Energy+Environmental Economics

Overview of E3 Storage Capabilities

Public Summary

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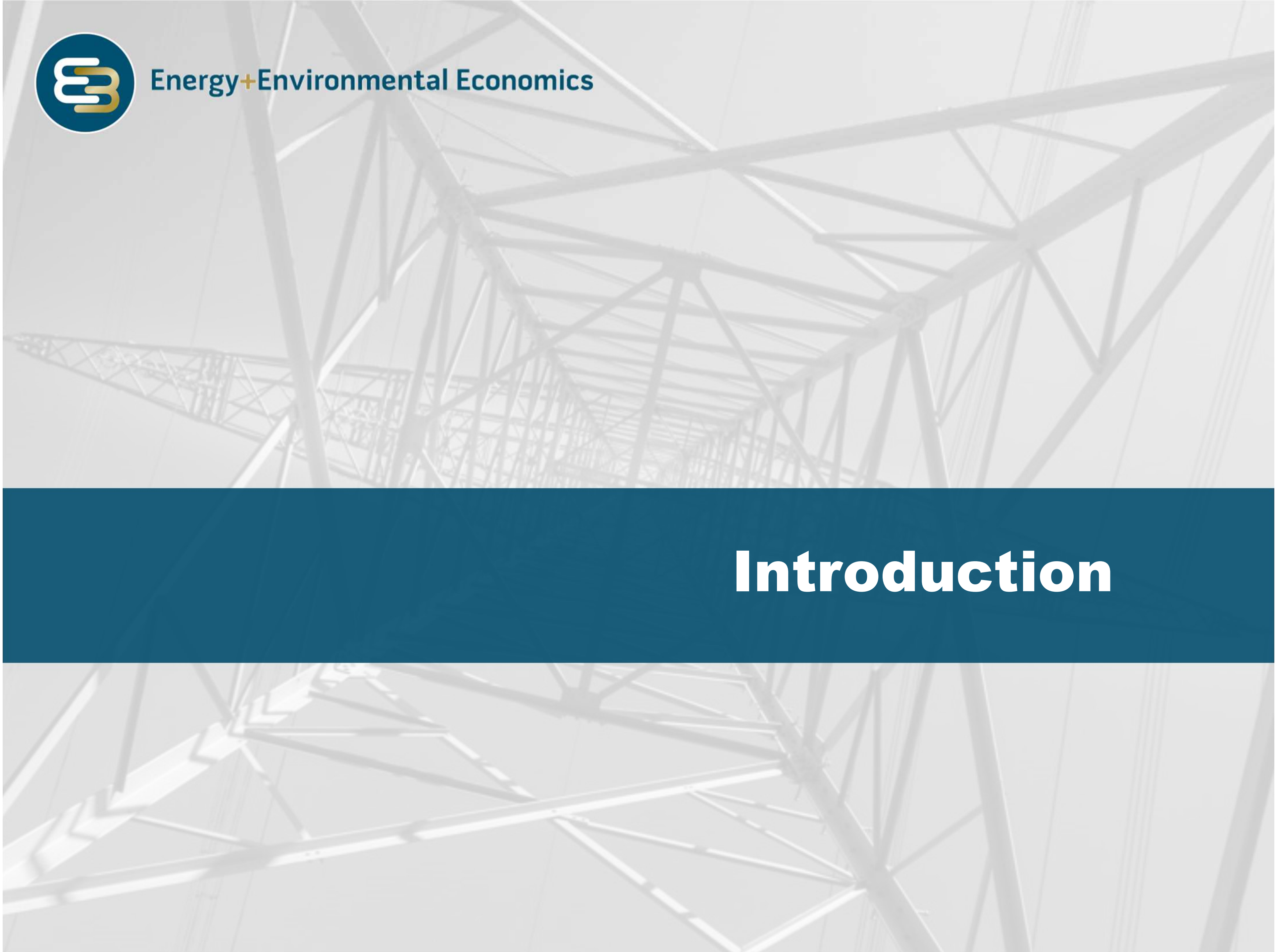

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Introduction

E3's History with Energy Storage Analysis

- **E3 has been analyzing utility storage use cases since the early 1990s, including many projects through Electric Power Research Institute (EPRI); early use cases included targeted non-wires studies and demand-charge arbitrage assessment**
  - More recent public work with EPRI involved co-developing the Energy Storage Valuation Tool (ESVT)*
- **We continually work with utilities, project developers, and technology vendors as well as state regulatory and research agencies to quantify energy storage costs, benefits, and overall value**
  - We also use analysis to inform high level public sector policy and regulatory actions as well as private sector investment decisions
- **Our storage modeling capabilities are constantly evolving to reflect both advances in technology as well as changes to markets, regulation, and policy**
  - Our storage tool, "RESTORE", is designed to be very flexible to model diverse use cases and accommodate ongoing policy and market changes

*See chapter 3: https://www.energy.ca.gov/2017publications/CEC-500-2017-016/CEC-500-2017-016.pdf

Primary Challenges Currently Facing Energy Storage Deployment

- <u>The inability to monetize the full value of storage.</u> Current operating restrictions and/or high costs from aggregation or telemetry that would enable monetizing multiple stacked services are one of the largest barriers to storage. The inability to fully monetize storage limits its value, and therefore its economics, in today's electricity markets.
- <u>Limited routes to existing markets.</u> Regulatory and market rules, which were put in place largely before resources like advanced energy storage were available, often limit the ability of storage to receive appropriate compensation. In some cases, these rules do not fully recognize the value of storage's near-instantaneous response as compared to alternatives in today's markets.
- <u>Confidence in performance and lifetime.</u> The diversity and relative "newness" of different types of energy storage technologies, products, applications, and use cases complicate understanding and confidence among potential customers, system operators, and investors.
- <u>Lack of common financing vehicles.</u> The relatively low volume of existing advanced energy storage projects contributes to a lack of standardized and transparent processes, procedures, and documentation, which in turn impedes investor confidence and traditional financing and increases transaction costs.
- <u>High costs</u> of hardware and "soft costs" related to permitting, siting, interconnection, customer acquisition, and financing.
- <u>Insufficient data and lack of situational awareness of the electric system,</u> which impedes efforts to site energy storage for maximum system benefit and identify potential customers

What Will be the Main Drivers to Unlock Storage Value Going Forward?

Cost declines

Technology improvements

System Flexibility Need

Increasing role in utility planning and procurement

Policy mandates

Regulatory changes

(FERC & State)

Market evolution

What are the Fundamental Storage Values?

Challenge #1:
Monetizing these Value Streams

Challenge #2:
Forecasting these Value Streams

Retail Level Value Streams	Distribution Level Value Streams	Wholesale Level Value Streams
ISO/RTO Programs	Losses	Blackstart
Utility Programs/Pilots	Congestion	Voltage Support
Power Quality	Voltage Support	Regulation
Backup Power	Reliability/Loading	Reserves (Spin/Non-Spin)
Retail Demand Charges	T&D Deferral	Energy
Retail Energy Charges	Capacity	Capacity

Value Stream Drivers

- **Customer Market**
  - Retail electricity prices
  - Retail demand charges
  - Utility programs/pilots
  - ISO/RTO programs
- **Distribution Market**
  - Emerging markets for distribution-level value streams like T&D deferral
- **Wholesale Market**
  - Wholesale capacity prices
  - Wholesale energy prices
  - Wholesale ancillary services prices

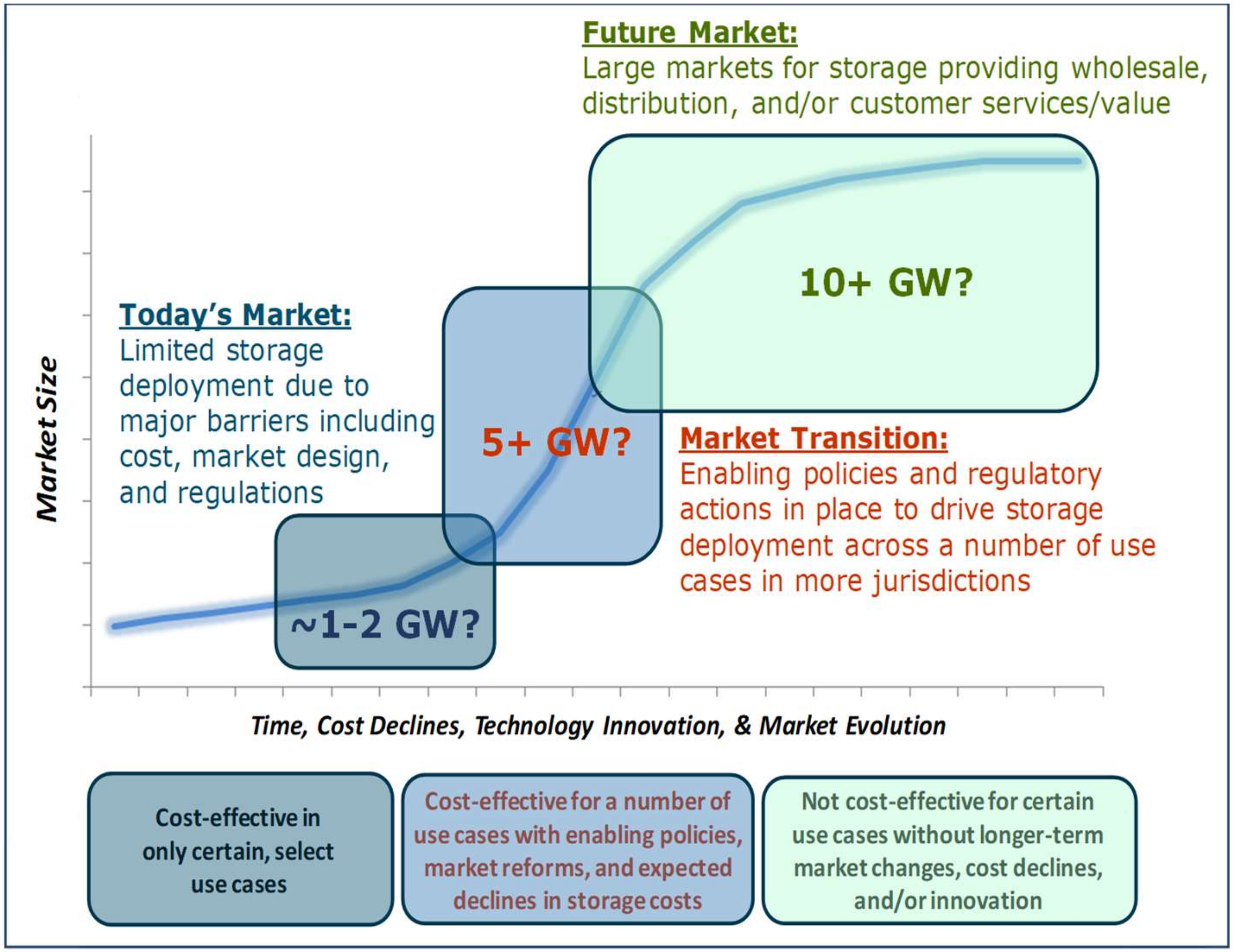
How to Group Energy Storage Technologies by the Services they can Perform?

+ Can perform service   **±** May perform service under certain circumstances   **-** Cannot perform service

Market Segment	Service (Value / Benefit)	Timescale	Chemical	Electrical	Thermal	Mechanical
Wholesale	Frequency Regulation	Seconds, minutes	+	+	-	+
	Load Following/Ramping	Seconds, minutes, hours	+	+	-	+
	Renewable Integration	Seconds, minutes, hours, days, seasons	+	+	-	+
	Spinning Reserves	Minutes, hours	+	+	-	+
	Non-Spinning Reserves	Minutes, hours	+	+	-	+
	Voltage Support	Minutes, hours	+	+	-	+
	Black Start	Minutes, hours	+	+	-	+
	Energy (arbitrage, peak shaving, shifting)	Minutes, hours, days	+	+	-	+
	Emission Reductions	Minutes, hours, days, months, seasons, years	±	±	±	±
	System Capacity or Resource Adequacy	Months, years	+	-	-	+
	Transmission Deferral/Avoidance	Months, years	+	-	-	+
Distribution	Volt/VaR Control	Seconds, minutes	+	-	-	-
	Outage Mitigation	Minutes, hours, days	+	-	-	-
	Distributed Generation integration	Minutes, hours, days	+	-	-	-
	Distribution Deferral/Avoidance	Months, years	+	-	-	-
	Distribution Congestion Relief	Months, years	+	-	-	-
Retail (Customer or Ratepayer)	Power Reliability	Seconds, minutes, hours	+	-	-	-
	Backup Power	Minutes, hours	+	-	-	-
	Utility Delivery Charge Savings	Minutes, days, months	+	-	±	-
	Retail Commodity Charge Savings	Hours, days, months	+	-	±	-

How will Storage Value Change Over Time?

- <u>Near-Term:</u> High value ancillary services markets, utility procurements for high need/compliance, and backup power/ resiliency
- <u>Mid-Term:</u> Transition to new flexibility and distribution level markets plus incorporation into utility planning / procurement decisions
- <u>Longer-term</u>: Significant flexibility required for a high renewables, low carbon grid



Figures cited are estimates of U.S. national potential

How to Holistically Think about Constructing Storage Use Cases?

