of their higher capital cost**
    a. Flow batteries (which can provide similar services as Lithium-ion batteries) might become cost-competitive in the future given their more aggressive cost decline projections and potential to provide long-duration storage at a lower cost than Lithium-ion



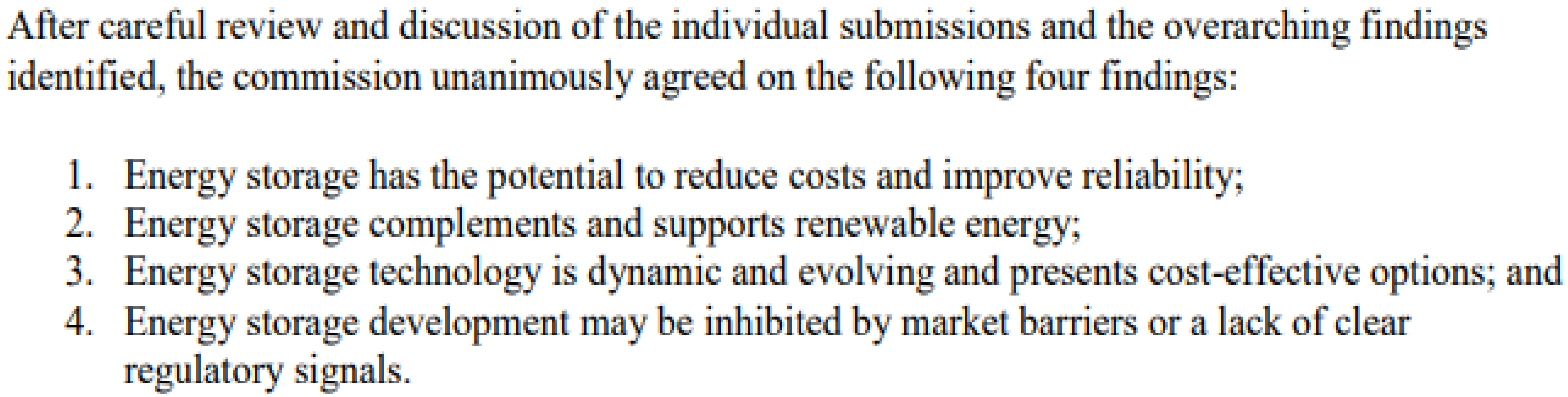
7. **If neighboring states adopt more renewables due to economic or policy-driven reasons, there may be a higher level of transmission congestion, limiting the ability to deliver renewable generation to load centers. In this case, energy storage could add value at congested transmission nodes and provide a timely alternative to hedge indeterminate transmission planning efforts.**
8. **The three key factors driving energy storage cost-effectiveness, as identified by our analysis, are:**
    a. Battery capital cost
    b. System and local capacity need (including T&D deferral opportunities)
    c. Renewable integration needs in the long-term
9. **The results from this study are broadly consistent with Minnesota's previous studies**
    a. A 2017 study conducted by the University of Minnesota (University of Minnesota, Strategen Consulting, and Vibrant Clean Energy, 2017) selected energy storage – when deployed with ITC incentives and GHG constraints – as a preferable resource by 2030; and, under less optimistic assumptions, in a later timeframe (e.g., 2045). Further, the study found solar + storage to be cost-effective in 2018, but did not find the storage-only resource to be cost-effective until 2023. Both of these findings are consistent with E3's current study.
    b. In the reference case of E3's recent analysis for the Xcel Minnesota IRP proceeding (Xcel, 2019), the optimal resource portfolio starts to include energy storage in 2030. And the finding is consistent with this study which calculates that stand-alone energy storage is cost-effective beginning in 2025 with the inclusion of potential value added from real-time market participation.

State of Maine Commission to Study the Economic, Environmental, and Energy Benefits of Energy Storage to the Maine Electricity Industry, 2019



The commission developed the following recommendations to capture the economic, environmental and energy benefits of energy storage:

1. Establish state targets for energy storage development;
2. Encourage energy storage paired with renewable and distributed generation resources;
3. Advance energy storage as an energy efficiency resource;
4. Address electricity rate design issues relating to time variation in costs;
5. Clarify utility ownership of energy storage;
6. Advocate for energy storage consideration in regional wholesale markets; and
7. Conduct an in-depth Maine-specific analysis of energy storage costs, benefits and opportunities.

