Integration of Energy Storage in Fossil Energy Power Plants (ES-FE) Market Analysis

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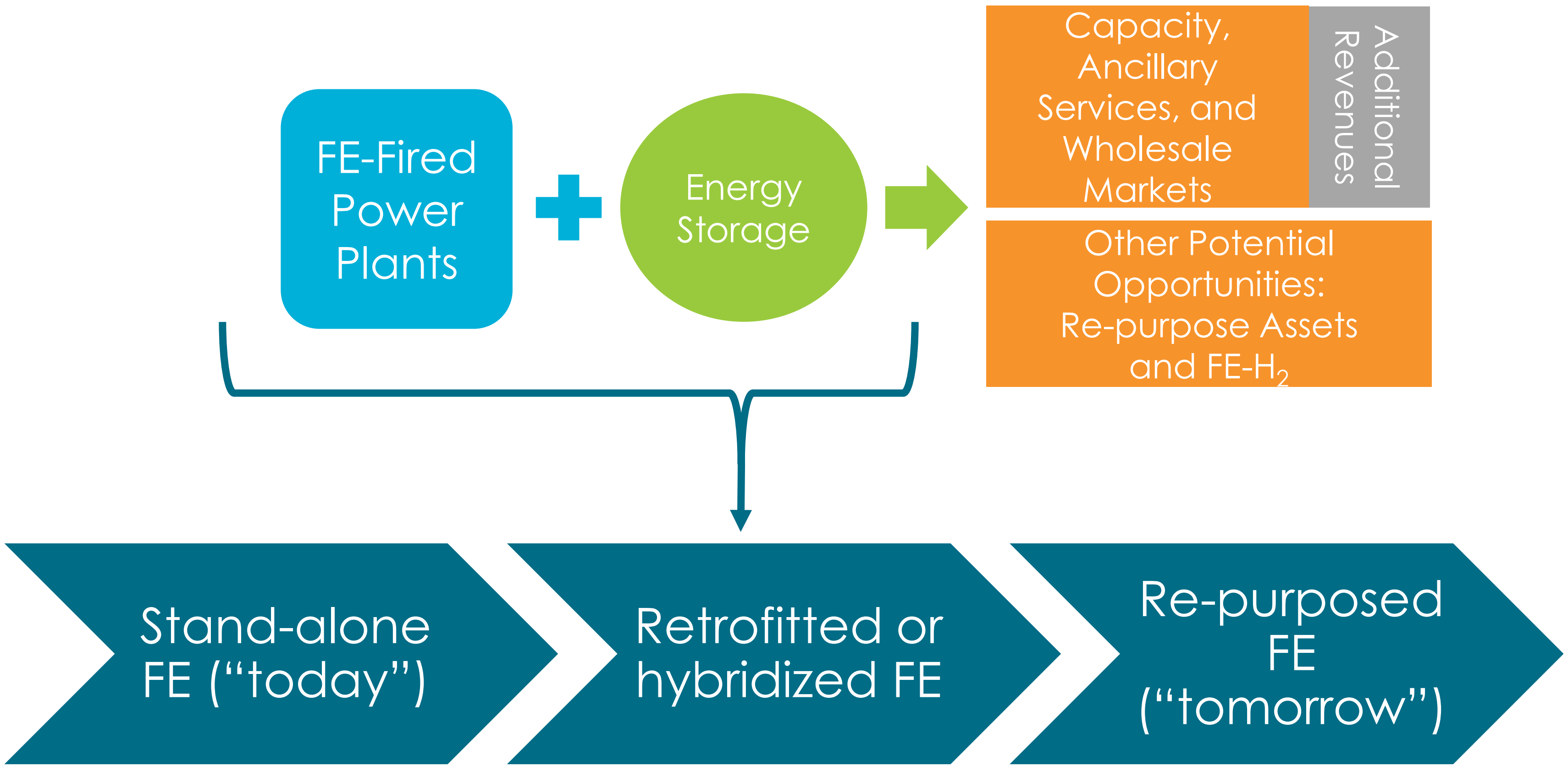
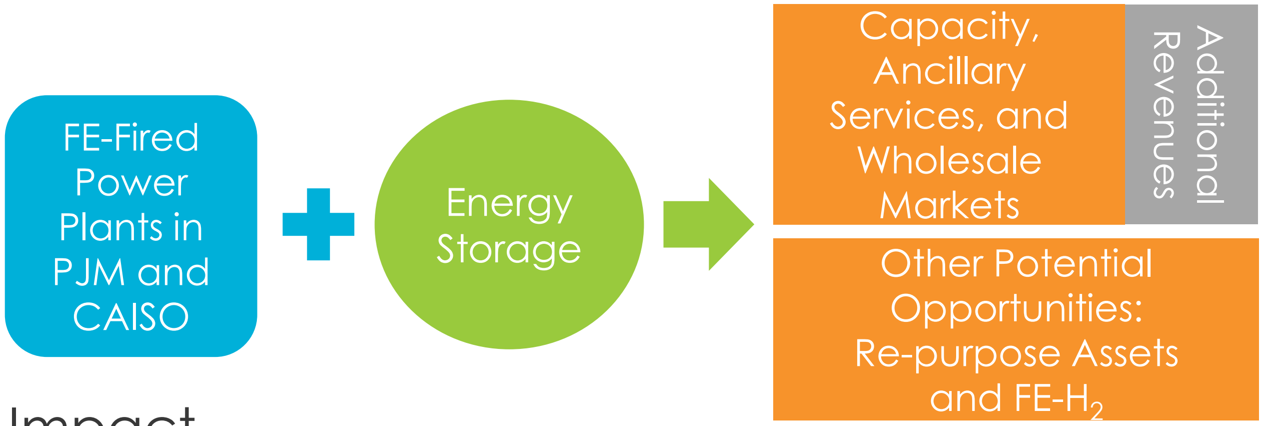
Overview

Energy Storage and Fossil Energy Power Plants



Overview



- Impact
  - Informs stakeholders of benefits of storage-enhanced flexible FE power plants
  - Enables plant power operators to understand market opportunities
  - Prepares groundwork for better market rules for hybrid assets in the power system
- Regions
  - PHASE I - Mid-Continent (MISO) and Electric Reliability Council of Texas (ERCOT)
  - PHASE II - California Independent System Operator (CAISO), and Pennsylvania, Jersey, Maryland Power Pool (PJM)

- Description
  - ES coupled with FE is important as it can provide operational benefits to the power plant generator and can be valuable to the whole system
    - Short-term storage: Added flexibility
    - Long-term storage: Contributes to maintaining system's reliability
  - Potential revenues streams should be evaluated from Ancillary Services, Wholesale Electricity, and Capacity Markets by pairing ES with FE
  - Revenues depend on market and policy conditions in PJM and CAISO

Benefits of ES in an FE Power Plant

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How can ES favor FE power plants in the short and medium term?

Themes	Service
Additional Revenue	Market rules for interconnection and participation in the capacity, electricity and Ancillary Services markets.
Avoided Costs	Reduce or avoid tear/wear costs, potentially extending the power plant lifetime and reducing emissions through smoother operation
Other Opportunities	-Re-purposing power plants as storage assets -Incentives and state and federal policies and targets that are beneficial to ES investment -Identification of additional services and revenue streams coming from other markets, creating favorable conditions for ES-FE concepts (e.g. production or storage of hydrogen)

Approach

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Step 1. Select Region

Region selection based on six criteria

- C1. Considerable current fossil generation
- C2. Presence of such technology that supports ES-FE pairings soon (5 years)
- C3. Extent of measures supporting storage
- C4. Presence of variable renewable energy (VRE)-balancing
- C5. Existence of H_2 market
- C6. Battery-focus current snapshot

Step 2. Create ES-FE Database

On-ground and new/upcoming ES-FE configurations

- Update of on-ground projects list
- Include awarded concepts under FOA 2332
- Describe projects and technologies that are being used

Step 3. Quantify Opportunities

Comprehensive analysis of each region using policy, regulatory, and market characteristics

- Perform revenue analysis of wholesale electricity, capacity and AS markets
- Identify policy and regulatory mechanisms supporting co-located and/or hybrid storage

Step 4. Identify Other Opportunities for ES-FE

- Describe repurposing opportunities
- Describe market conditions that favor FE-H_2 concepts