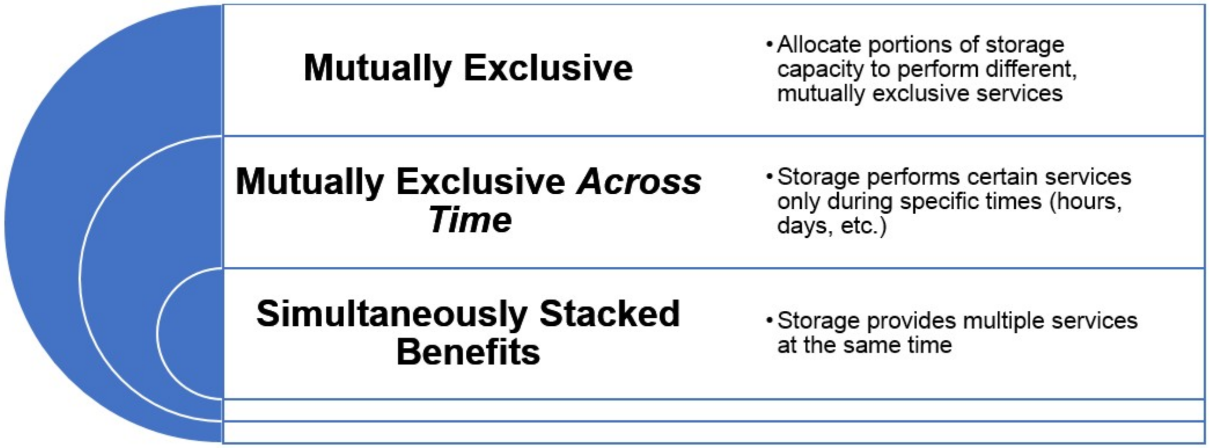
- Storage is like a swiss army knife and it has many uses and applications
- This means that storage "use cases" can be defined along many different dimensions *(the table below is a high level representation of this for New York)*
- A common challenge when examining and analyzing storage use cases is defining a representative and informative set of use cases given the multitude of potential use case combinations in the context of continuing market evolution

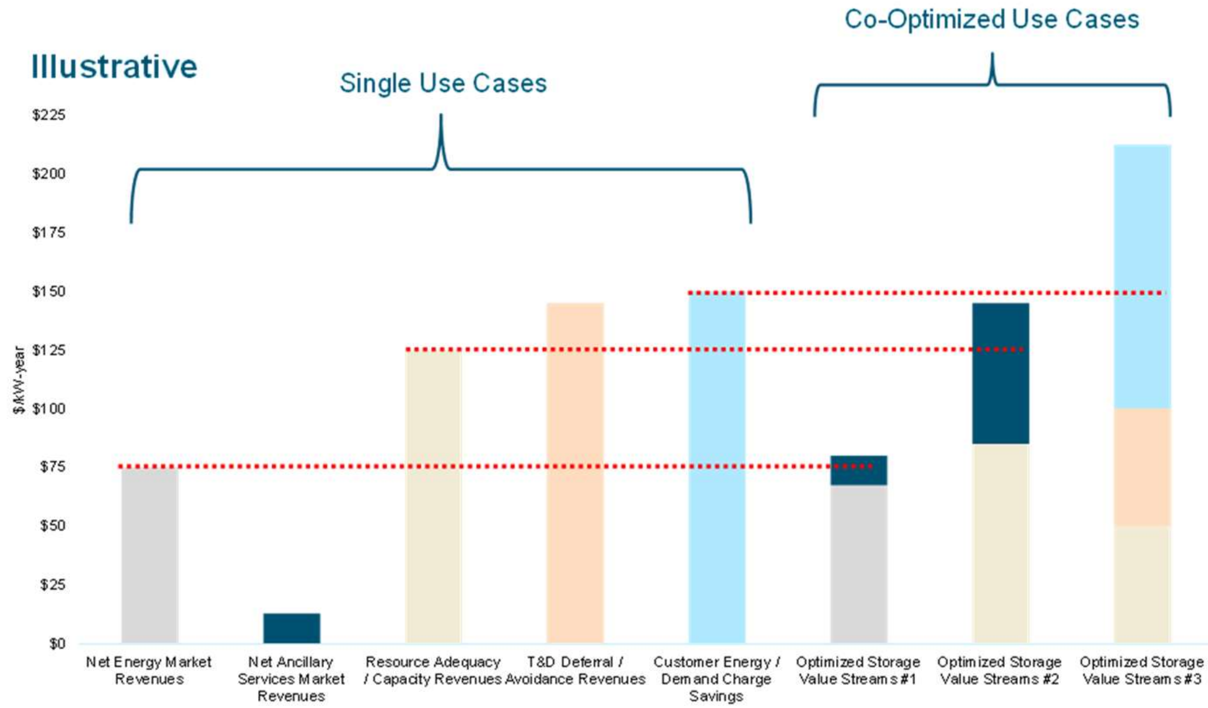
Storage Tech	Li-on	Flow	PSH	Ice	CAES	Flywheel	Other?	
Metering	BTM	FOM						
Utility/Geography	Upstate	Downstate						
Control mode	Customer	Utility	Partial/Mixed					
Paired?	Load	Renewables	EE	Smart appliances	EVs			
Ownership	Customer	3rd Party	Utility					
Aggregation	3rd Party	Direct/None	Utility					
Market Prioritization	Wholesale	Distribution	Customer	Optimized (Joint/Layered)				
Wholesale Markets	Energy (Direct/DR)	Capacity (Direct/DR)	Regulation	10-min sync	10-min non-sync	30 min reserves	Renewable integration	G&T deferral / avoidance
Utility Markets	NWA	VDER	DR	Demos/pilots	Congestion / Load relief	Volt/VaR support	Outage mitigation	DER integration
Customer Markets	Energy charge savings	Demand charge savings	Backup power	Power reliability				
Non-Market Values	Societal carbon	Market transformation	Economic development					

How to Think about Stacking Multiple Storage Values, Benefits, or Services?

+ **Storage offers many stackable value streams depending upon siting, market products and prices, and co-location with solar, wind, or other generation**

+ **Storage cannot perform all services simultaneously and given a choice of revenues, will optimize its operations to maximize the total revenues across all potential value streams under a given set of market, financial, and physical operational constraints**
    - In other words, a storage asset may sacrifice revenues in one value stream to access revenues in another stream to maximize total revenues

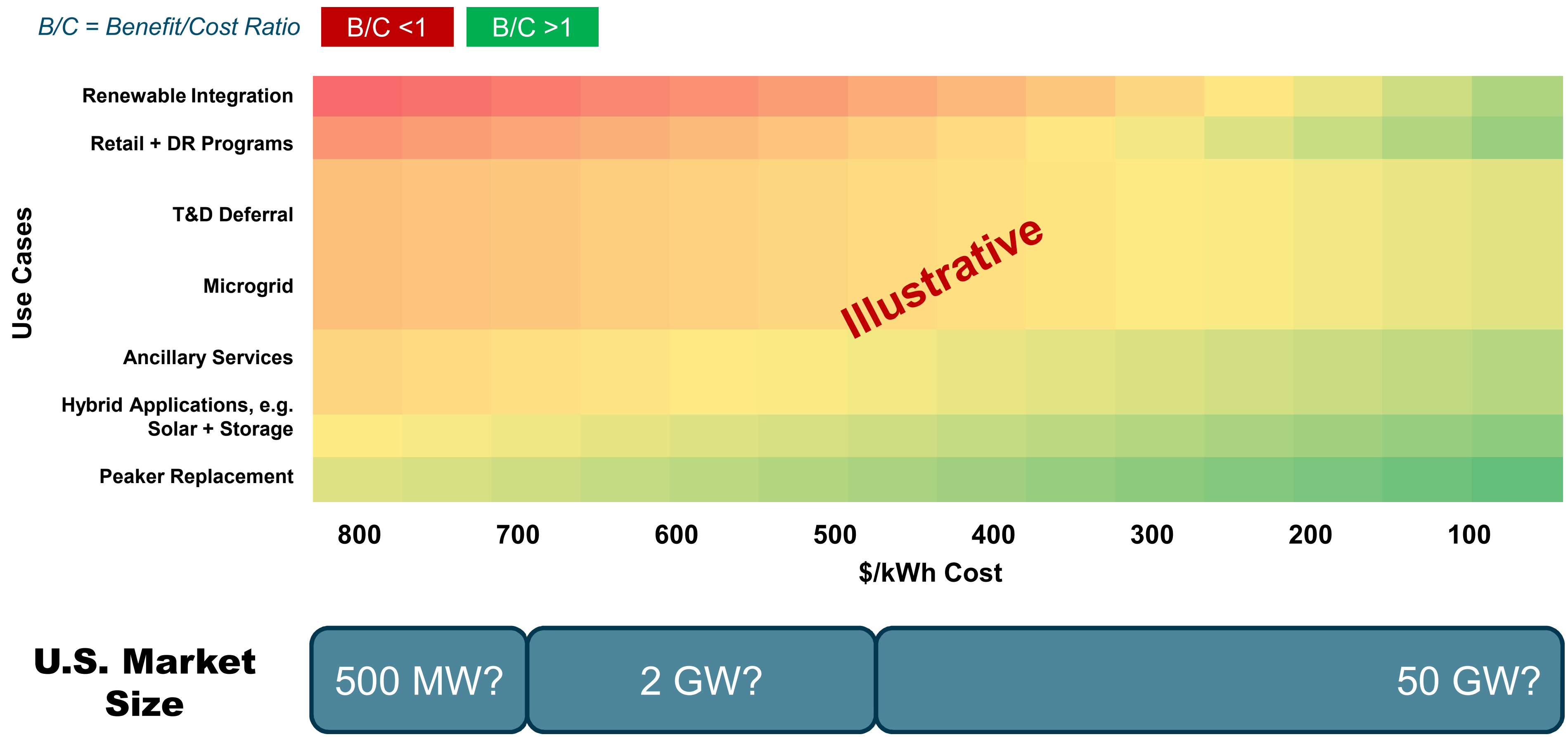




When will Each Storage Use Case Become Cost-Effective and Deployable?

Deployment timeline depends on continuing market evolution, policy/regulatory actions, cost declines, and technology innovation

B/C = Benefit/Cost Ratio



Example Steps in a Storage Market Analysis

Three steps of analysis can be used to inform and assess the market and value for storage

1

Fundamental Market Analysis

- What are the fundamental values/services that storage can provide delineated by market?
  - Customer Market: backup power, customer bill savings, utility/ISO programs
  - Wholesale Market: energy, capacity, and ancillary services (regulation, reserves, etc.)
  - Distribution Market: T&D value (deferral, CapEx, OpEx, etc.), congestion, etc.

2

Revenue Stream Analysis

- How are these fundamental values currently realized (by market) for storage?
- What are the barriers (by market) that need to be overcome to realize these values?
- How are these fundamental values (by market) going to evolve over time?
- How can storage maximize value (by market) now and over time?

3

Strategic Road Map and Business Model Formulation

- What are the markets (customer, wholesale, and/or distribution) of most interest for storage both now and in the future?
- What are the size ($ and MW) of these market opportunities for storage?
- What is the strategic road map to take advantage of these opportunities?

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Brief Thoughts on Future Market Evolution

It is Important to Remember that Market Evolution will be Complex and Uneven

+ **E3 believes the electric grids and markets across the U.S. will evolve along the key dimensions of "price" and "flexibility" as more renewables are added to the system**

+Price

High Price, Low Flex Grid

- High gas and/or REC prices
- High carbon prices and/or RPS reform
- Relatively large load growth
- No large transmission buildout
- No full regionalization or increased integration of markets
- Major retirements of existing generation leading to high costs to maintain reliability
- Flexibility solutions are limited in terms of type, magnitude, and capability, i.e. storage, flexible loads, new dispatchable generation, etc.

High levels of renewable curtailment; higher prices support the economics of certain existing and new resources

High Price, High Flex Grid

- High gas and/or REC prices
- High carbon prices and/or RPS reform
- Relatively large load growth
- Large transmission buildout
- Full regionalization or increased integration of markets
- Sufficient existing generation remains to maintain reliability at relatively low costs
- There are abundant flexibility solutions in terms of type, magnitude, and capability, i.e. storage, flexible loads, new dispatchable generation, etc.

Lower levels of renewable curtailment; higher prices support the economics of certain existing and new resources

+Flex

- Low gas and/or REC prices
- Flat or negative load growth
- No large transmission buildout
- No full regionalization or increased integration of markets
- Major retirements of existing generation leading to high costs to maintain reliability
- Flexibility solutions are limited in terms of type, magnitude, and capability, i.e. storage, flexible loads, new convention generation, etc.

High levels of renewable curtailment; lower prices puts economic pressure on certain existing and new resources

Low Price, Low Flex Grid

- Low gas and/or REC prices
- Flat or negative load growth
- Large transmission buildout
- Full regionalization or increased integration of markets
- Sufficient existing generation remains to maintain reliability at relatively low costs
- There are abundant flexibility solutions in terms of type, magnitude, and capability, i.e. storage, flexible loads, new dispatchable generation, etc.