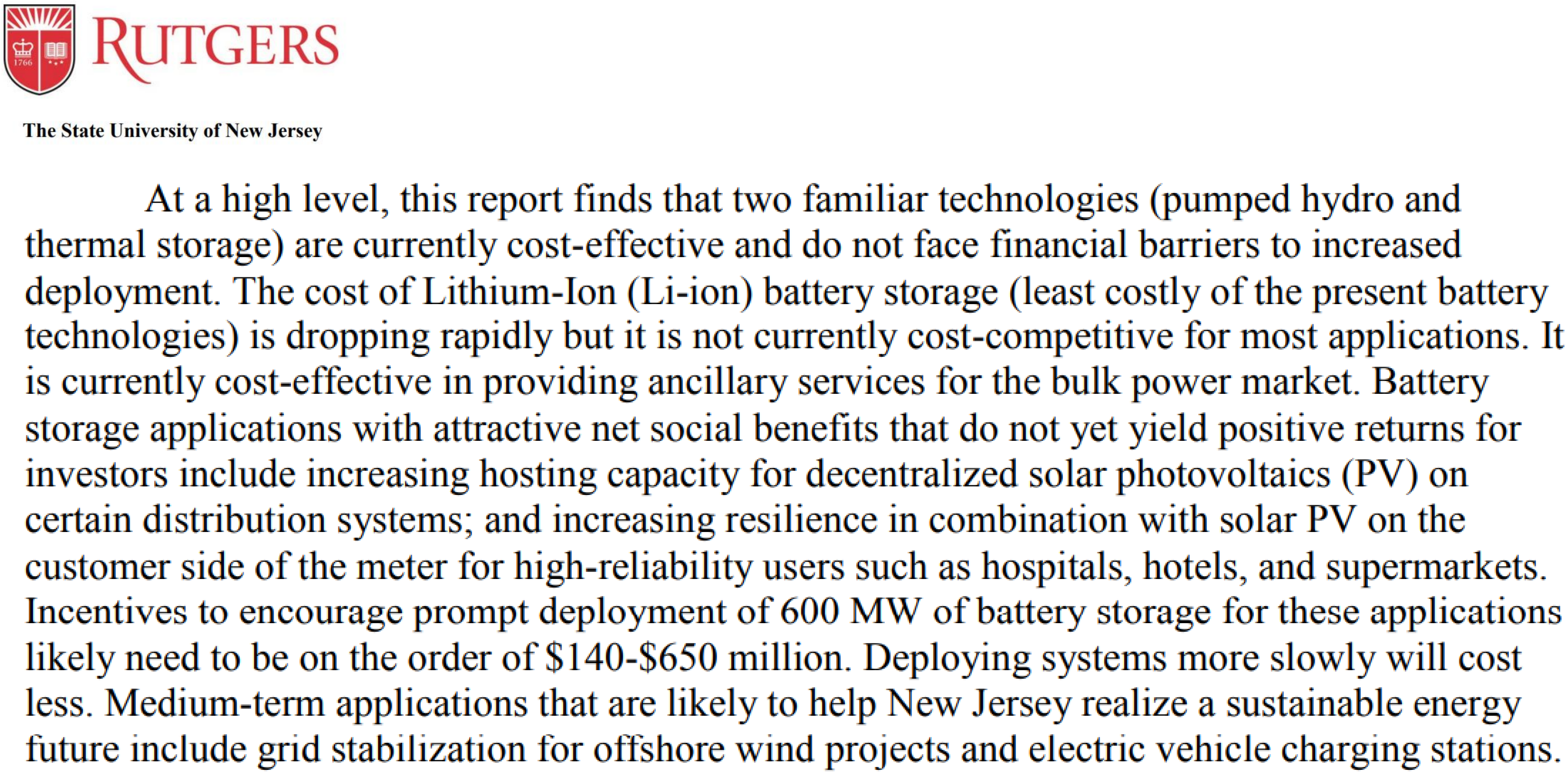


After careful review and discussion of the individual submissions and the overarching findings identified, the commission unanimously agreed on the following four findings:

1. Energy storage has the potential to reduce costs and improve reliability;
2. Energy storage complements and supports renewable energy;
3. Energy storage technology is dynamic and evolving and presents cost-effective options; and
4. Energy storage development may be inhibited by market barriers or a lack of clear regulatory signals.