Step 2: Create ES-FE Dataset

- Standardized dataset of ES-FE projects created from
  - Environmental Information Administration (EIA)-860/923 Data*
  - Sandia Global Energy Storage Database
  - Lawrence Berkeley National Laboratory Online Hybrid and Energy Storage Projects Dataset
  - Hitachi Energy Velocity Suite
  - Awarded concepts from NETL's Funding Opportunity Announcement (FOA) 2332
  - Potential re-purposed assets via web search
- Dataset features
  - Identifiers for associating with original dataset (plant identification [ID], generator ID, storage unit ID)
  - Plant information, i.e., plant name, location, project type (co-located/hybrid/standalone), project status, etc.
  - Plant technical details
    - For storage unit (capacity, discharge rate, technology)
    - For power plant (capacity, heat rate, efficiency, technology)
  - Storage services provided, e.g., load following, frequency regulation, arbitrage

*EIA 923 was included for Phase I

Step 2: Create ES-FE Dataset

Dataset at a Glance

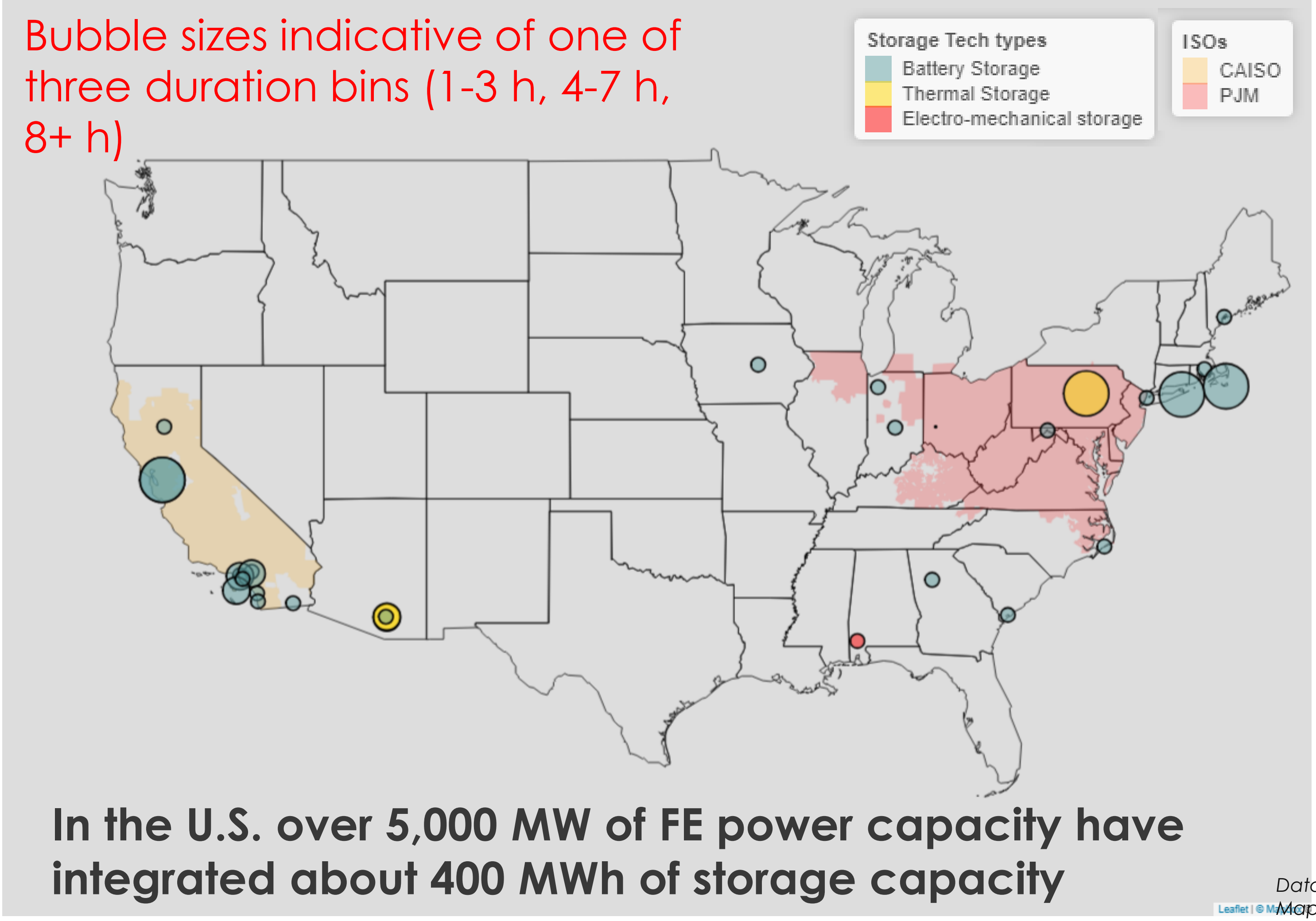
	On-the-Ground ES-FE Projects	Pilot Projects	Combined Generating (MW)	Combined Storage (MWh)	Max Duration (hours)	Most Common Power Tech	Most Common Storage Tech
Continental U.S.	35	32	5337.5	425.6	13.33	Petroleum Liquid, NGCT	Lithium-ion Battery
CAISO	14	5	802.3	122.8	13.33	NGCT	Lithium-ion Battery
PJM	3	8	237.9	14	8	-	Lithium-ion Battery

- **16 unique states** with on the ground ES-FE projects
- 7 unique power unit technologies
- 7 unique storage unit subtypes*
- Most common pilot project storage tech: **Surface storage (Hydrogen)**

*Only 3 storage unit tech types (Batteries, Thermal, Electro-Mech.)

Step 2: Create ES-FE Dataset

Storage Duration for Co-located + Hybrid



- 8+ hour duration
  - Massachusetts, New York, California
  - 5 storage units, 4 Li-ion, 1 Chilled water thermal storage
  - Paired with natural gas (NG) combined cycle (CC), petroleum liquids
- 4–7 hour duration
  - California, Arizona, Hawaii
  - 5 storage units, 4 Li-ion battery, 1 Chilled water thermal storage
  - Paired with NGCC, NG combustion turbine (CT), petroleum liquids, other NG
- 1–3 hour duration
  - 14 states
  - ~23 storage units, Li-ion, and 1 NG compressed air

Data from EIA 860 (2019)

Maps have data only on co-located and hybrid storage, but durations are shown for standalone as well.

Step 3: Quantify Opportunities

Analysis: Annual Revenues from Participation of ES in Different Markets

- **Participation in capacity market**
  - **The ES component provides capacity value and the FE power plant is compensated for it**
  - **Applying rules that exist to single technology assets if no rules are yet enacted for hybrid assets**
  - **Using capacity auction clearing prices**
- Participation in wholesale electricity market via price arbitrage
  - The ES component allows FE power plant to make rents out of the capacity to defer discharge
- Participation in ancillary services (AS) market
  - The ES component provides balancing services and the FE power plant is compensated for it
  - Revenue estimates for provision of one single AS throughout the year
- Value-stacking algorithm
  - Conducting both – AS and price arbitrage

Base Case ES component specification:

- Storage capacity: 10 MW (ES capacity of existing ES-FE is 10–30 MW)
- Duration: 1 hour (AS are an hourly service, and arbitrage peaks also last an hour)

Step 3: Quantify Opportunities

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Highlights: Accrued Revenues from Existing Markets

- **Capacity provision** revenues in PJM range approximately $5.5–60/kW-yr, depending on the area of connection, and on the effective load carrying capability (ELCC) class rating of the ES component of the ES-FE. CAISO does not have a capacity market, and the ES advantage is to release the FE from the obligation of provision of capacity availability

Capacity Provision in PJM

- PJM has a formal forward-looking capacity market to procure resource adequacy

Capacity payment (\$/MW) = Capacity Clearing Price (\$/MW) x UCAP

- The elements of the capacity market (also called Reliability Pricing Model [RPM] auction) are
  1. PRODUCT: Capacity is procured three years before it is needed through a competitive auction
     - The product that is offered/transacted and delivered is Unforced Capacity (UCAP), the metric for capacity value
     - Traditionally, for all generation resources

UCAP = ICAP x (1-EFORd)

     - After the Federal Energy Regulatory Commission (FERC) approval of PJM's revisions to Open Access Transmission Tariff and Reliability Assurance Agreement (December 2021), intermittent resources:

UCAP = Effective Nameplate Capacity x ELCC Class Rating x Performance Adjustment

  2. PRICE: Locational pricing for capacity that varies to reflect limitations on the transmission system
  3. DEMAND: A variable resource requirement curve, which is the demand formula used to set the price paid to market participants for capacity and the amount of capacity

Capacity Provision in PJM (cont'd)

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UCAP = Effective Nameplate Capacity x ELCC Class Rating x ELCC Resource Performance Adjustment