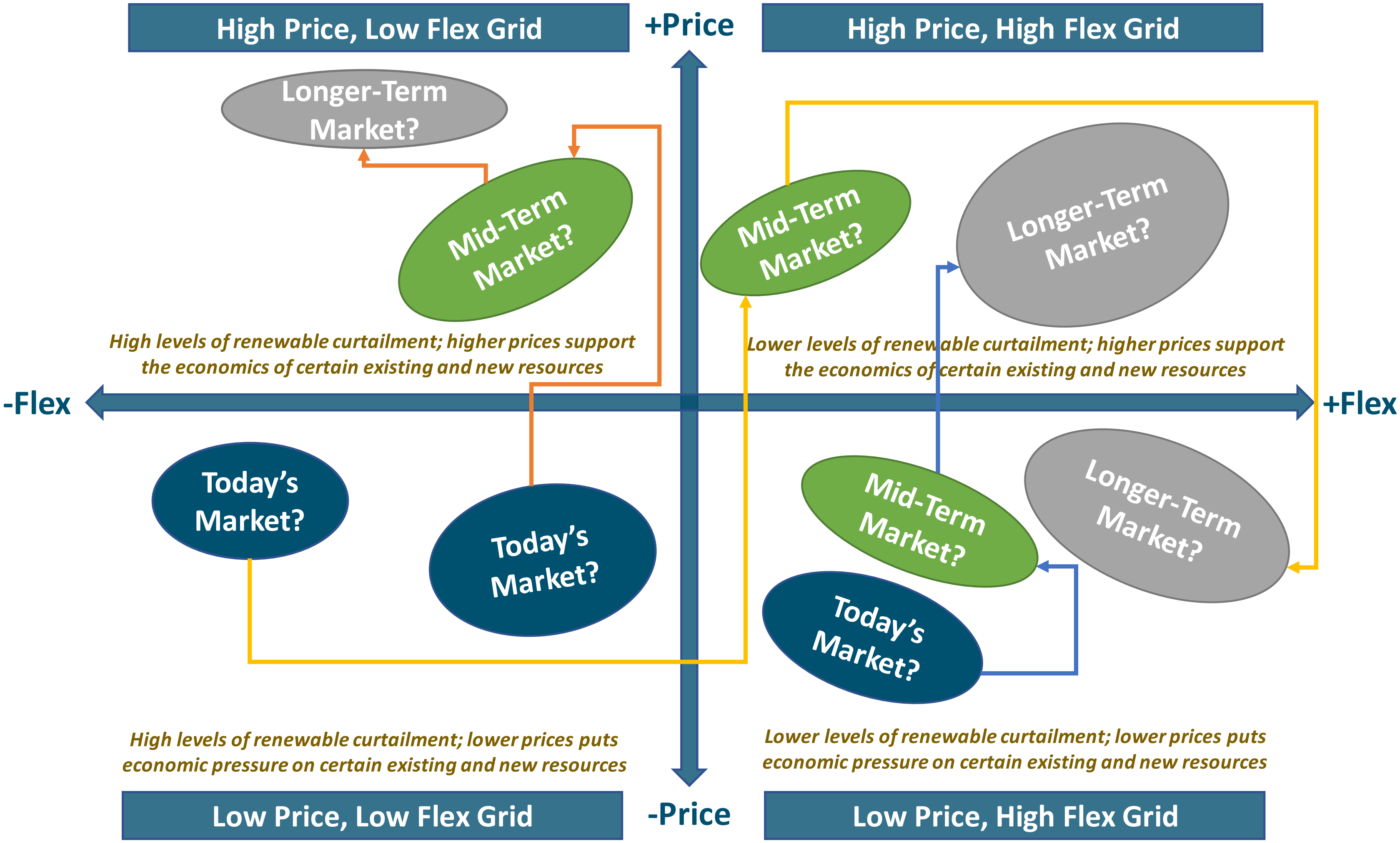
Lower levels of renewable curtailment; lower prices puts economic pressure on certain existing and new resources

Low Price, High Flex Grid

-Price

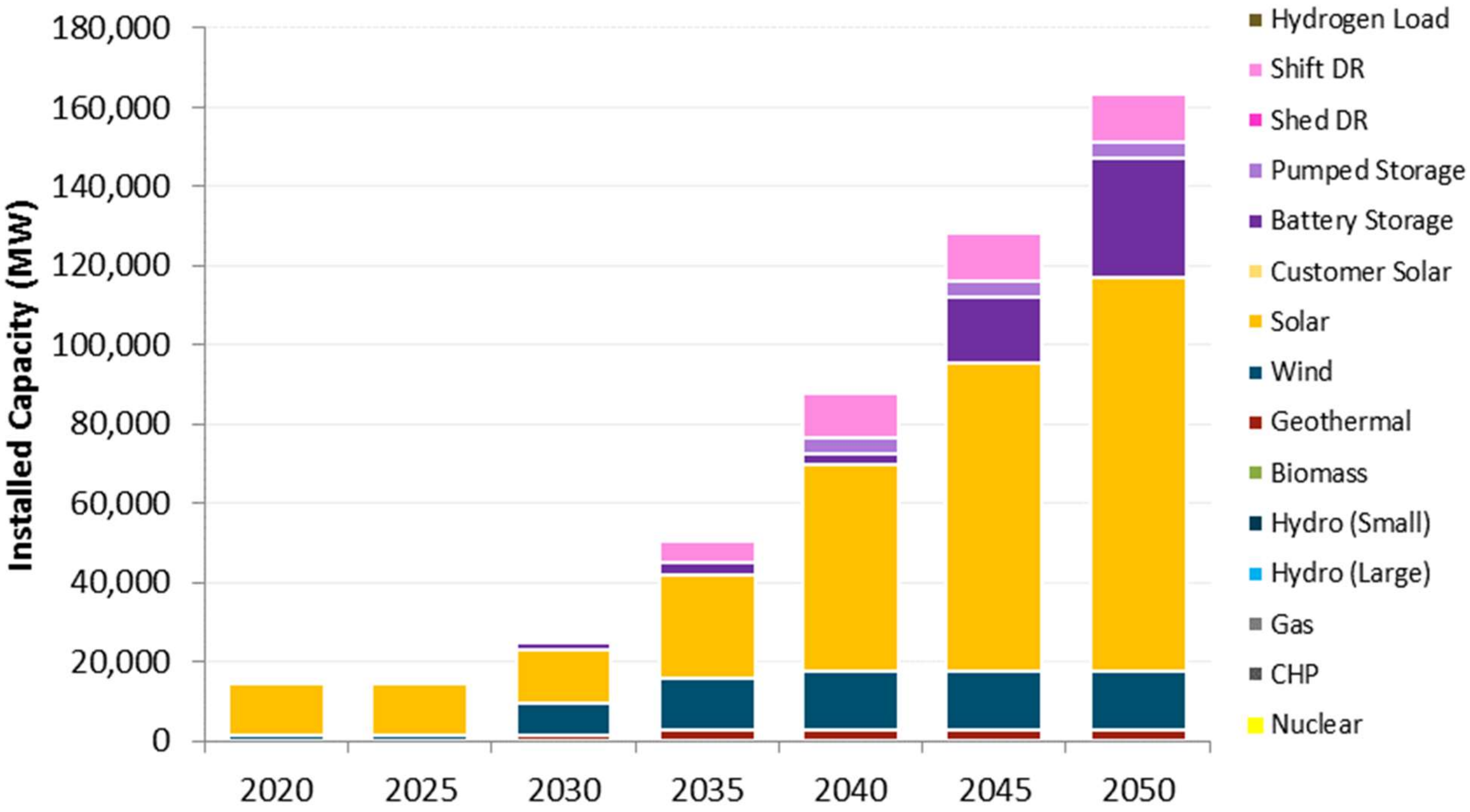
It is Important to Remember that Market Evolution will be Complex and Uneven, cont.

+ **However the path and pace of that evolution across these dimensions will vary by jurisdiction and may be non-linear due to a variety of factors**



As Markets Evolve Different Resources will become Optimal, Especially Storage

+ Illustrative visualization of California's resource portfolio over time under a "deep decarbonization" scenario, i.e. 80% GHG reductions by 2050



Source: E3 analysis from California Public Utilities Commission Integrated Resource Planning Proceeding

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E3 Storage Tools

E3's Storage Tool: (1) RESTORE

+ **RESTORE is our storage price-taker dispatch model that has been used by a diverse set of clients to examine behind and in-front of the meter storage technologies in a variety of contexts:**

  - Benefit-cost analysis
  - Asset valuation
  - Simulation of market operations
  - Market revenue potential
  - Utility retail rate design
  - Adoption modeling

  - Batteries
  - Pumped Hydro
  - CAES
  - Flow batteries
  - Ice storage

Sample Client List

PG&E
NEXTera ENERGY
NEW YORK STATE OF OPPORTUNITY. | NYSERDA Department of Public Service
MACQUARIE
nationalgrid ventures
CALIFORNIA ENERGY COMMISSION
aeso ALBERTA ELECTRIC SYSTEM OPERATOR
California Public Utilities Commission
Sempra Energy

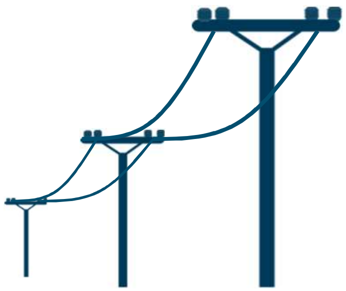
(1) RESTORE: Overview

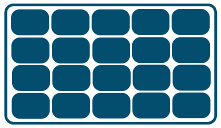
- **Optimization across multiple revenue streams with perfect foresight**
  - Objective function: Minimizing net costs
  - Subject to battery technology and market constraints
- **Model is able to simulate multiple saving/revenue streams**
  - User can select more than one revenue streams to model
  - Market price taker: Dispatch has no impact on market prices
- **Common objective functions:**
  - Bulk (FTM): Maximizing market revenues
  - Utility: Deferring T&D investment (NWA)
  - Utility: Maximizing avoided costs
  - Customer-sited (BTM): Minimizing retail bills

Available revenues/savings

- T&D Deferral
- Interconnection Costs Reduction
- Utility Programs / Customer Bill Savings
- Grid Services / Wholesale Market
- Back-Up Power / Resiliency

Model Highlights

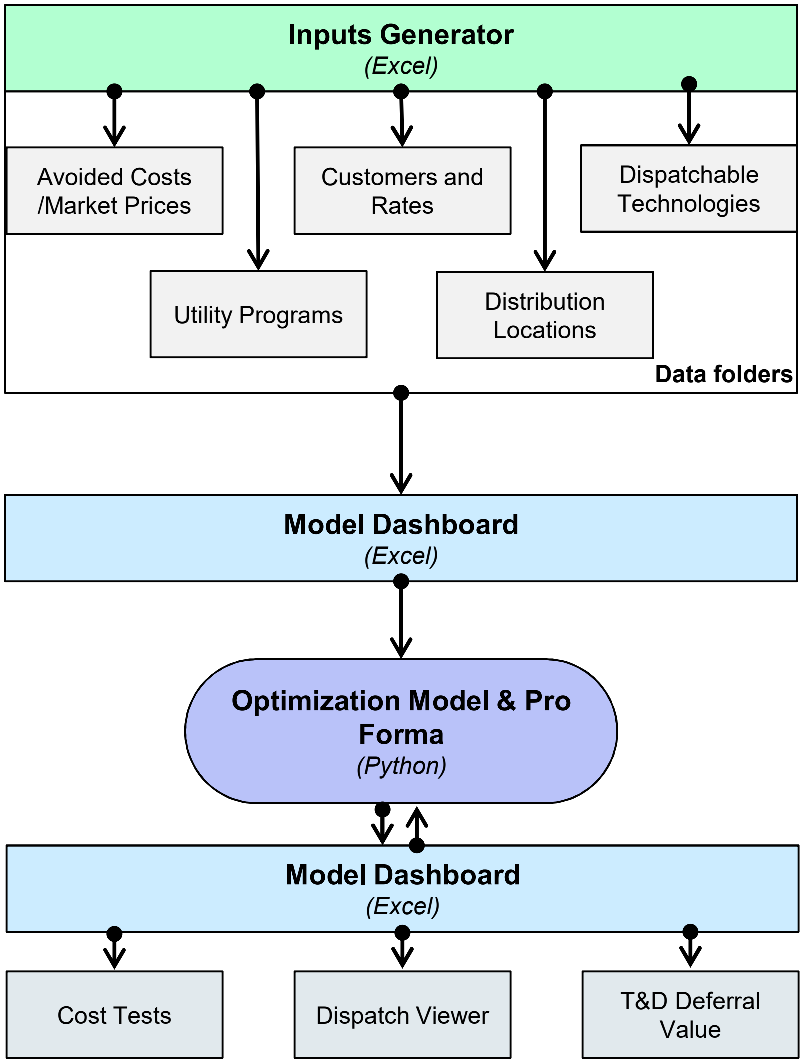




- Project-specific T&D Deferral Values
- Utility Programs Revenue Simulation
- Standalone Storage / Storage+Solar / Storage+DER Systems
- Pro Forma Analysis
- Temperature-based day mapping
- Flexible Optimization Window (Daily, Monthly, Annual) and Intervals (Hourly, 15mins, 5mins)

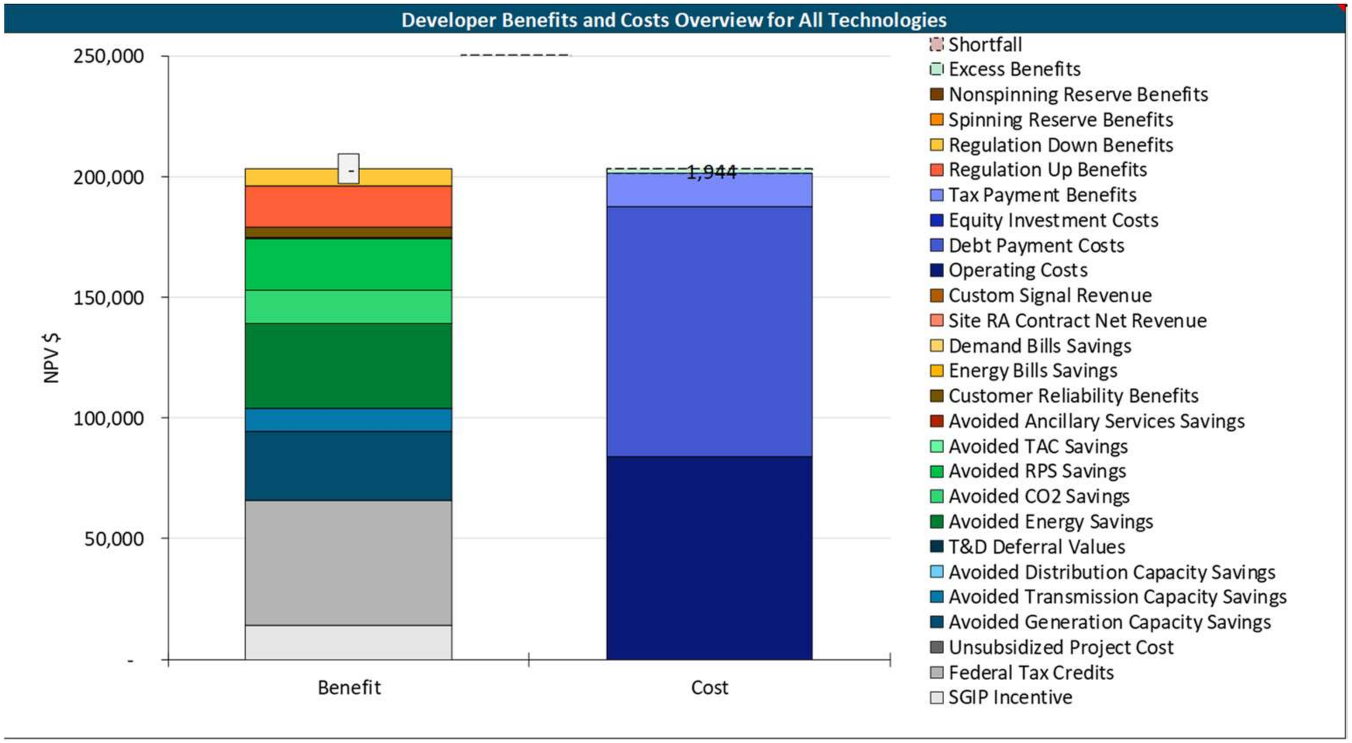
(1) RESTORE Structure

+ **RESTORE consists of three components:**
  - **Inputs Generator**
    Excel-based input fields to generate CSVs
  - **Model Dashboard**
    Excel-based interface to execute Python code and interpret and display results
  - **Optimization Model & Pro Forma**
    Python-based price-taker dispatch optimization model & Pro Forma calculation