Citation: https://legislature.maine.gov/energy-storage-commission

New Jersey Energy Storage Analysis Final Report, 2019



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The State University of New Jersey

At a high level, this report finds that two familiar technologies (pumped hydro and thermal storage) are currently cost-effective and do not face financial barriers to increased deployment. The cost of Lithium-Ion (Li-ion) battery storage (least costly of the present battery technologies) is dropping rapidly but it is not currently cost-competitive for most applications. It is currently cost-effective in providing ancillary services for the bulk power market. Battery storage applications with attractive net social benefits that do not yet yield positive returns for investors include increasing hosting capacity for decentralized solar photovoltaics (PV) on certain distribution systems; and increasing resilience in combination with solar PV on the customer side of the meter for high-reliability users such as hospitals, hotels, and supermarkets. Incentives to encourage prompt deployment of 600 MW of battery storage for these applications likely need to be on the order of $140-$650 million. Deploying systems more slowly will cost less. Medium-term applications that are likely to help New Jersey realize a sustainable energy future include grid stabilization for offshore wind projects and electric vehicle charging stations.

Citation: https://www.bpu.state.nj.us/bpu/pdf/commercial/New%20Jersey%20ESA%20Final%20Report%2005-23-2019.pdf

New Jersey Energy Storage Analysis Final Report, 2019

BCRs in the Rutgers study are consistently <1

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- For installations modeled at hospitals, apartment complexes, hotels, offices, secondary schools, supermarkets
- Values include resiliency, avoided emissions, VOLL, electricity bill management, all as NPVs)
  - Standalone Li-ion battery storage -- 1 MW, 4 hr, 10 yrs; BCRs **0.19 -- 0.25**
  - Standalone Li-ion battery storage -- 0.25 MW, 4 hr, 10 yrs; BCRs **0.33 – 0.58**
  - ES with PV (1 MW, 4 hr, 10 yrs -- ITC: BCRs **0.30 – 0.66**
  - ES for freq. reg only -- 1 MW, 4 hr, 10 yrs; BCRs **0.92 – 1.50**
  - ES for arbitrage only – 1 MW, 4 hr, 10 yrs; BCRs **0.36 – 0.68**
  - 25% freq. reg & 75% arbitrage – 1MW, 4 hr, 10 yrs BCRs **0.91 – 1.49**
  - Centralized with PV – BCR **0.41 – 0.57**
  - Decentralized with PV -- BCR **0.53 – 0.67**
  - Centralized ES Only – BCR **0.27 – 0.57**

What are the key findings specific to regulatory reform?

1. Most of the BCAs are showing positive BCR's.
2. The BCA can be used to determine the potential amount of ESS that should be deployed to achieve a certain level of benefits at specific points across the distribution grid. (TX)
3. BCAs are being used to support utility regulatory requirements that utilities incorporate ES into large-scale renewable procurements (NY).
4. Use the BCA as a starting point for Value of Storage proceedings and/or Value of Resilience proceedings. (VA)**
7. Distribution planning for ES, could become an increasingly important lever in terms of meeting ambitious state goals.
    - A BCA with a targeted scope of focus on the distribution grid could justify utility investment in ES. (TX)

How can the ICC utilize the findings?

Common suggestions for further studies:

- **Value stacking:** 1) How will it improve the value proposition for ES applications; 2) What rules are necessary to ensure that customer-side applications can be stacked with distribution-level and bulk power-level applications, without inappropriate double-dipping or sub-optimization?
- **Battery costs** are dropping rapidly, but many future cost reductions will need to come from reducing soft costs such as permitting, customer acquisition, and financial risk.: 1) Which market rules and incentive arrangements have lower soft costs?; 2) Which ones encourage market learning, experience acquisition, and achievement of scale economies?
- **Hosting Capacity** (on distribution systems) How can policies encourage collection and public sharing of regular data on ES installations and their performance, and on market opportunities that may emerge on T&D networks?
- **Utility Ownership:** Should utility ownership of ES devices be limited to ensure creation of a robust market, or do the benefits of vertical integration outweigh this concern?.
- **Pilot Programs:** Pilot programs can be used to test the market, specifically to examine use cases associated with bulk power system, distribution-level, and customer-side applications, and multiple technologies.

Final thoughts…

- In a BCA, all model parameters are important – size, power, energy, round trip efficiency, costs, prices, rates, projected decreasing costs, duration, policies . . . But all are not always included. Standardization would help.
- Value stacking and dual market participation (wholesale & distribution) are crucial.
- Frequency regulation and ancillary benefits consistently yield BCR >1, but so do many other combinations of stacked values.
- How to improve Benefit Cost Ratios? Streamline, standardize, and/or advance valuation, rate reform, interconnection, codes and standards, commissioning, risk & finance, marketing, and education.

> *"If energy storage is not cost effective, it is partly because the regulatory environment does not allow it to be."*
>
> Dr. Imre Gyuk, DOE OE Energy Storage Program Director

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Dr. Imre Gyuk, Program Manager

Q&A Session

Thank you!

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