2024/2025 BRA ELCC Class Ratings

ELCC Class	ELCC Class Rating for 2024/2025 BRA
Onshore Wind	16%
Offshore Wind	37%
Solar Fixed Panel	36%
Solar Tracking Panel	54%
4-Hour Storage	82%
6-Hour Storage	97%
8-Hour Storage	100%
10-Hour Storage	100%
Solar Hybrid Open Loop – Storage Component	82%
Solar Hybrid Closed Loop – Storage Component	82%
Hydro Intermittent	46%
Land Gas Intermittent	60%
Hydro with Non-pumped Storage*	96%

- To develop revenue estimates, ES is considered a co-located, separate asset from the FE power plant
- Upper bound of ELCC rating of ES of ES-FE was set to 80%
- New class ratings can appear. In this case, the operator of the hybrid asset is responsible for submitting information to PJM to accredit its ELCC Class Rating
- Lower bound of ELCC rating of ES of ES-FE was set to 30% for potential hybrid ES-FE (conservative)

**PJM performs an ELCC analysis for each individual unit in this class. The value shown is a representative value provided for informational purposes; data from PJM, (2021) "2024/2025 BRA Effective Load Carrying Capability (ELCC) Class Ratings" https://www.pjm.com/-/media/planning/res-adeq/elcc/elcc-class-ratings-for-2024-2025.ashx*

Estimates of Capacity Provision in PJM via ES-FE

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Capacity payment ($/MW) = Capacity Clearing Price ($/MW) x UCAP

UCAP = Effective Nameplate Capacity x ELCC Class Rating x ELCC Resource Performance Adjustment

	UCAP (per MW installed)		Capacity payment (per day, $/MW)		Capacity payment (annual, $/MW)	
LDA/External Source Zone	UCAP (/MW-installed), lower bound*	UCAP (/MW-installed), upper bound*	Lower bound, Annual Revenues ($/MW-day)	Upper bound, Annual Revenues ($/MW-day)	Lower bound, Annual Revenues ($/MW-yr)	Upper bound, Annual Revenues ($/MW-yr)
RTO	**0.3**	**0.8**	**$15.0**	**$112.0**	$5,475	**$40,880**
MAAC	0.3	0.8	28.7	112.0	10,489	40,880
EMAAC	0.3	0.8	29.4	132.6	10,716	48,393
SWMAAC	0.3	0.8	28.7	112.0	10,489	40,880
PS	**0.3**	**0.8**	**29.4**	**163.4**	**10,716**	**$59,653**
PSNORTH	0.3	0.8	29.4	163.4	10,716	59,653
DPLSOUTH	0.3	0.8	29.4	132.6	10,716	48,393
PEPCO	0.3	0.8	28.7	112.0	10,489	40,880
ATSI	0.3	0.8	15.0	137.1	5,475	50,028
ATSI-CLEVELAND	0.3	0.8	15.0	137.1	5,475	50,028
COMED	0.3	0.8	20.7	156.4	7,551	57,101
BGE	0.3	0.8	38.0	160.2	13,852	58,488
PL	0.3	0.8	28.7	112.0	10,489	40,880
DAYTON	**0.3**	**0.8**	**15.0**	**112.0**	**$ 5,475**	**40,880**
DEOK	0.3	0.8	21.5	112.0	7,850	40,880

Annual revenue of $5.5-60/kW

*Assumption:
Lower bound: ELCC class rating of 30%
Upper bound: ELCC class rating of 80%

Step 3: Quantify Opportunities

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Step 3: Quantify Opportunities

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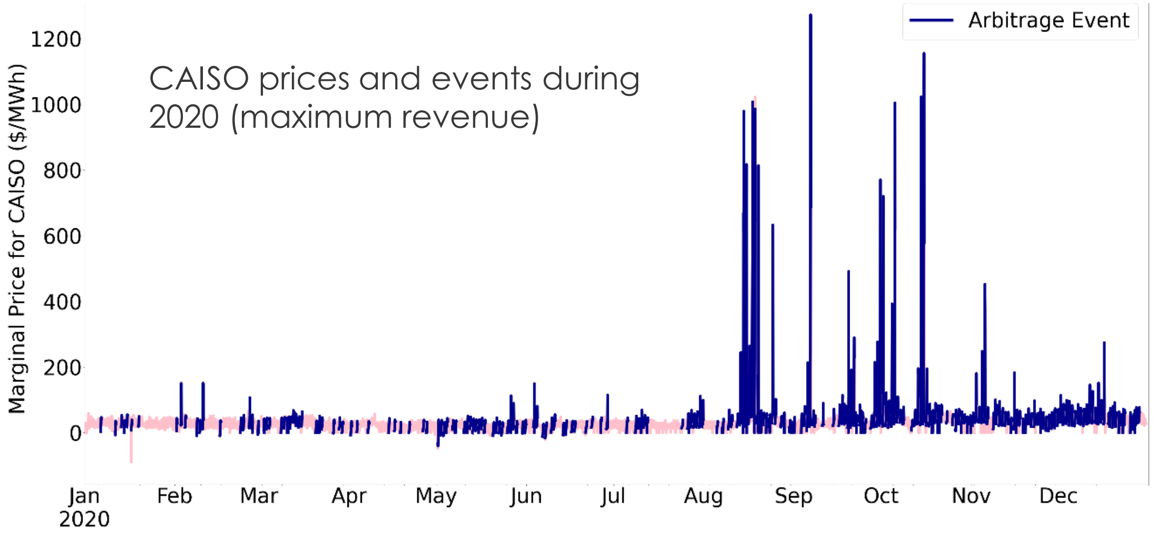
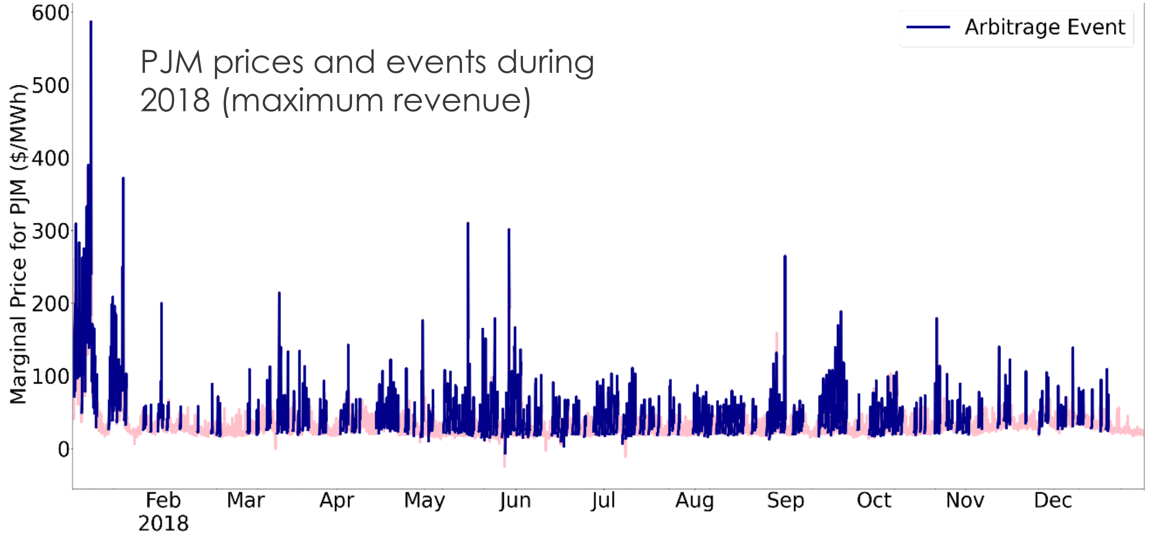
Highlights: Accrued Revenues from Existing Markets

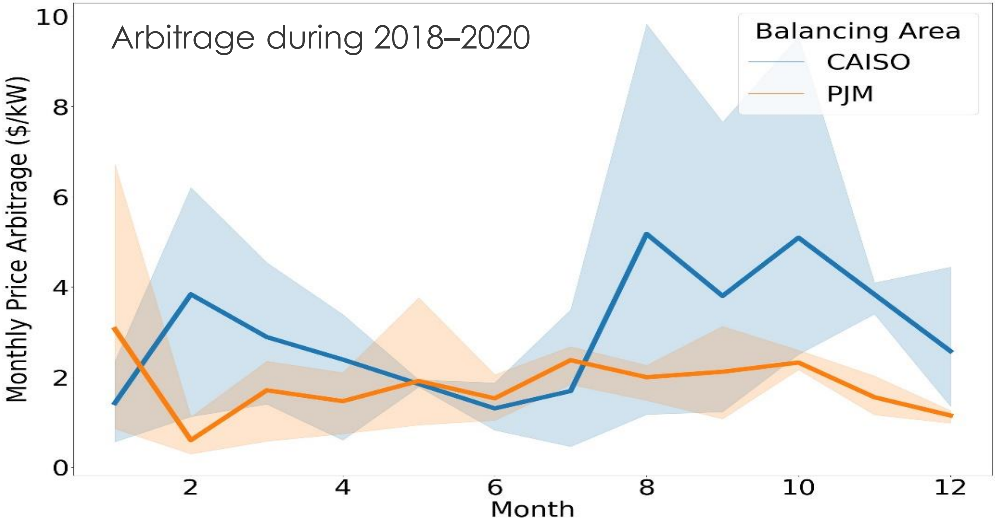
- Participation in the **wholesale market** and **AS markets** provide, at most, annual revenue streams of ~$74/kW for PJM (coming from provision of regulation services) and ~$54/kW for CAISO (coming from price arbitrage)