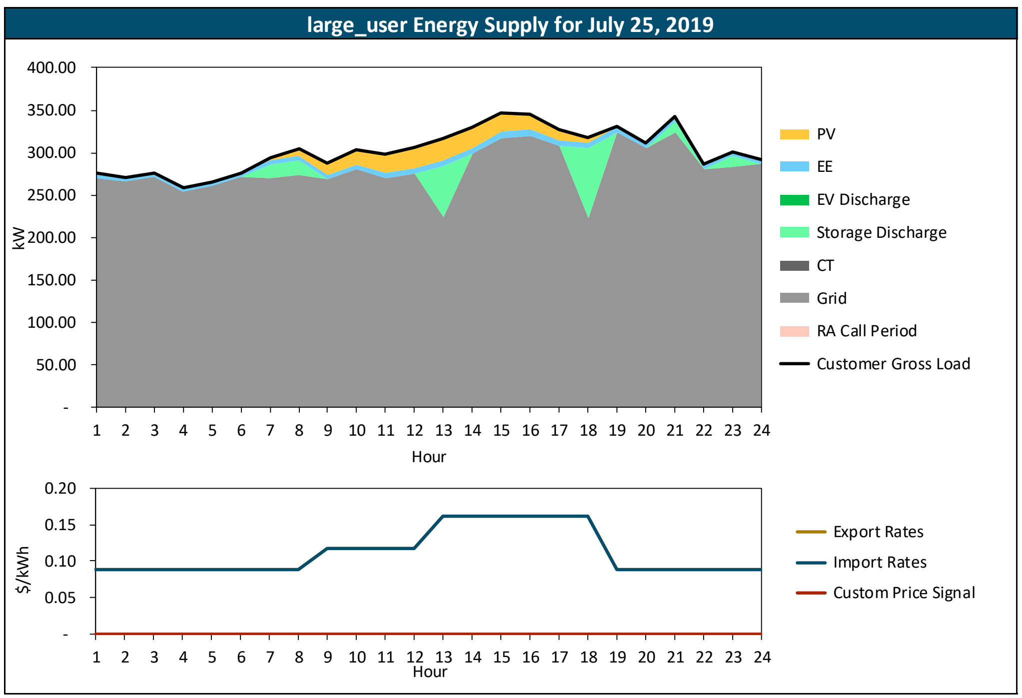
(1) RESTORE Structure: Developer View
Detailed Project Costs

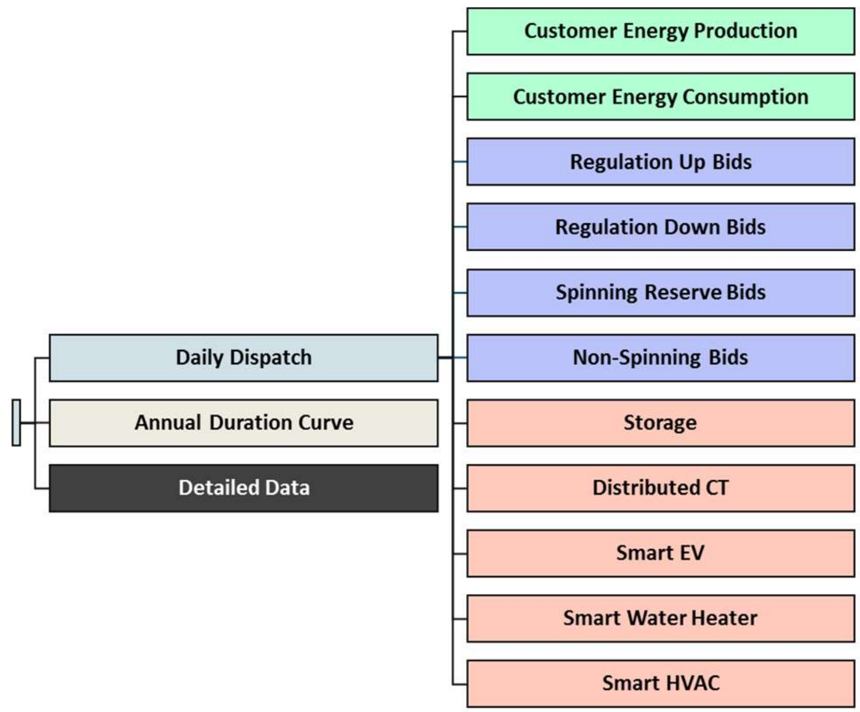
+ **On the Detailed Developer View tab, project costs are further broken out into:**
  1. Equity investment cost
  2. Net finance cost
  3. Operating cost
  4. Other taxes



(1) RESTORE Structure: Detailed Operations

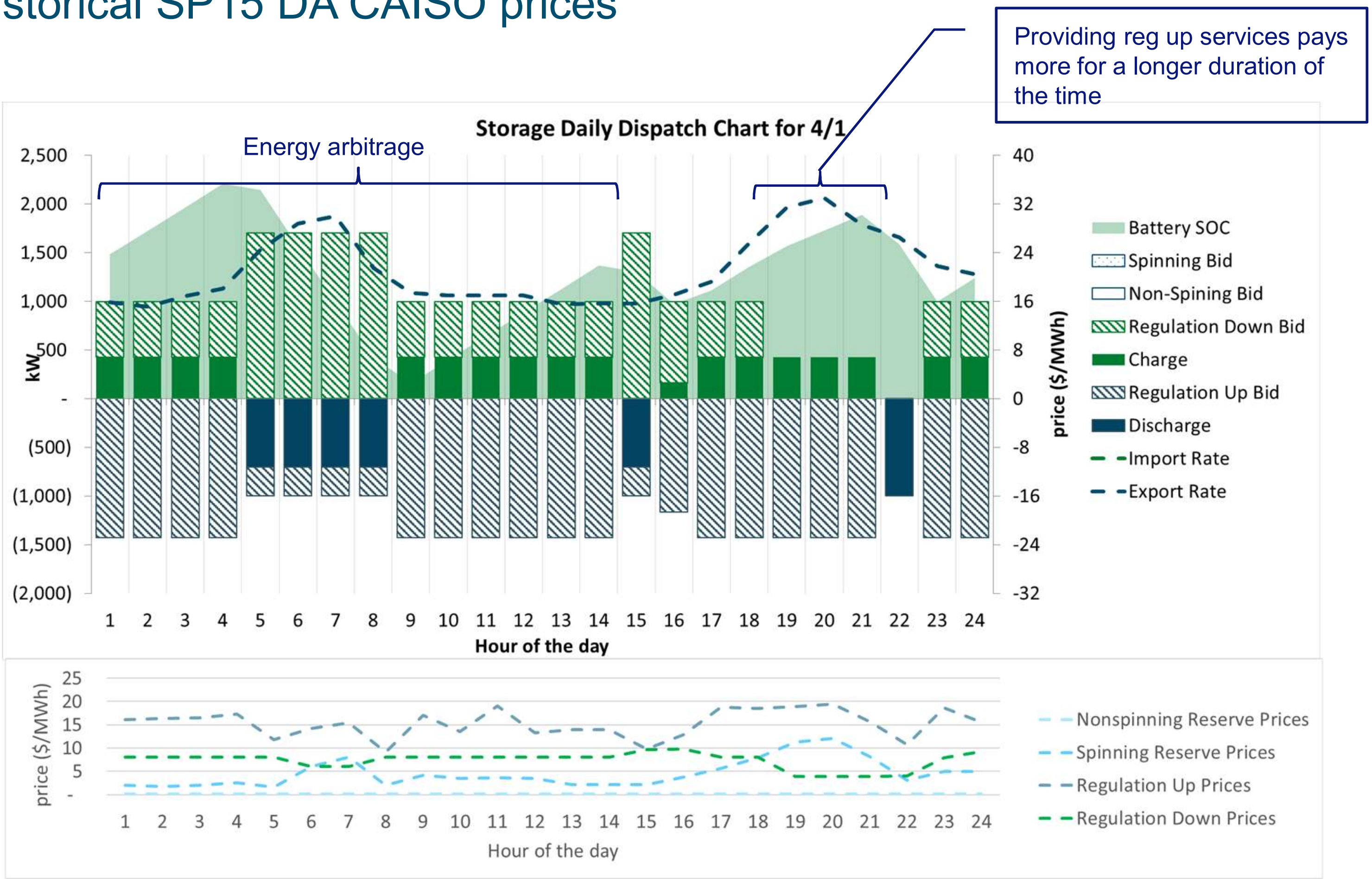
+ The **Detailed Operations** tab allows users to view the chronological operations of each technology in the DER portfolio





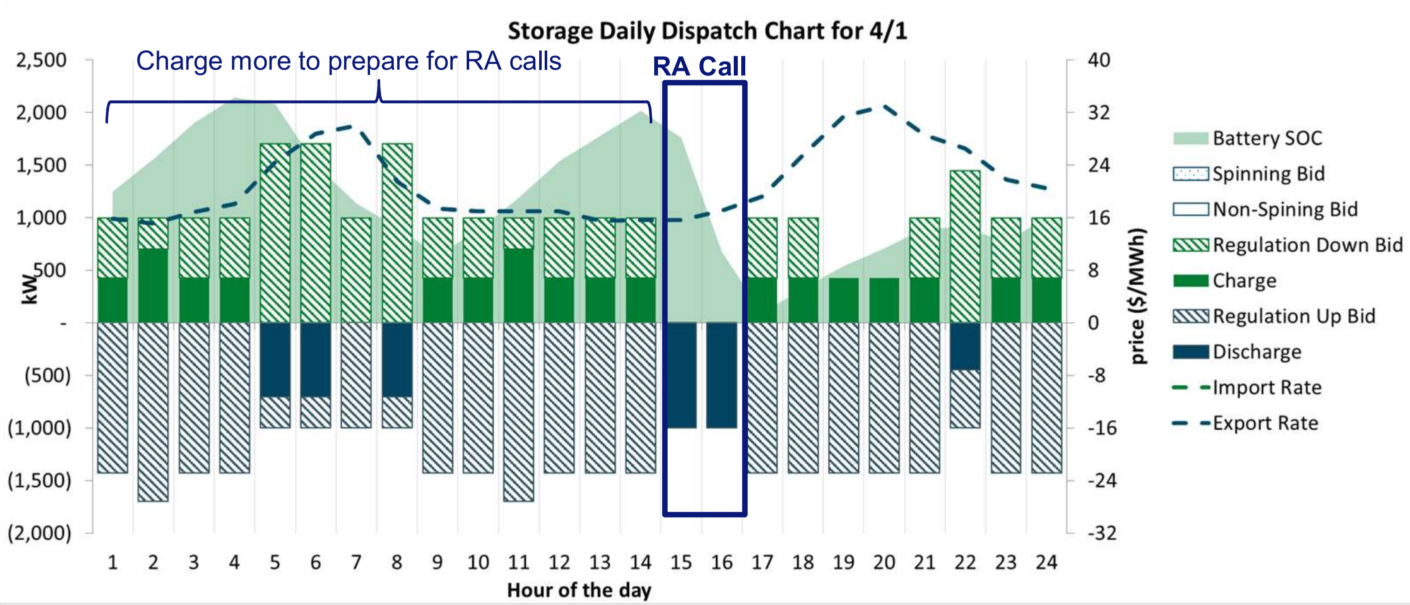
(1) RESTORE Structure:
Example Day w/o Capacity (RA) Call – Spring in California

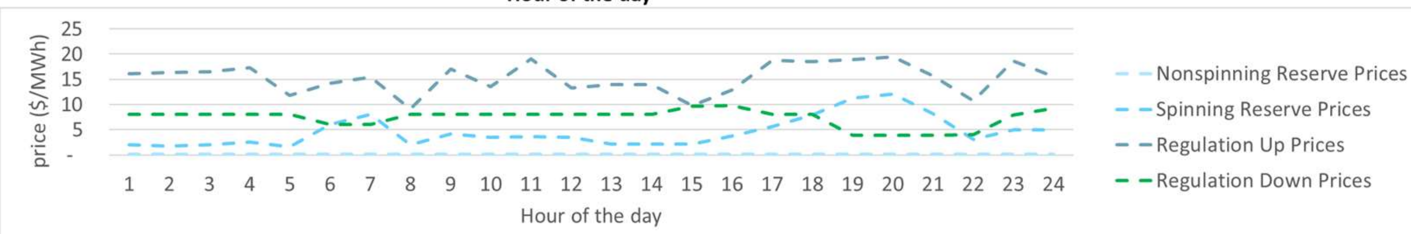
- **1 MW 4-hour battery with 85% round trip efficiency**
  - Historical SP15 DA CAISO prices



(1) RESTORE Structure:
Example Day w/ Capacity (RA) Call – Spring in California

+ **1 MW 4-hour battery with 85% round trip efficiency**
    - Historical SP15 DA CAISO prices
    - With RA call at hour 15 and 16





(2) The Solar + Storage Assessment Tool

The Solar + Storage Assessment Tool (S+SAT) optimizes the operations of a battery paired with a PV system to determine future revenues available across different market products

+ **Meant to be used to support contracting and/or merchant revenue estimation**
+ **Allows the battery to be contracted by a third-party entity**
  - This effectively blocks out certain hours during the year for market participation and the model then determines the price required for such a contract to obtain merchant-equivalent value
+ **Completely programmed in Excel**
+ **Has the option of AC-coupled or DC-coupled PV + storage systems**
+ **Captures market revenues for the following revenue streams: energy arbitrage, capacity, regulation, and spinning reserves**

(2) S+SAT: Daily Optimization Logic for Revenue Streams

+ **Choose the best hours for charging and discharging**
  - Takes into account energy arbitrage and capacity revenues
  - For the first five years, the battery can only charge from PV generation (to obtain the ITC), which may limit charging
  - Assumes perfect foresight
  - Does not take into account sequential state of charge constraints
+ **Determine the hourly revenue for providing all services except for regulation service**
  - Energy arbitrage, merchant capacity, and spinning reserves
+ **Decide whether better to provide regulation service or energy arbitrage + merchant capacity + spinning reserves during each day**

Some Common Questions that are Answered Using our Storage Tools

Storage modeling can address questions from the customer, developer, utility, and policy maker perspectives

- What locational value does storage provide?
- How should storage contracts be structured and/or merchant revenues be forecasted and accounted for?
- What are the projected revenue streams for storage that participates in multiple markets, i.e. retail, distribution, and/or wholesale?
- What is the expected return on investment, customer payback, and value to the utility?
- What are the system/utility avoided costs by component?
- How should utility and state programs be designed to maximize value?
- What is the bill savings opportunity for customers who install storage?