Step 3: Quantify Opportunities

Price Arbitrage (PA)-Only: Base Case Results for ES of 2-Hour Duration





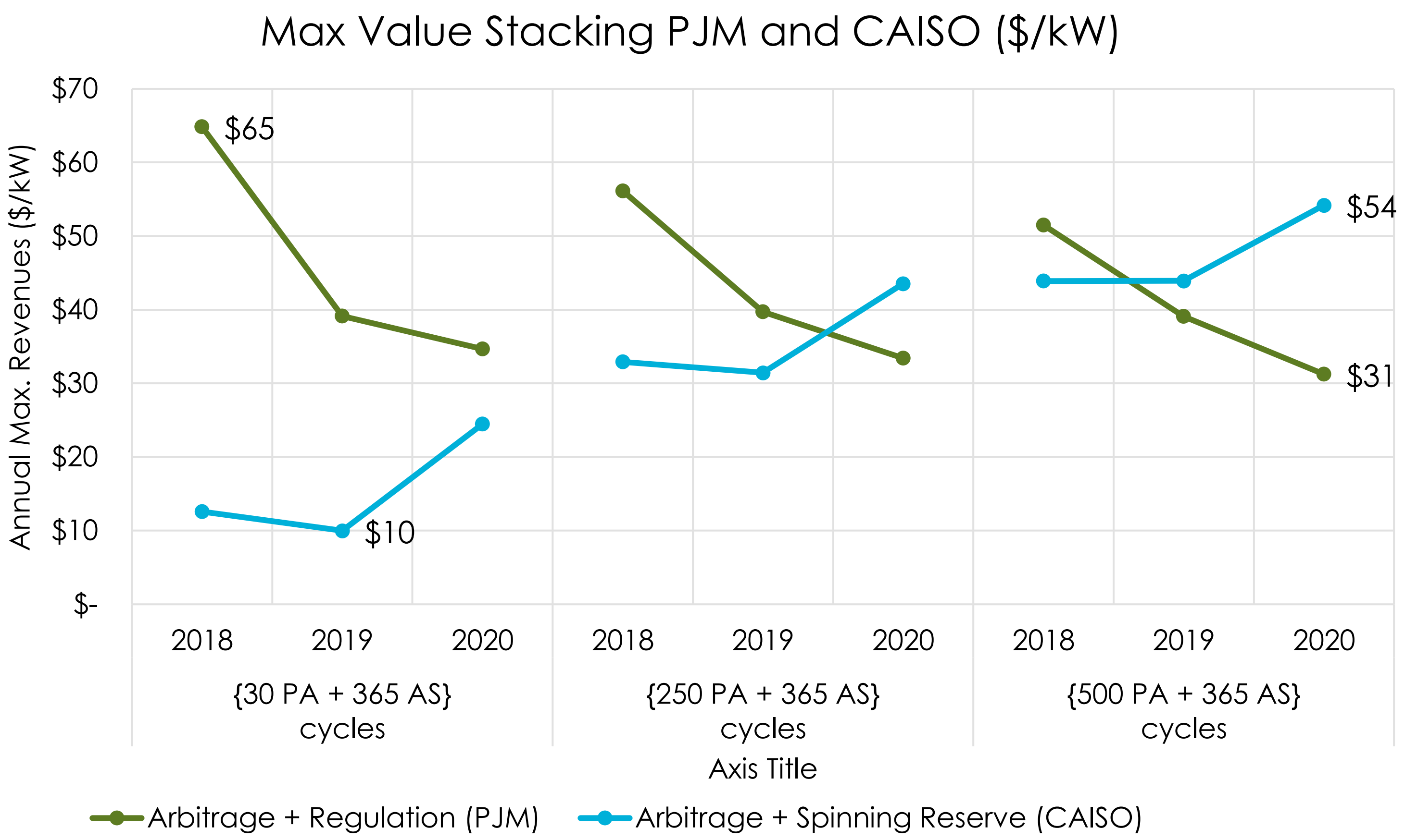


- Revenues vary by month and year. PJM has more steady revenues than CAISO
- Annual ranges for CAISO: $31–44/kW and PJM: $16–28/kW in base case
- Average values for CAISO: $36/kW and PJM: $22/kW in base case

Data sources: Hitachi Energy Velocity Suite for PJM and S&P Capital IQ Pro for CAISO (averaged across NP15, SP15, ZP26)

Step 3: Quantify Opportunities

Value Stacking (PA + AS): Results

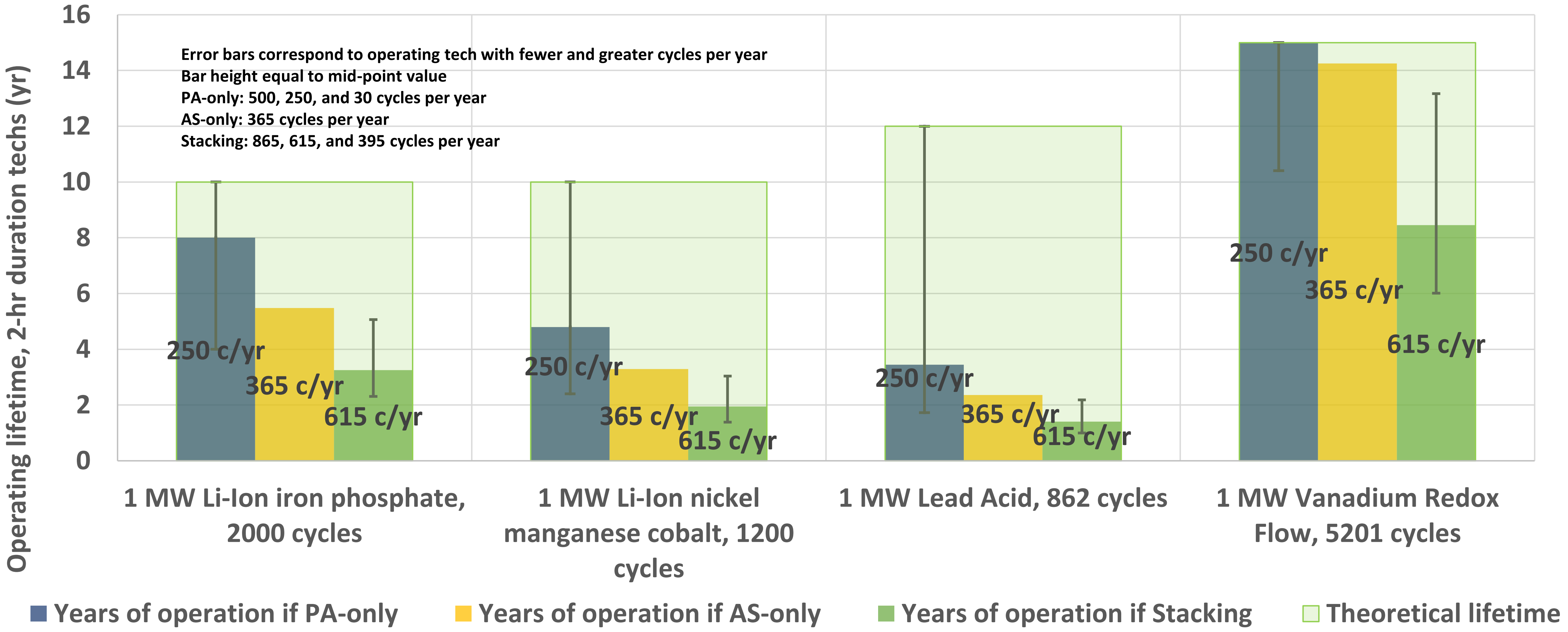


- Comparing revenues
  - Stacking revenue ranges $5–65/kW in PJM and $10–54/kW in CAISO*
    - Both regions have comparable revenues under current model setup and data availability
  - Arbitrage + Regulation is most profitable in PJM
  - Stacking revenues in CAISO are driven entirely by arbitrage*

*Based on Velocity Suite hourly price data for CAISO AS.