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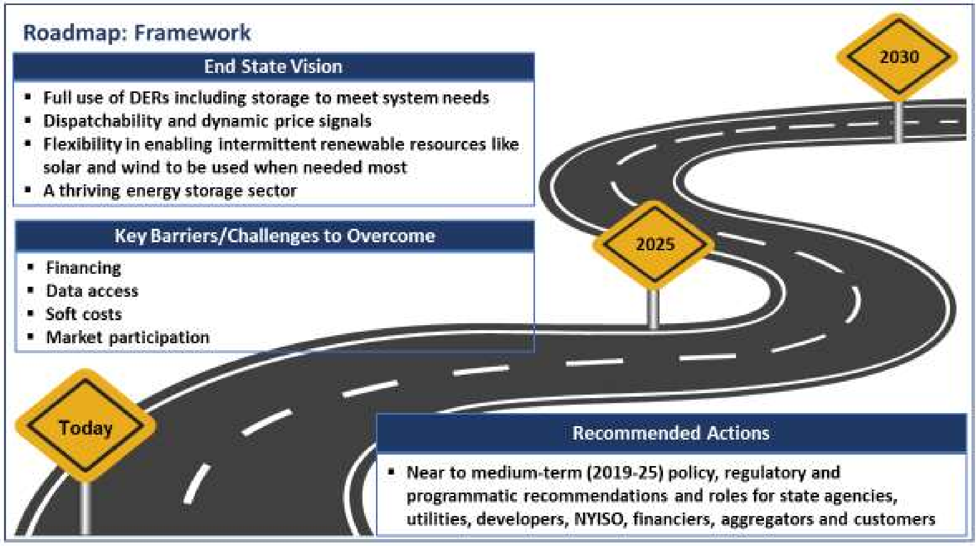
Case Study:
New York Storage Roadmap

Background on the NY Storage Roadmap

- E3 worked with a senior-level Department of Public Service (DPS) and the New York State Energy Research Development Agency (NYSERDA) team to support the development of a first-of-its-kind Energy Storage Roadmap for New York State
- The Roadmap charted a path forward to achieve that State's goal to install 1,500 megawatts of energy storage by 2025
- The Roadmap's recommendations were the foundation of the Public Service Commission's 2018 landmark order implementing many of the Roadmap' recommendations

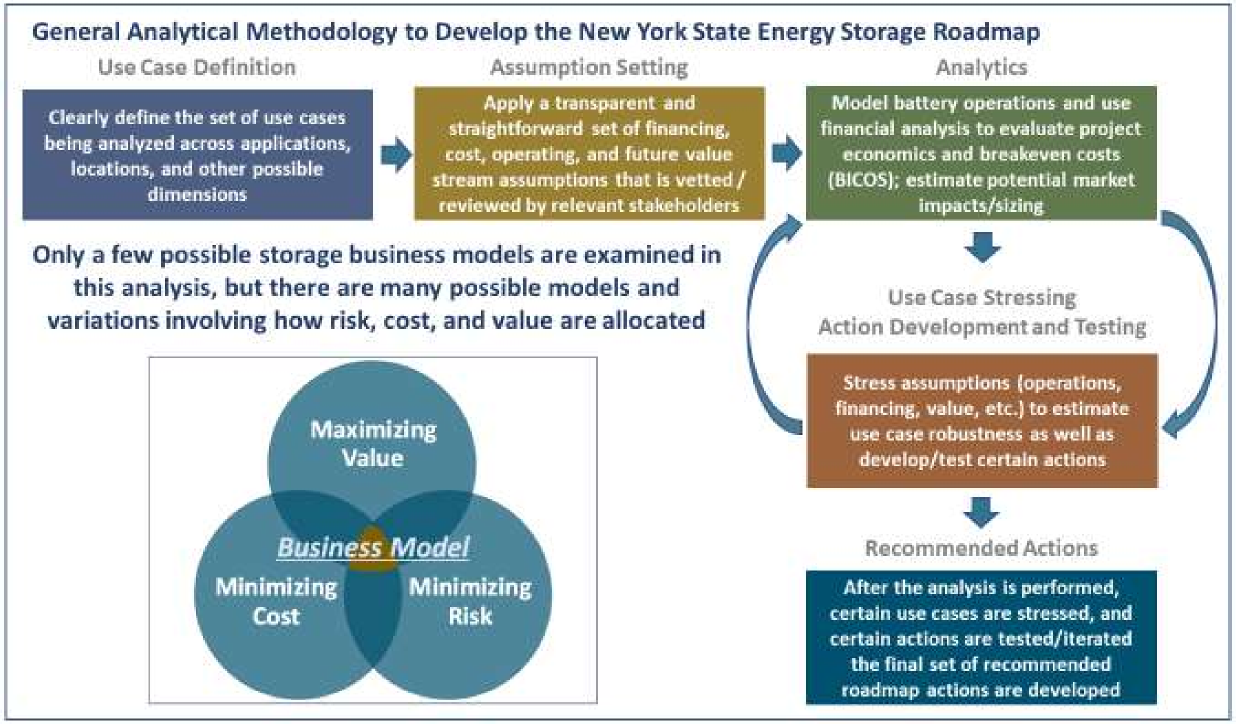


- E3 worked with DPS and NYSERDA leadership team to develop specific, tangible recommendations to support deployment of the most promising energy storage applications in the near-to-medium term (2019-25) to achieve New York's energy storage goals in a manner that adds value to the electric system while targeting market barriers and accelerating cost reductions
- E3 used its energy storage dispatch model (RESTORE) to perform in-depth economic analysis of a broad range of storage project configurations and use cases across customer, distribution and bulk system market segments
- This analysis informed the Roadmap's recommendations and evaluated how they improve project economics and bankability

https://www.ethree.com/e3-helps-new-york-state-develop-energy-storage-roadmap/
https://www.utilitydive.com/news/new-york-psc-sets-states-energy-storage-target-at-3-gw-by-2030/544371/

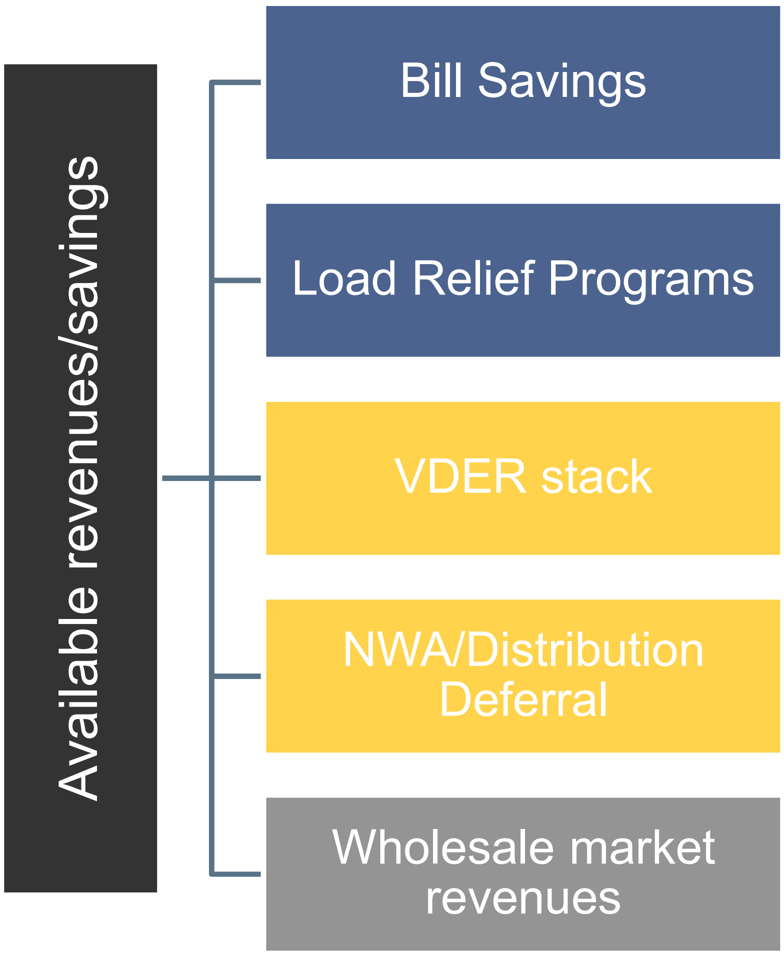
E3's Role in the New York Energy Storage Roadmap

- **E3 performed in-depth economic analysis of a broad range of storage project configurations across customer, distribution, and bulk system market segments**
  - Modeled hundreds of use cases in up and downstate regions to study storage economics
- **Analysis used to inform Roadmap recommendations and the recent PSC order**
- **Process involved broad stakeholder collaboration:**
  - NYSERDA, DPS, the IOUs, LIPA, NYISO, storage developers and other relevant parties

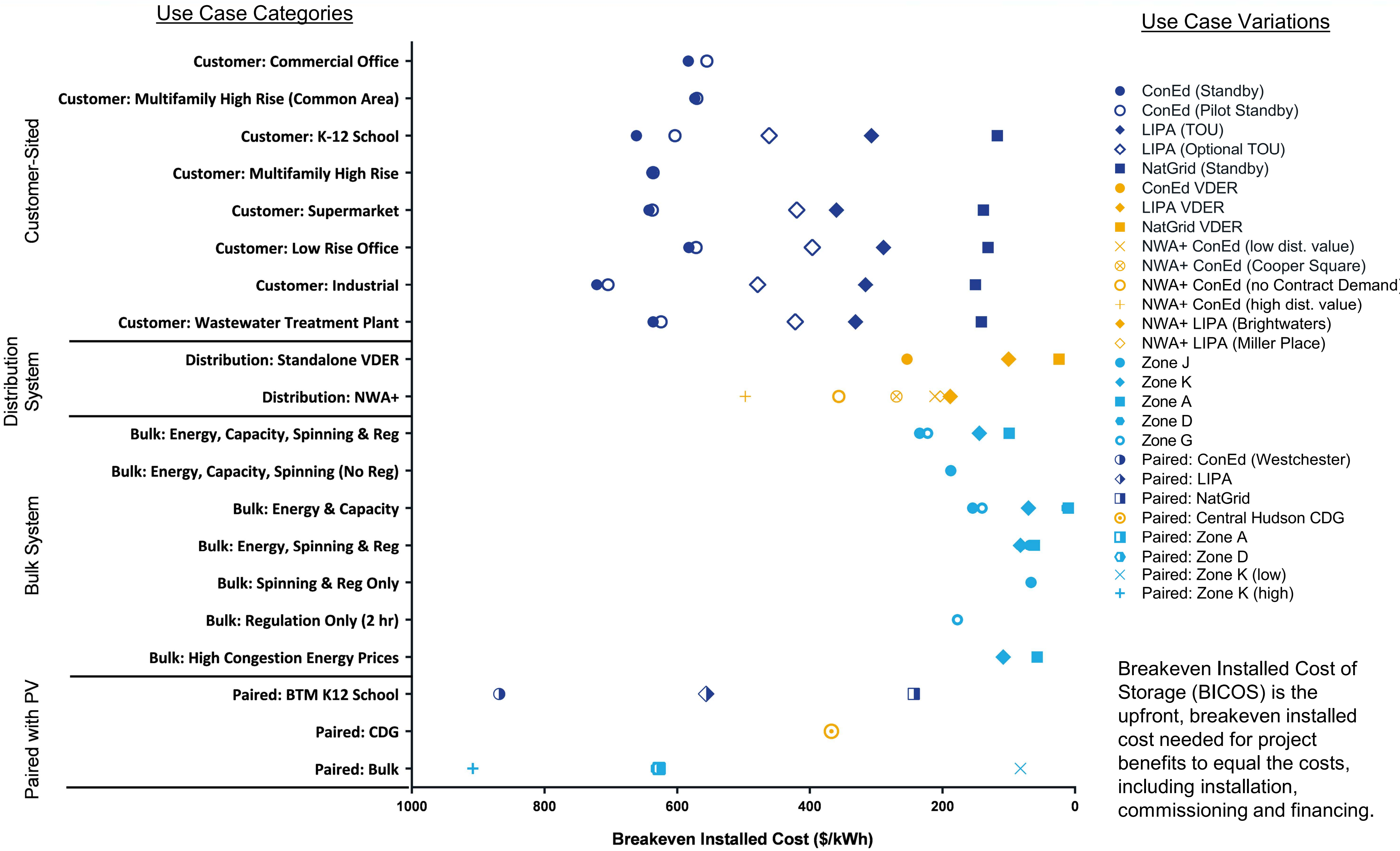


Analytical Framework for New York Energy Storage Roadmap

- **BICOS= Breakeven Installed Cost of Storage**
  - Primary Roadmap metric that provides a relatively simple way to assess use case economics and viability, e.g. are current storage costs less than the breakeven cost and if so what more is needed for deployment to occur?
  - Upfront installed cost ($/kWh) that results in levelized benefits = costs
- **BICOS determined for each use case under all three market segments using RESTORE modeling**
  - Quantified potential benefits under different degrees of revenue certainty and financing assumptions