Technology Lifetimes

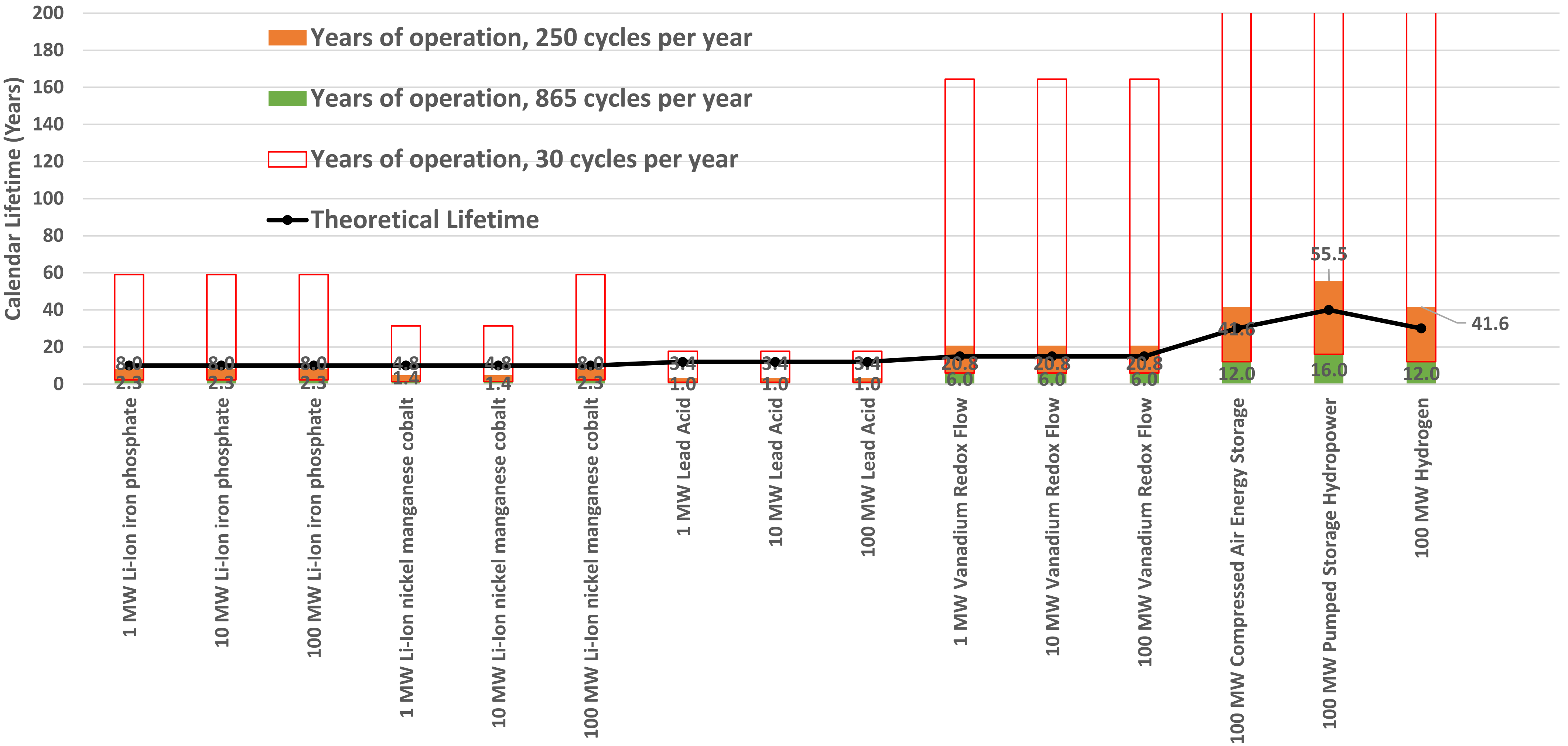
How Often to Operate the ES Component for the Three Use-Cases



Lifetime data from PNNL's Storage Database

Technology Lifetimes

How Often to Operate the ES Component for the Three Use-Cases (cont'd)



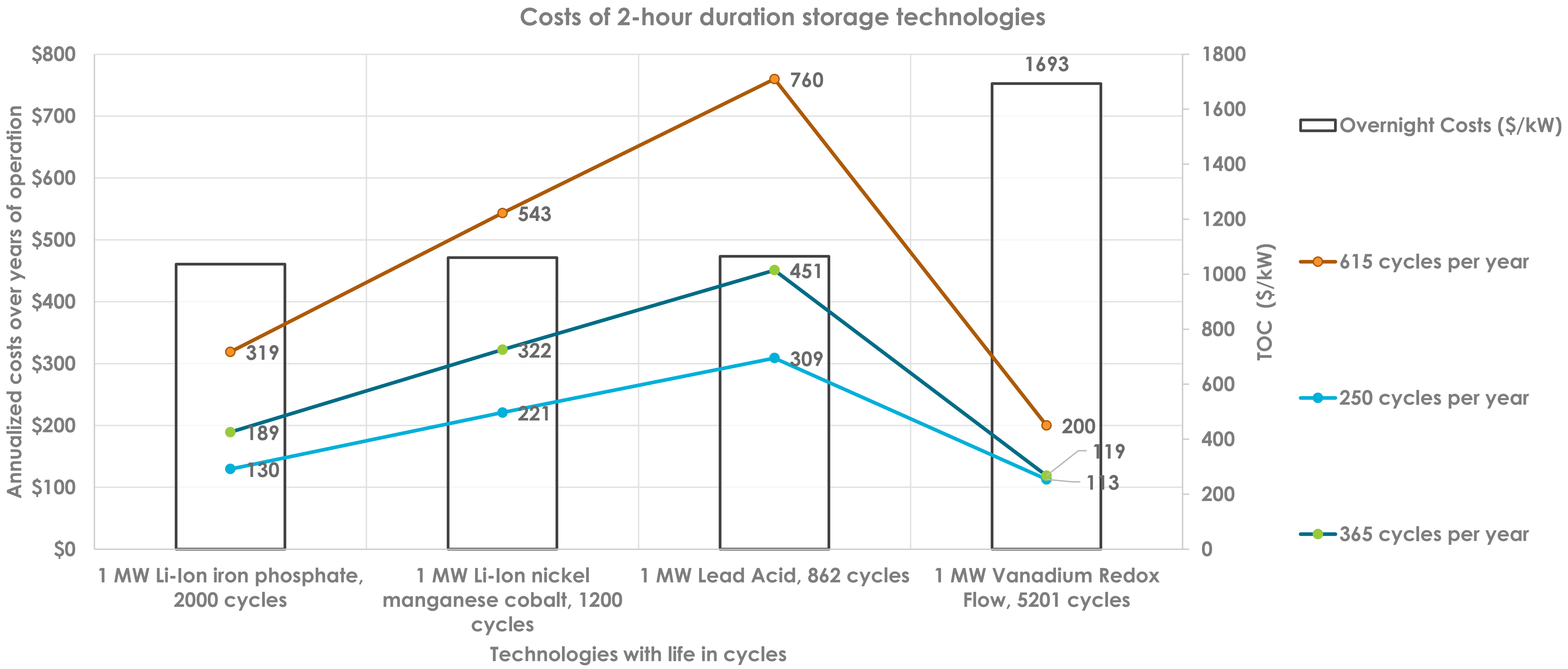
Step 3: Quantify Opportunities

Highlights

- To some extent, FE power generators can monetize short duration storage (SDS) technologies additions via the traditional electricity market mechanisms. However, costs can be as high as 2x to 10x higher than expected revenues
  - PJM's max: approx. $5.5-60/kW (capacity) + $74/kW (wholesale/AS)
  - CAISO's max: $54/kW (wholesale/AS)
  - Annualized TOC: $113-760/kW (2-hr storage technologies)
- The revenue gap, the difference between annual costs and annual revenues, is still significant for the SDS use cases. Li-ion batteries and redox flow batteries are the two technologies with the lowest gap between annual revenues and annual costs, when considering price arbitrage and AS provision
  - Even under conservative assumptions: no consideration of impacts of supply chain challenges in costs of the technologies, perfect market information, 100% roundtrip efficiency