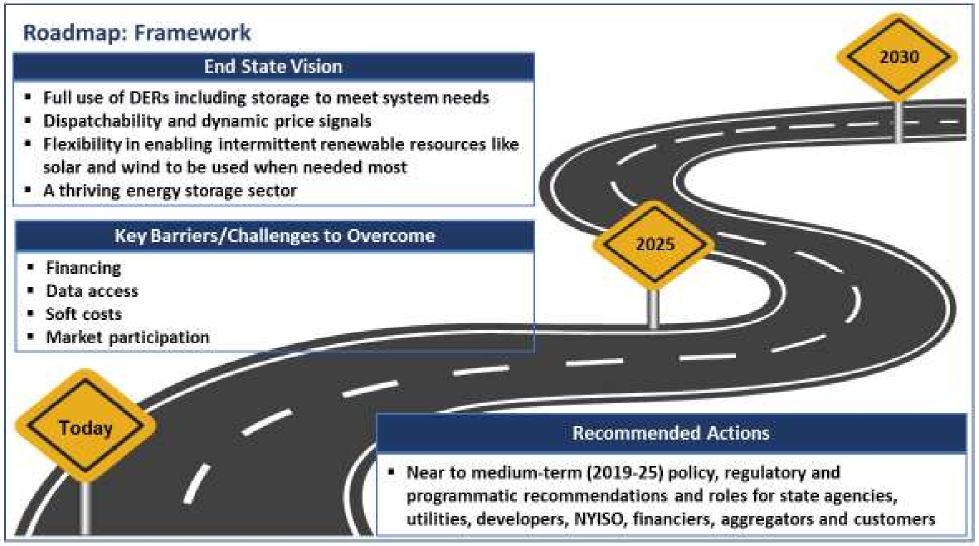
Summary Results Across All Use Case Types Analyzed in the Roadmap



Breakeven Installed Cost of Storage (BICOS) is the upfront, breakeven installed cost needed for project benefits to equal the costs, including installation, commissioning and financing.

Summary of the Roadmap's Recommendations

+ **E3's use case modeling indicated that many customer-sited and distribution system use cases and paired solar + storage projects are already viable in downstate New York or will soon become so**
+ **In the longer term, many diverse use cases will become economic across the State as the system adds more renewables and storage costs continue to decline**



+ **E3's analysis was central to developing the Roadmap's policy, regulatory, and programmatic recommendations:**
  - Providing $350 million in statewide market acceleration incentives to fast-track the adoption of advanced storage systems;
  - Adding incentives for energy storage to NYSERDA's successful NY-Sun Initiative to accelerate the development of solar + storage projects and allow access to federal tax credits;
  - Regulatory changes to utility rates, utility solicitations, and carbon values to reflect the system benefits of storage projects;
  - Continuing to address permitting and siting challenges and reduce indirect expenses and soft costs; and,
  - Modifying wholesale market rules to better enable storage participation, including allowing storage to meet both distribution and wholesale system needs to provide greater ratepayer value

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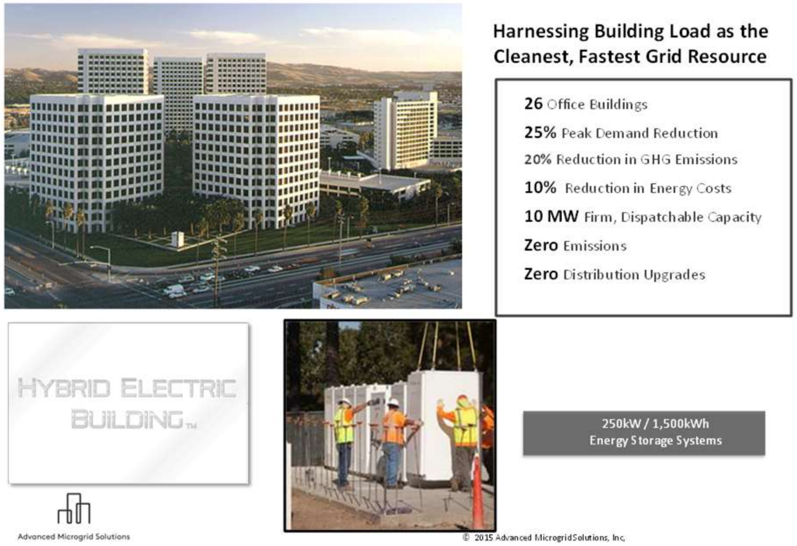
Case Study:
California Storage Financing

First of its Kind Storage Financing

- E3 provided analytical services, strategic advice, and market analysis expertise to Macquarie Capital in its assessment of a potential $200M investment in a 50 MW distributed storage project that was being developed in Southern California by Advanced Mircrogrid Solutions
- E3 performed detailed analytical simulations to verify the benefits, costs, and value proposition of behind-the-meter customer sited storage assets that could provide a number of different services
- E3 also modeled and co-optimized/stacked the potential revenue streams the storage project could access over a 20-year period, which involved in-depth analysis of the project and the underlying business model as well as forecasting wholesale and retail electric markets
- E3 also provided an investment-grade financial analysis and report for project investors and lenders
- E3's played a key role in Macquarie Capital's decision to extend $200M in financing and take ownership of the project which represents the largest distributed storage project financed in the U.S. to date

Example AMS Storage Project

10 MW HYBRID ELECTRIC BUILDING® PROJECT



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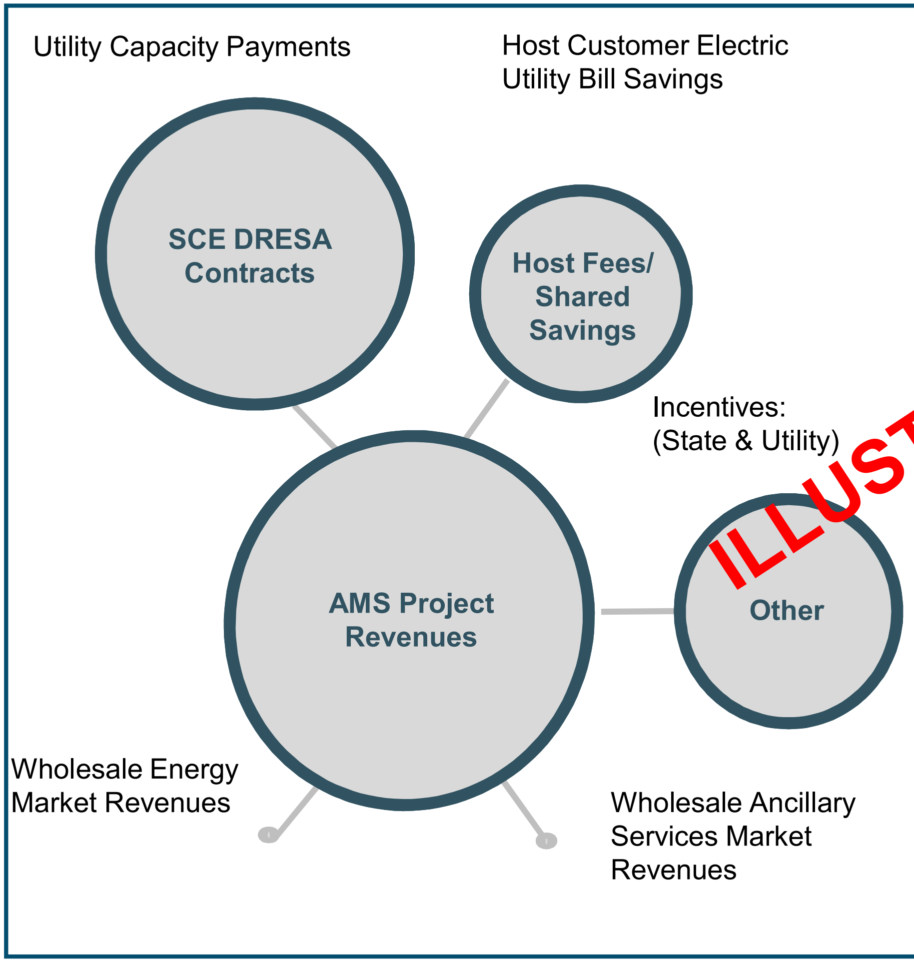
https://www.macquarie.com/us/corporate/advisory-and-capital-markets/articles/ams
https://www.greentechmedia.com/articles/read/advanced-microgrid-solutions-gets-200m-from-macquarie-to-finance-aggregate

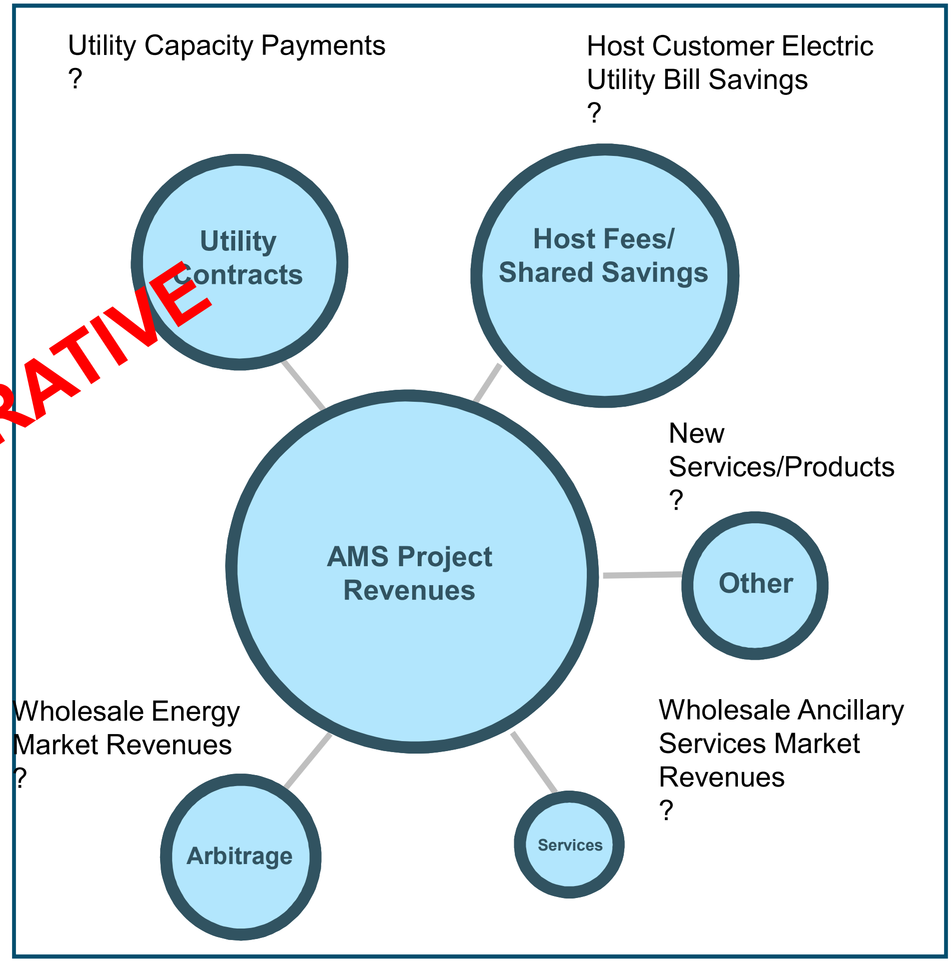
E3 was Tasked to Examine the Future Potential Revenue Streams of the Project

Revenue Stream   Size = Revenue Value

Project Revenue Streams (1-10 Years)



Project Revenue Streams (10+ Years)



Some Key, High-Level Qualitative Takeaways from our Analysis

Storage is the most flexible energy resource currently available and it can offer a very broad set of grid and customer services, but not all at the same time and not all services can be currently monetized

Host Customer Value

- Storage can be used to provide benefits for host customers to manage their electricity bill, especially for larger commercial & industrial (C&I) customers that have high demand charges based on peak usage
- There is upward pressure on retail electricity rates including demand charges in California and absent any major retail rate redesign this value should stay constant or increase over time

Project Location Value

- Storage can be used to provide capacity value, i.e. option for energy production during peak demand periods
- The L.A. Basin is a high value location, where there is a significant premium for capacity resources due to local constraints
- This premium is expected to persist over time as capacity supply decreases and new supply in the form of transmission and/or new generation is difficult to site and build

Wholesale Market Value

- Storage can be used to perform arbitrage services in the energy markets, which under high renewable energy penetration may experience significant volatility including negative pricing, which will make storage more valuable
- Storage can also provide ancillary services such as frequency regulation in addition to arbitrage services

Future Value?