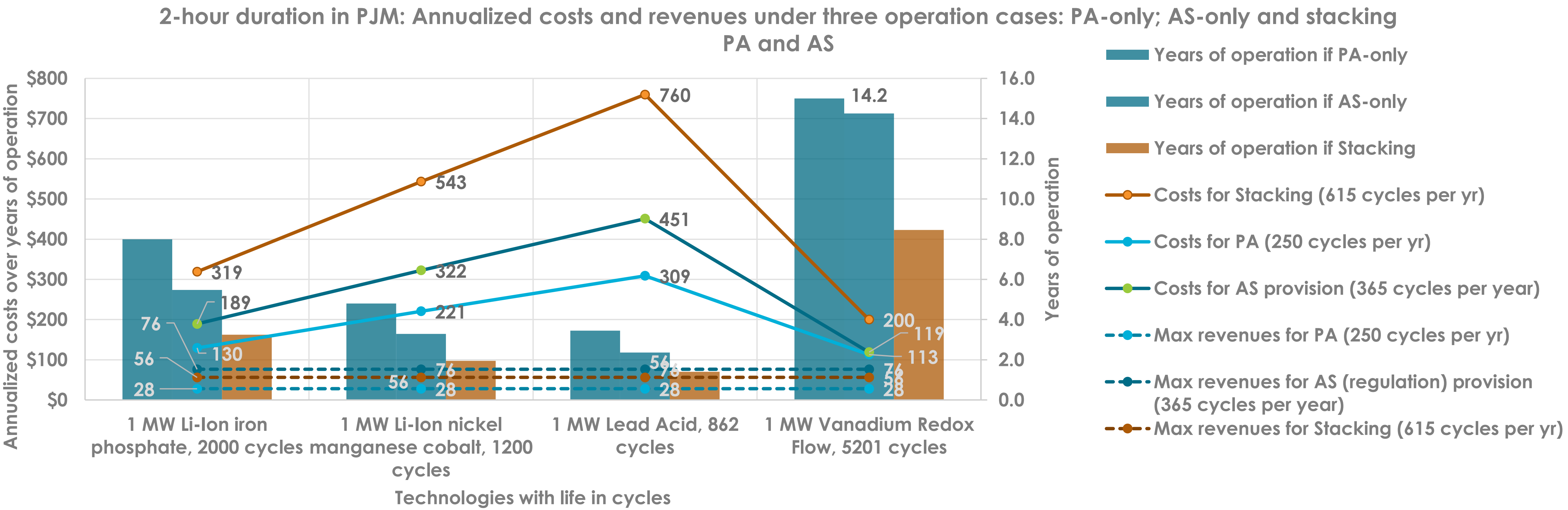
Technology Overnight Costs

Annualized Costs Depend on Lifetime



Comparing PJM Annualized Revenues to Costs

Annualized Revenues for Three Use Cases Are Not Sufficient to Cover Costs



- When the three use cases PA-only, AS-only, and stacking are compared against costs of ES technologies, none of these justify the investment
- The longer life-time of Vanadium Redox (up to 15 years) compared to the other technologies, is a comparative advantage, and results in a smaller revenue-costs gap

Comparing CAISO Annualized Revenues to Costs

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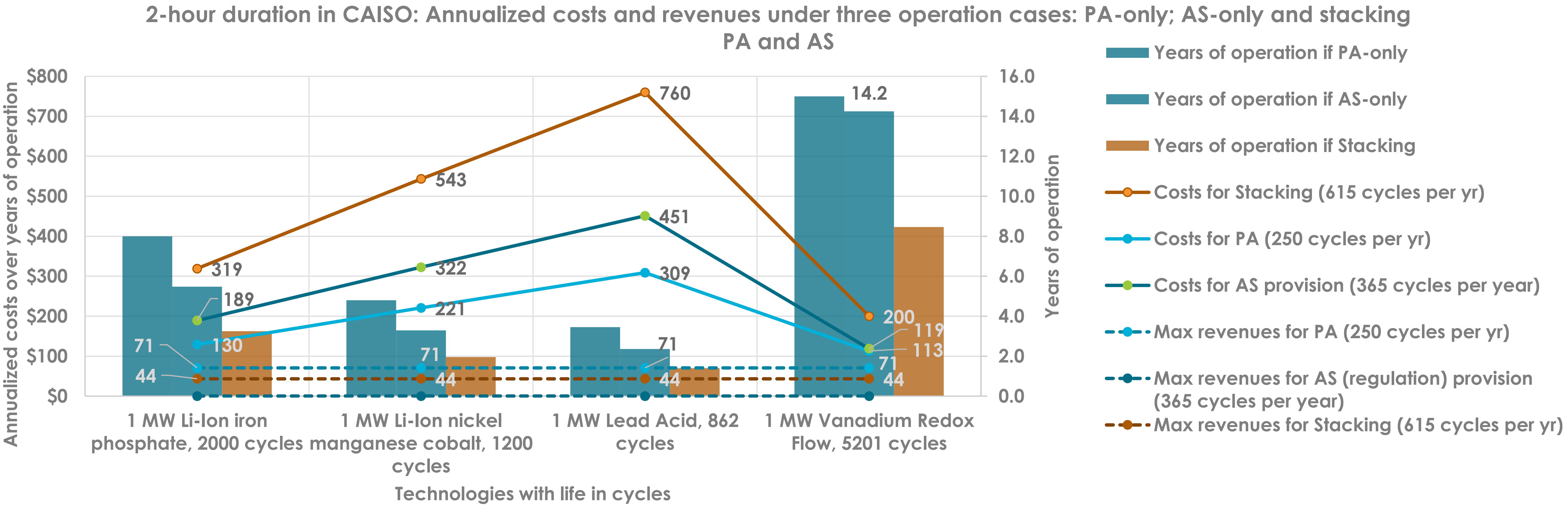