- Currently, behind-the-meter storage can not participate in the wholesale markets, but that is likely to change relatively soon
- There may be additional value for storage to provide more local area value like utility deferral of T&D investment
- There may be additional value for storage to provide “flexibility” services for renewable integration needs

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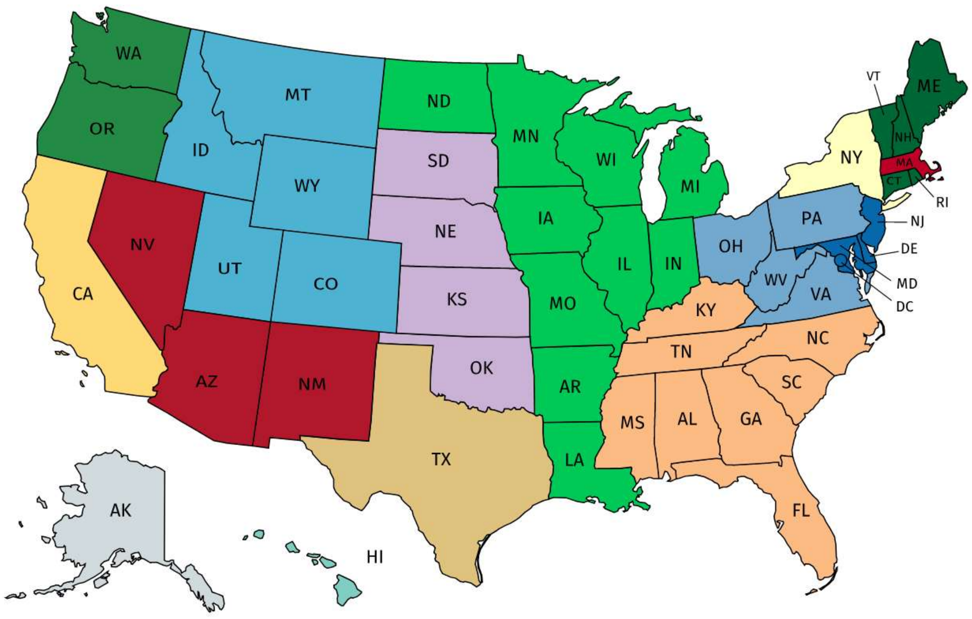
Case Study: U.S. Wide Storage Market Assessment

Key Takeaways from U.S. Wide Storage Market Assessment

- **Storage market is in nascent stages, driven primarily by policy mandates and promise of future value if costs continue to decline**
  - CA, NY, and other progressive states are ensuring sizeable storage deployment via policy mandates and targets
  - High-value ancillary service products provide small, initial pool of market potential for storage
  - Large renewable energy buildouts, especially solar, will drive complementary wholesale market conditions for storage projects
    - Today, hybrid storage is most cost-effective due to ITC eligibility
  - Distributed storage solutions like non-wires alternative programs may unlock significant value in locally constrained areas, but supportive regulatory frameworks are needed to monetize. NY and CA are policy leaders for these use cases
- **8-10 GW of storage, $10-12 billion in investment likely by 2025, concentrated in states that are leading on renewables deployment like California, the Southwest, and the Northeast**

US Market Overview: Segmentation by State/Region/ISO



- **Selected regions are defined as single state**
  - States with their own ISO (CA, TX, NY)
  - States with specific policy targets or technical issues (HI, MA)
- **Other regions are defined by broader market dynamics**
  - Capacity constrained PJM East (NJ, MD, DE) vs. rest of PJM

State(s)	ISO/RTO Market
CA	CAISO
TX	ERCOT
NY	NYISO
HI	-
MA	ISO-NE
DSW AZ, NM, NV	-
Rocky Mountain UT, CO, WY, MT, ID	-
PNW WA, OR	-
Greater New England CT, RI, VT, NH, ME	ISO-NE
PJM East NJ, MD, DE	PJM
PJM West IL, IN, OH, VA, WV, PA	PJM
MISO IL, MO, IN, MI, WI, MN, IA, AR, LA, ND, SD	MISO
SPP OK, KS, NE, SD	SPP
Southeast NC, SC, GA, TN, AL, MS, FL	-

Example Regional Overview: Rocky Mountain (UT, CO, WY, MT, ID)

+ State of market

- Median price of $36/MWh for solar+storage bids, just $7/MWh above solar-only PPAs, in Xcel RFP for 2022 resources
- CPUC approved Xcel's preferred portfolio, which includes three large solar+storage projects totaling 275 MW in storage capacity

+ Storage policy drivers

- RPS: CO 30% by 2020, MT 15% by 2015
- Storage required for consideration in resource planning in UT, CO

+ Storage market drivers

- IRPs from vertically-integrated utilities (e.g. Xcel)
- Tri-State co-ops growing more interested in self-generation, using community solar and storage to reduce bills (e.g. United Power)
- Increasing wind penetrations and early coal retirements could bolster the need for storage
- CO: capacity need in 2023; current wind curtailment of 2-3%; ambitious RE targets with renewable penetration >50%
- WY: supporting pumped hydro & transmission over batteries; 1,150 MW wind & transmission expansion approved in April 2018
- MT: RFI from NorthWestern Energy utility on July 2018 that seeks information on new capacity resources including storage

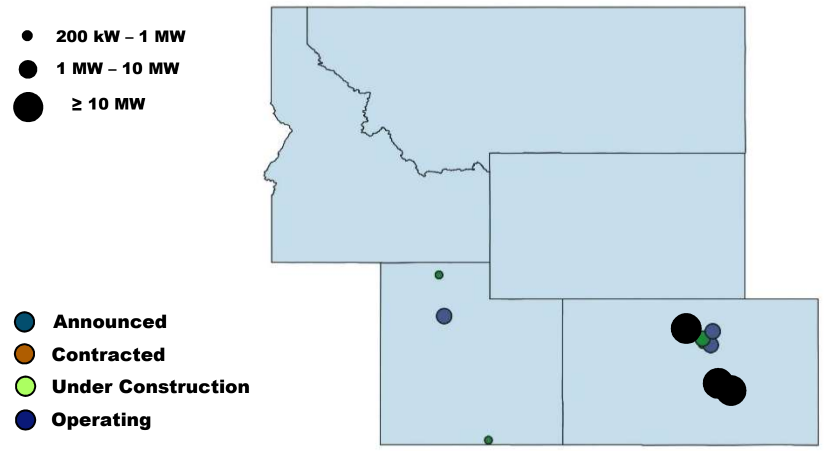
+ Key offtakers

- Xcel, PacifiCorp, Tri-State G&T member co-ops

+ Contracting trends

- Long-term "Semi-dispatchable PPAs" in CO for hybrid projects
- Bundled value in CO (ancillary services, capacity, etc.)

Storage projects



Storage forecast (total MW; # of projects)

	Operating	Contracted	Announced
Standalone	15.9 MW; 5		
Hybrid-solar	2.5 MW; 2	10 MW; 1	275 MW; 3
Hybrid-wind	58.1 MW; 5		
Other storage (PSH, CAES, flywheel, etc.)	12.5 MW; 6	8 MW; 1	317 MW; 1

Primary storage type	Primary storage value	RPS demand	Primary RE regime	Overall storage outlook
Hybrid-RE	Capacity / Firming RE	Already met	Wind	Moderate

Closer Look: Colorado

Policy Developments

- **SB 18-009** directs the Colorado PUC to adopt rules governing the installation, interconnection, and use of customer-sited energy storage systems
- **HB 18-1270** integrates storage into utility planning process and allows electric utilities to file applications for rate-based storage projects of up to 15 MW capacity
- CO is a big proponent of community solar & has also shown regulatory support in storage

State of Market

- Current penetration of renewables around 29% of net generation
  - 3,100 MW of Wind; 465 MW of Solar (≈1,000 MW with BTM); 690 MW of Hydro
- Curtailment of wind was 3.1% in 2016 and 1.9% in 2017

Market Drivers

- Xcel issued an all-source solicitation in 2017 for resources to start operation in 2023 that led to historically low prices in energy storage and storage-RE hybrids
  - Hybrid bids with storage add $2.90/MWh (wind median) or $6.50/MWh (solar median)
- Xcel filed an aggressive preferred portfolio in June 2018 that includes over 50% clean energy by 2026 and 275 MW of hybrid solar+storage. Portfolio was approved by Colorado PUC in August 2018
- Union Power is building a 4 MW/16 MWh battery under an innovative community-owned storage model where C&I customers can offset peak demand by buying into the project

Primary Storage type	Primary value	RPS demand	Primary RE regime	Offtakers	Overall outlook
Hybrid-RE (solar)	Capacity / RE Firming	30% by 2020; 50% by 2026 (target)	Wind with growing solar	LSEs	Moderate

Case Study: Solar + Storage Model For a Large Developer

Project Overview

+ **Develop an Excel-based model that can be used to inform project development activity for PV systems paired with battery storage**
+ **Apply the model to specific projects across the U.S. to help inform contract prices for seasonal capacity, seasonal tolling, and annual tolling contracts**
+ **Capture particular characteristics of PV + storage systems:**
  - Charging from PV during first 5 years to receive ITC for storage
  - DC-coupled systems that allow for increased inverter loading by using the battery to avoid PV clipping
  - Operations constrained by particular contracting arrangements
+ **Provide an overview of how storage can currently participate in markets across the U.S., as well as model potential future changes**

Key Categories of Inputs to Solar + Storage Contracting Model

Project specifications

- Solar generation profile: location and inverter loading ratio (ILR)
- Sizing of solar vs. storage
- Duration of storage
- AC vs. DC coupling

Price forecasts for available market products

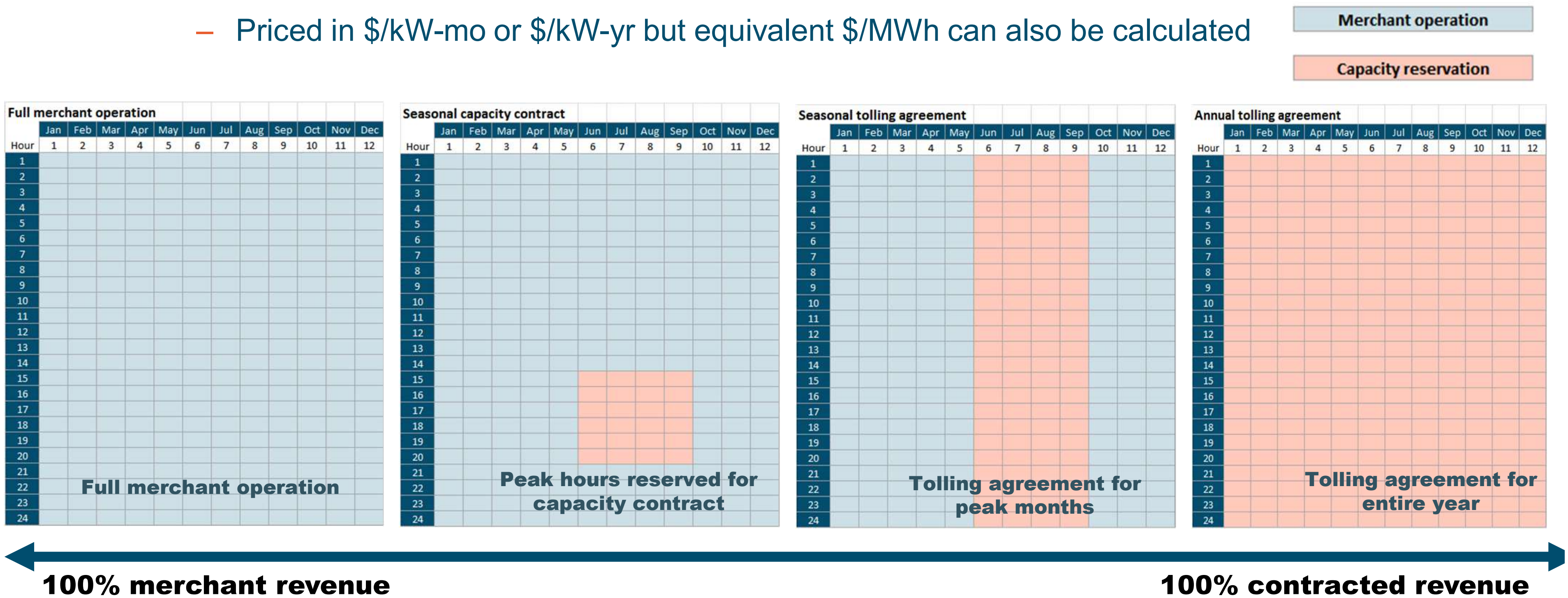
- Energy
- Ancillary services
- REC prices
- Capacity

Contract types

- Capacity: monthly/annual for specified hours of day
- Tolling: monthly/annual for control of plant
- Contract duration: 10-, 15-, 20-, or 25-year