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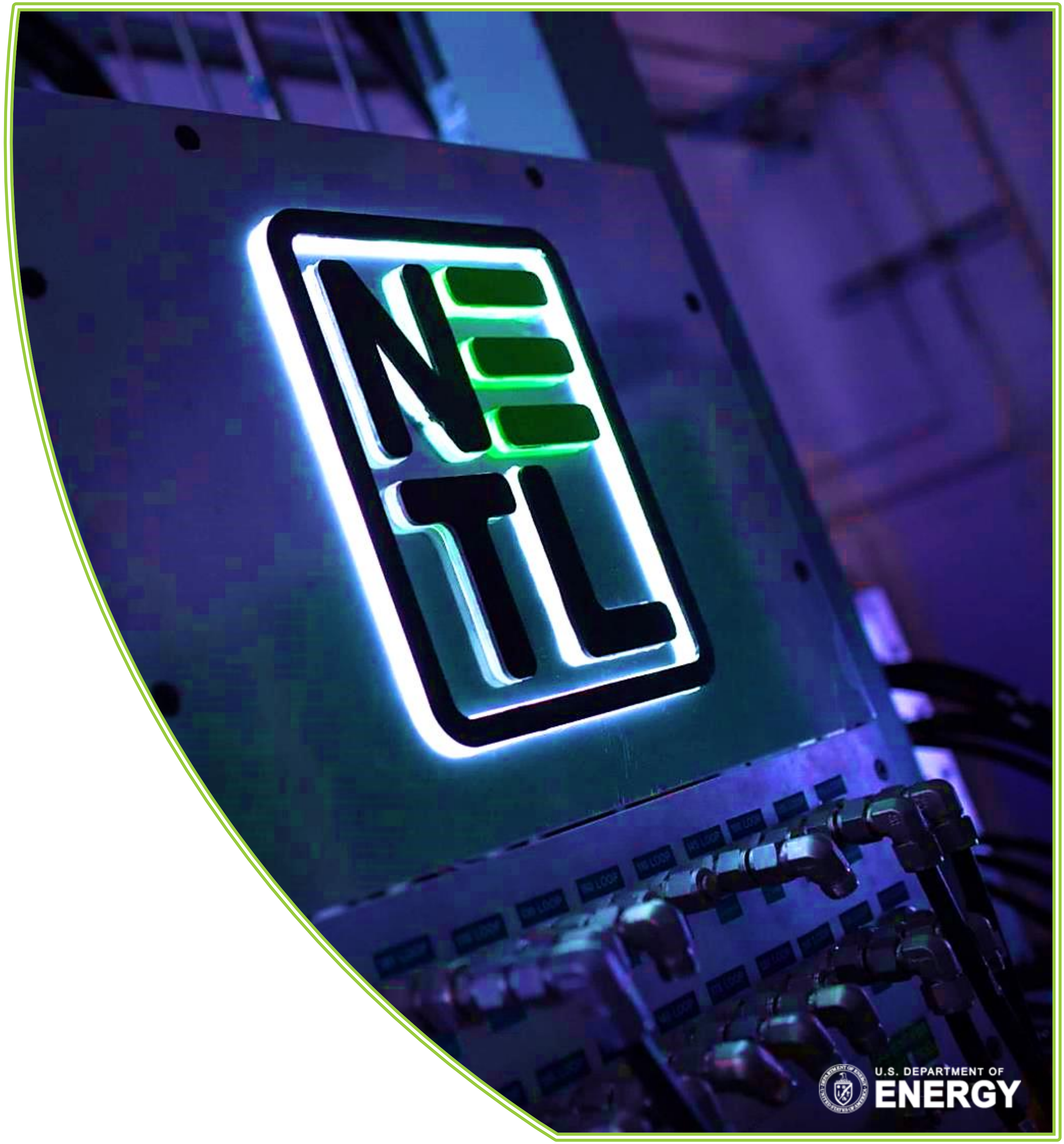
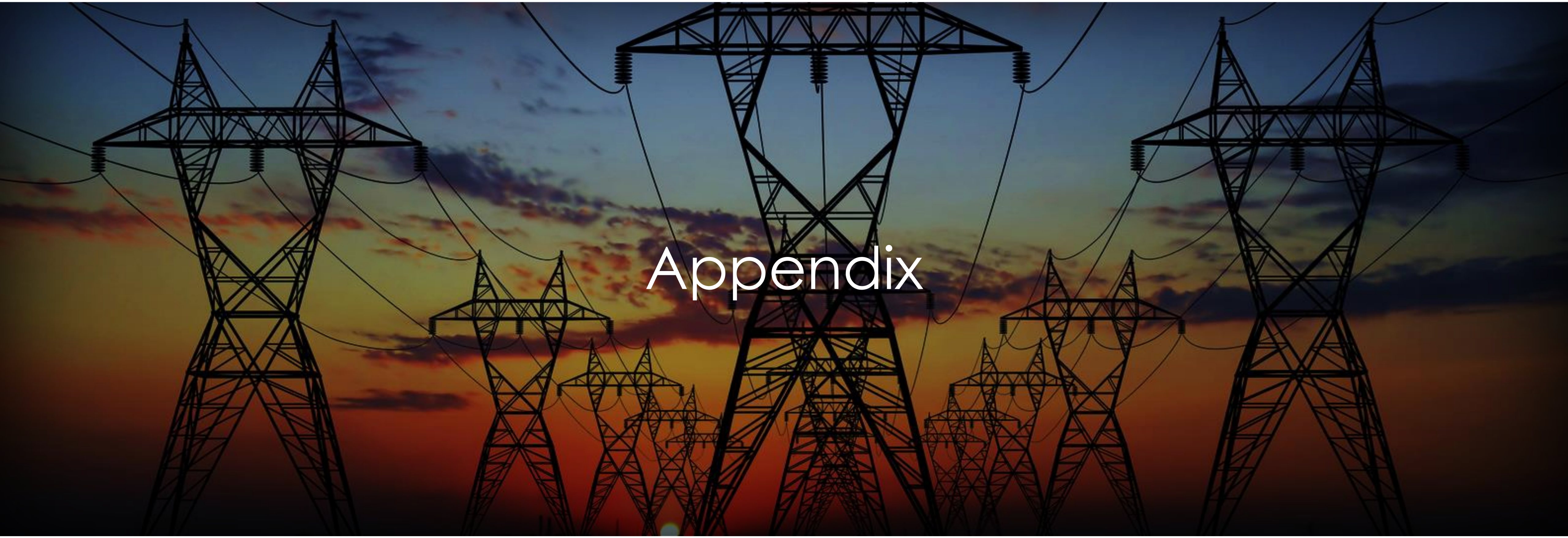


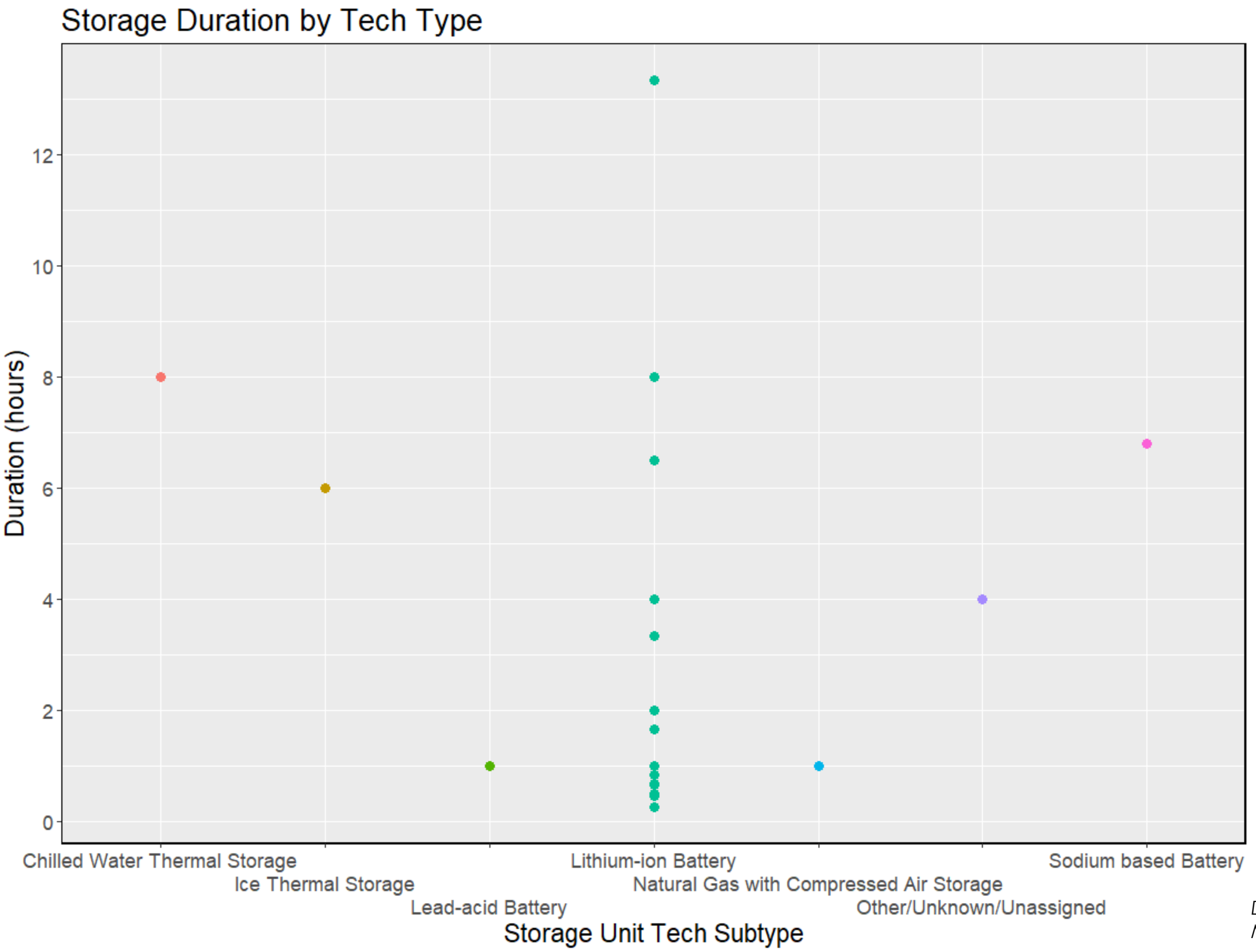
U.S. DEPARTMENT OF ENERGY

Appendix



Step 2: Create ES-FE Dataset

Storage Duration for Co-located + Hybrid

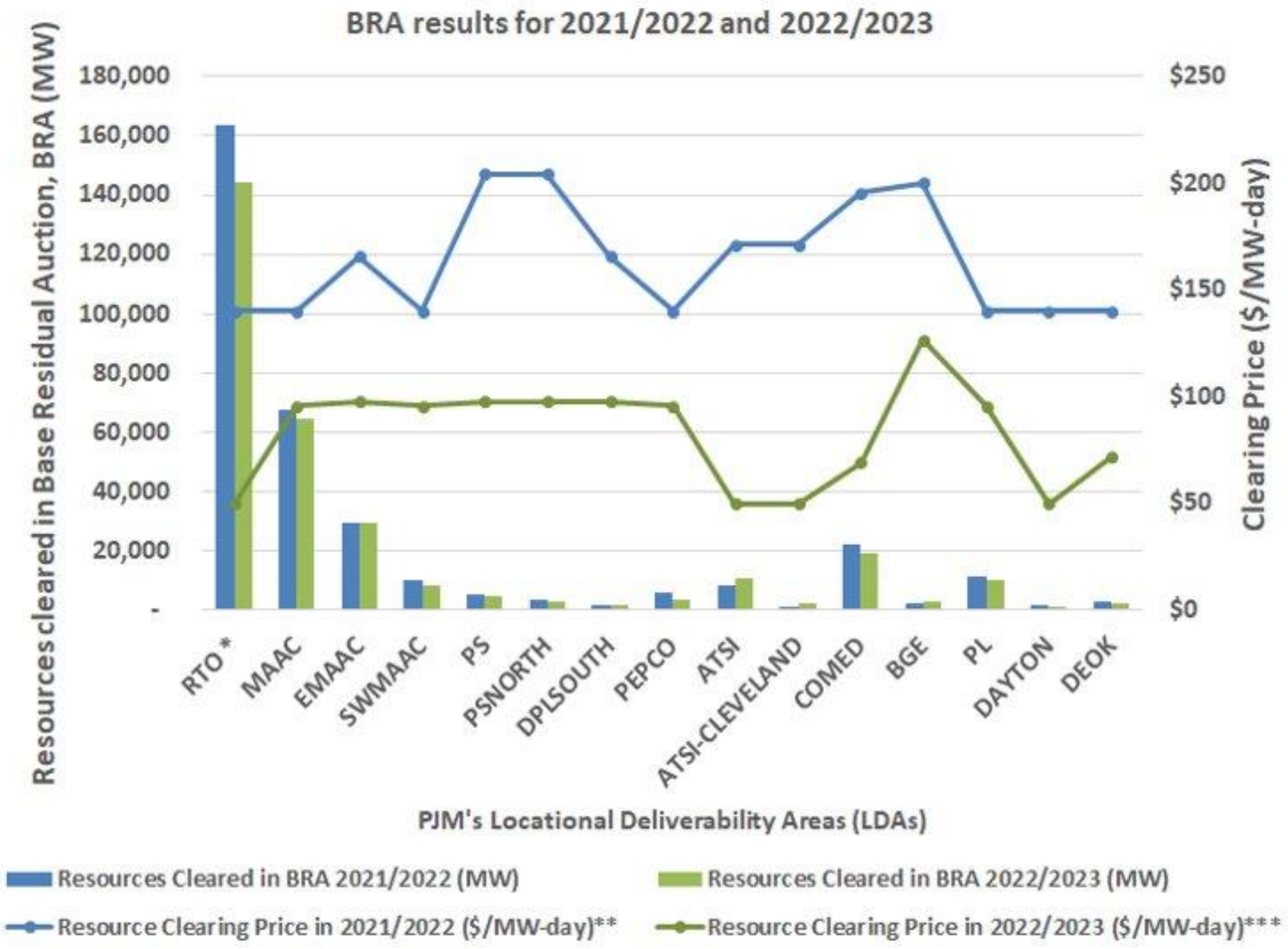


- 8+ hour duration
  - Massachusetts, New York, California
  - 5 storage units, 4 Li-ion, 1 thermal storage
  - Paired with NGCC petroleum liquids
- 4–7 hour duration
  - California, Arizona, Hawaii
  - 5 storage units, 4 Li-ion battery, 1 thermal (University of Arizona)
  - Paired with NGCC, NGCT) petroleum liquids, other NG
- 1–3 hour duration
  - 14 states
  - ~23 storage units, Li-ion, and 1 NG compressed air

Data from EIA 860 (2019)
Maps have data only on co-located and hybrid storage, but durations are shown for standalone as well.

Capacity Provision in PJM

Capacity payment ($/MW) = Capacity Clearing Price ($/MW) x UCAP



- Base residual auction (BRA) results shown are for auctions that happened before new ELCC framework
- Range ~$50–200/MW-day

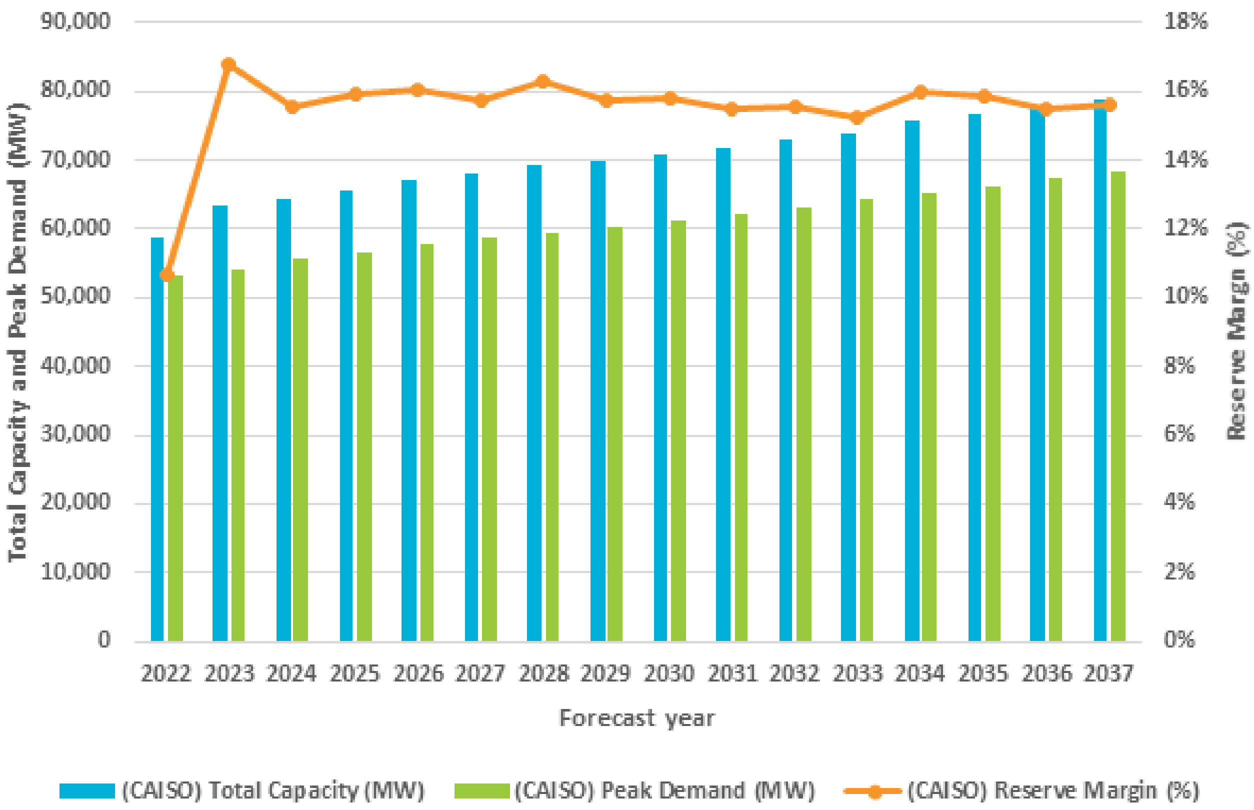
* RTO resources include resources from External Source Zones.
**In 2021/2022 BRA, system's marginal clearing prices was $140/MW-day. The difference corresponds to the locational price adder
***In 2022/2023 BRA, system's marginal clearing price was $50/MW-day. The difference corresponds to the locational price adder

Data from PJM, (2022) "Capacity Market (RPM)" https://pjm.com/markets-and-operations/rpm.aspx

Capacity Market in CAISO

- CAISO does not operate a formal capacity market
- CAISO uses a mandatory resource adequacy requirement
  - Requires that load serving entities procure 115 percent of their aggregate system load on a monthly basis
  - Each supply resource is obliged to be available
    - It is incentivized via the Resource Adequacy Availability Incentive Mechanism (RAAIM)
    - **Resource adequacy (RA) resources that fail to meet the threshold are subject to a penalty, while resources that exceed the threshold may receive a payment**

CAISO's reserve margin forecast



Capacity Market in CAISO

RAAIM

Penalties and payments between generators and CAISO, under RAAIM

Month and Year	Total Non-Availability Charge (Penalty)	Total Availability Incentive Payment	Flexible Average Actual Availability*	System Average Actual Availability*
Oct 2019–Dec 2021	Cost of $1,050,000–6,267,000	Payment of $1,050,000–3,188,710	94–98%	91–98%

*Starting from May 2018, the ISO reports the system RA average actual availability and flexible RA average actual availability separately

- Hybrids are not required to participate – adding ES to become an ES-FE hybrid makes the asset exempt of the requirement
- The monetary benefits for ES-FE could be then avoided expected penalties (charges) that apply for stand-alone FE power plants
    - No public information of how often a FE power plant is charged with penalties in RAAIM
    - ES is considered not to bring an economic value for FE power plants under the RAAIM

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