Default Storage Contract Inputs

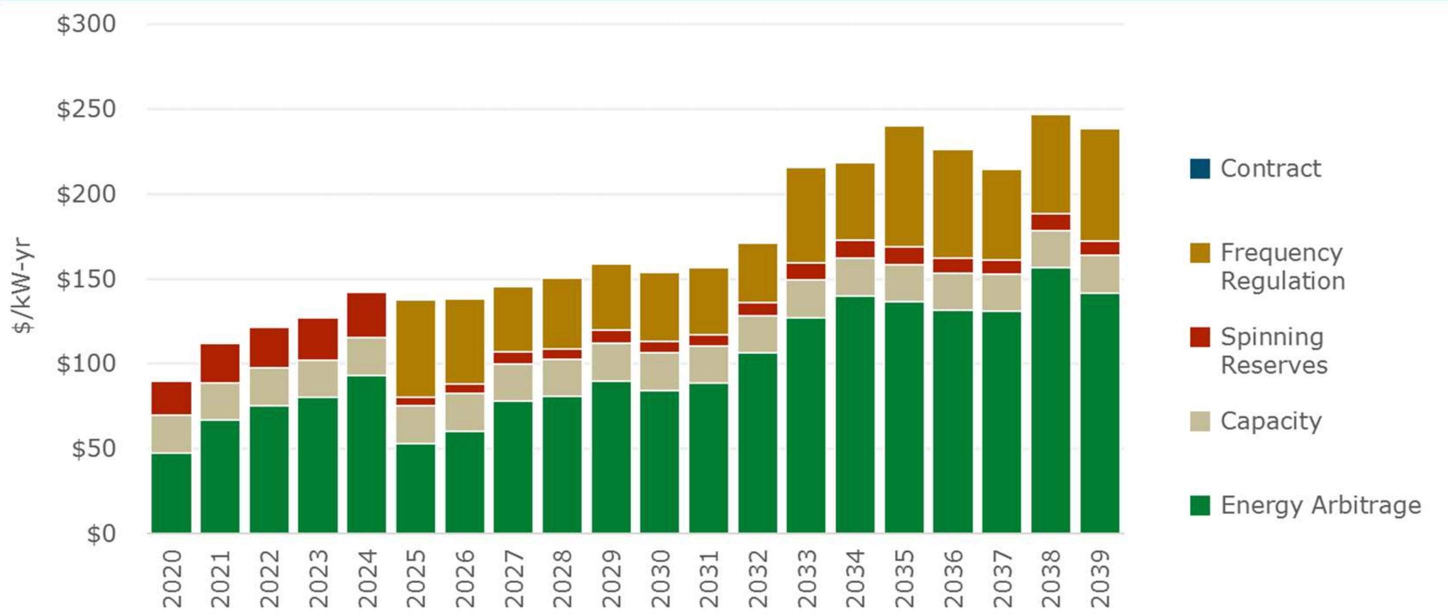
+ **Three contract options (plus full merchant operation) as initial defaults**
  - Summer capacity contract for peak hours: $/kW-mo
  - Seasonal tolling agreement for peak months: $/kW-mo
  - Annual tolling agreement
    - Priced in $/kW-mo or $/kW-yr but equivalent $/MWh can also be calculated



Illustrative California Merchant Revenue Output

- Ancillary services (AS) adds significant value (~25-40%) in this high value illustrative case for AS prices
- Assumed in input assumptions that merchant value for storage increases in future

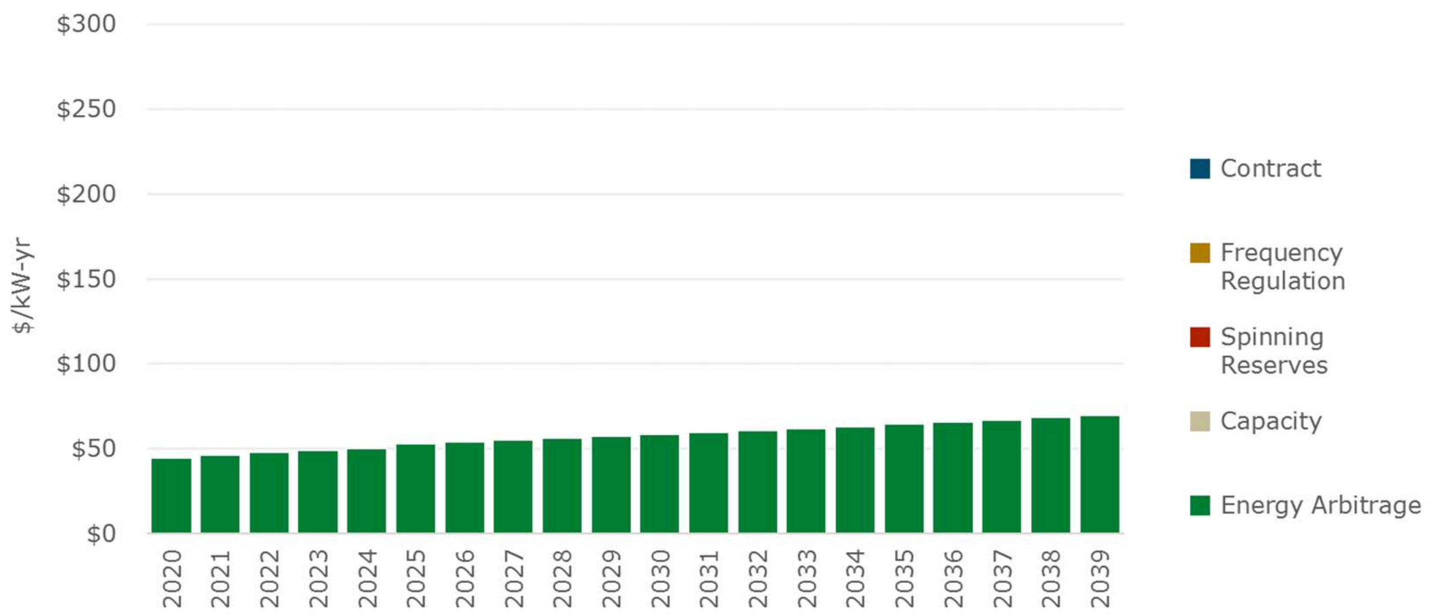
Total merchant value by revenue stream
$/kW-yr



Illustrative Desert Southwest Merchant Revenue Output

- Under this energy price price input assumptions, the Desert Southwest does not have high merchant revenues
- Capacity value to offtakers is another additive value stream that is not modeled in this illustrative output

Total merchant value by revenue stream
$/kW-yr



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Case Study:
Solar + Storage in SPP

Model Assumptions

Technical Specifications

- **PV System**
  - Nameplate Capacity: 50 MW
  - Inverter Ratio: 1.3
- **Battery**
  - Power Capacity: 12.5 MW
  - Energy Capacity: 50 MWh
  - Duration: 4 hour
  - Round-trip efficiency: 85%
- **No charging restrictions due to ITC, etc.**

Market Assumptions

- **Location: Kansas City (SPP)**
- **Prices: 2018 (Dec 20, 2017 to Dec 19, 2018)**
- **Available revenue streams:**
  - Energy arbitrage
  - Ancillary Services (Regulation, Spinning Reserves, Non-spinning Reserves)
- **Two separate runs with different revenue streams**
  - Energy Arbitrage + Grid Services
  - Energy Arbitrage only

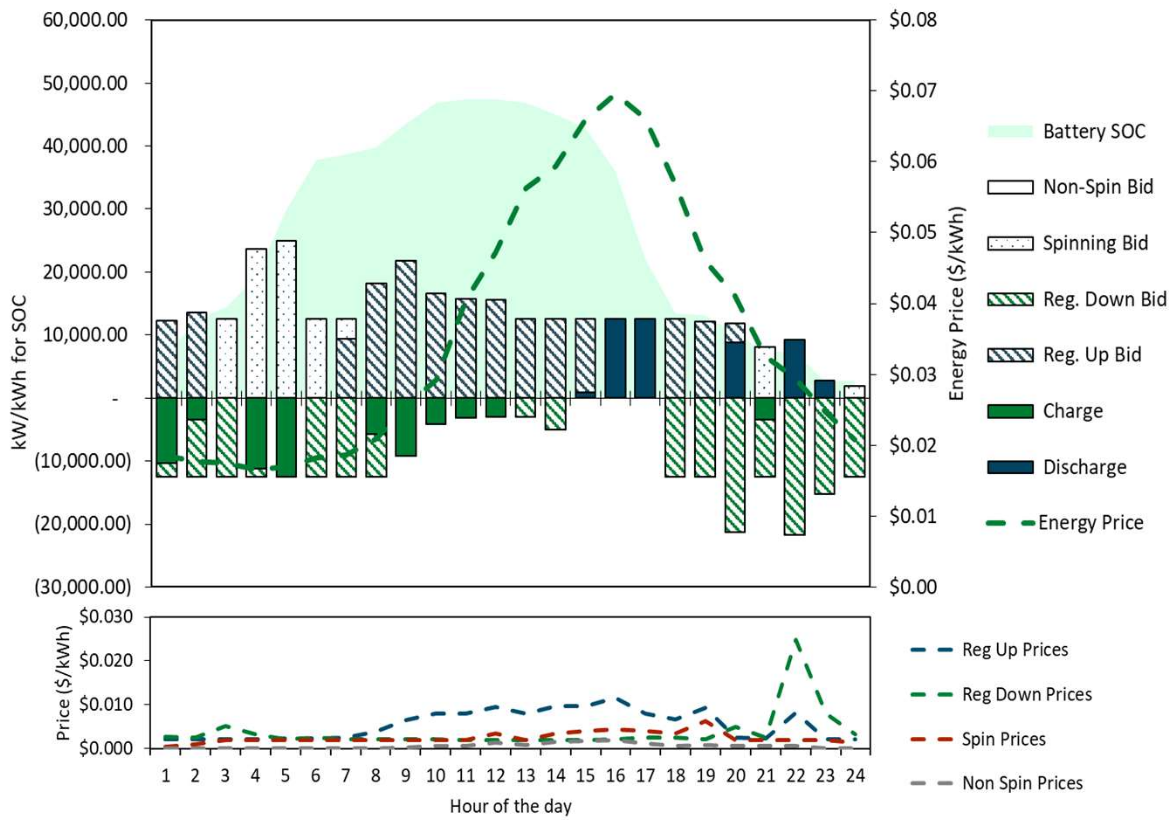
Annual Revenues

+ **Both models show similar revenues for 50 MW solar + 12.5 MW, 4-hr battery**

		Energy Arbitrage and Grid Services		Energy Arbitrage Only	
Annual Revenue Stream	**Units**	**RESTORE**	**S+SAT**	**RESTORE**	**S+SAT**
PV Energy Revenue	$000	$4,070	$4,140	$4,070	$4,140
Energy Arbitrage	$000	$71	$64	$430	$408
Spinning Reserves	$000	$545	$29	-	-
Non Spinning Reserves	$000	$0	$0	-	-
Regulation Reserves (Up + Down)	$000	$2,296	$2,040	-	-
Grid Services (Reg + Spin + Non-spin)	$000	$2,841	$2,069	-	-
Total Battery	$000	$2,912	$2,133	$430	$408
Total Solar + Storage	**$000**	**$6,982**	**$6,273**	**$4,500**	**$4,548**
Energy Arbitrage	$/kW	$6	$5	$34	$33
Spinning Reserves	$/kW	$44	$2	-	-
Regulation Reserves (Up + Down)	$/kW	$184	$163	-	-
Total Battery	$/kW	$233	$171	$34	$33
Total Solar + Storage	$/kW	$559	$502	$360	$364

Battery Dispatch from RESTORE: Peak Summer Day

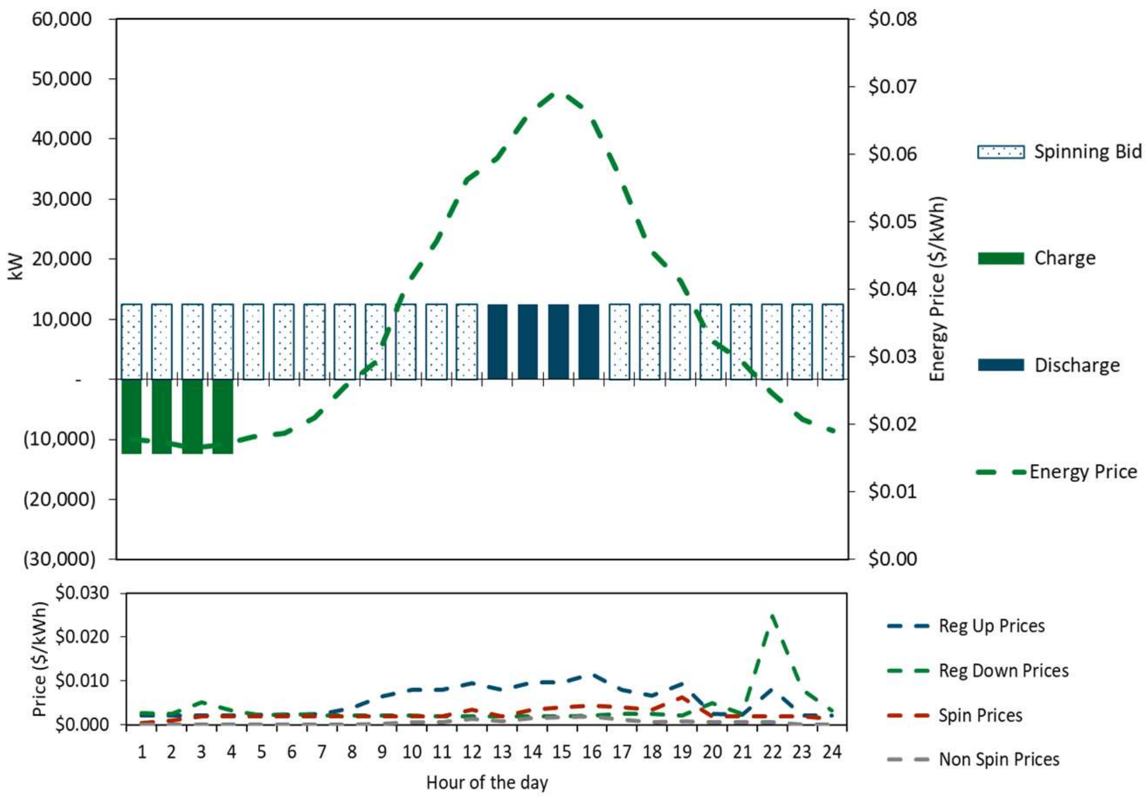
+ July 12, 2018 (Peak day)



+ Battery charges in low price hours and discharges in high price hours
+ Battery provides grid services (reg up, reg down, spin) in most of the hours

Battery Dispatch from S+SAT: Peak Summer Day

- July 12, 2018 (Peak day)



- Battery charges in low price hours and discharges in high price hours
- Battery provides spinning reserve in most of the hours but not reg up or reg down due to modeling simplification (either energy or regulation)

Differences Between RESTORE and S+SAT

+ Hourly Optimization:

- RESTORE optimizes all revenue streams on an hourly basis, allowing it to capture short-term price spikes for different market products
- S+SAT currently chooses daily between providing regulation and providing energy + spinning reserves
  - This assumption is easily changed

+ State of Charge:

- RESTORE performs an optimization that respects state of charge constraints
- S+SAT does not track state of charge as it chooses the highest energy price hours and lowest energy price hours to discharge and charge, respectively

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Thank You

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