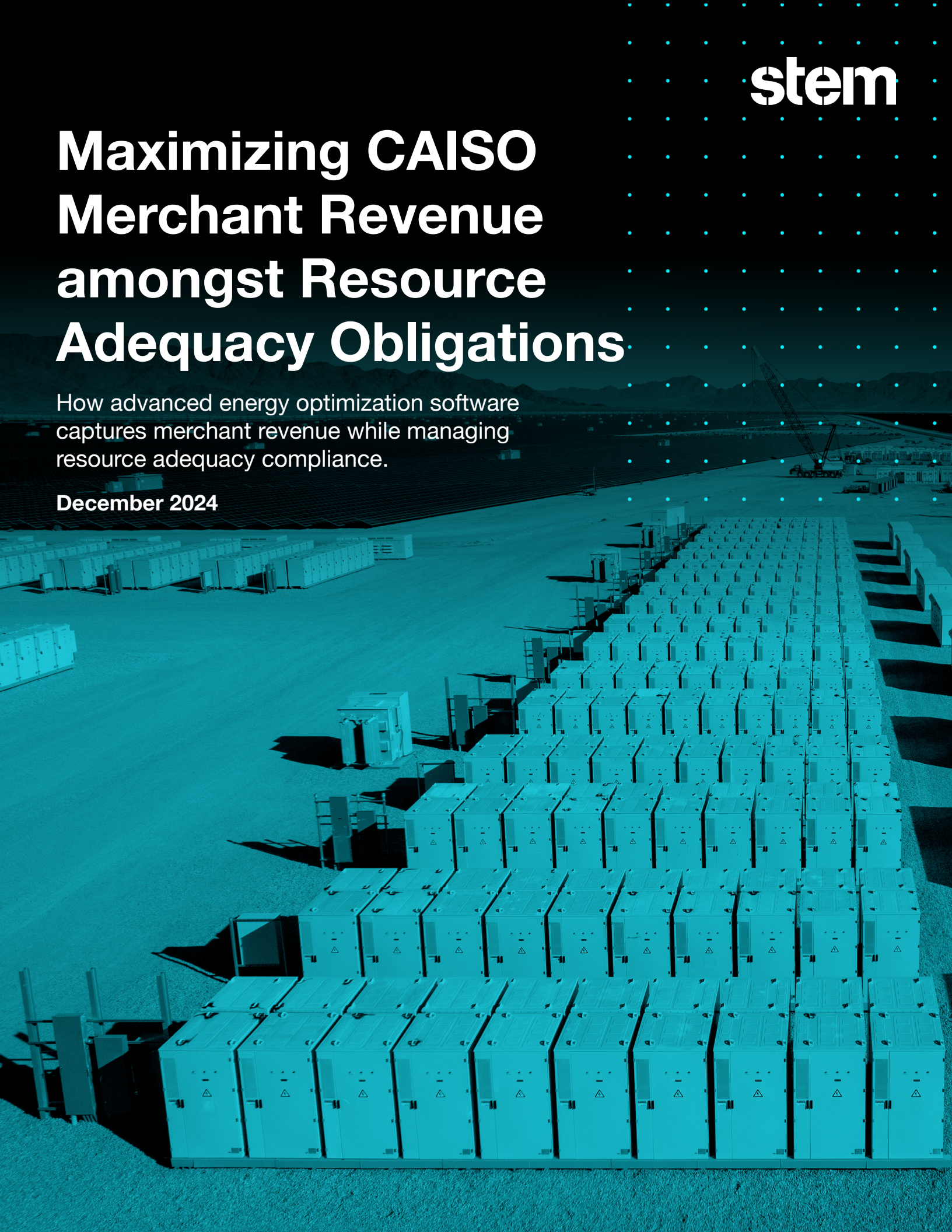
stem

Maximizing CAISO Merchant Revenue amongst Resource Adequacy Obligations

How advanced energy optimization software captures merchant revenue while managing resource adequacy compliance.

December 2024



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Executive Summary

Optimization software offers a significant opportunity for storage asset owners in the California Independent System Operator (CAISO) market to boost merchant revenue while fulfilling their Resource Adequacy (RA) obligations. Stem's digital twin bid simulator analyzed the impact of various RA contract configurations on the revenue potential of a simulated CAISO storage asset in 2023. This study examines how different RA contract variations influence bidding behavior and revenue, demonstrating how toll off-takers and asset owners can maximize value through CAISO merchant optimization while fulfilling RA obligations.

Key Takeaways

1. Advanced optimization software maximizes revenue outcomes while concurrently managing RA bidding constraints for storage assets.
2. In our simulations, merchant optimization generated $10.4 million, or 58% of total revenue, by strategically combining real-time and day-ahead energy bids and offers, along with participation in ancillary services to capitalize on CAISO price volatility.
3. Estimated capacity payments comprise 42% of revenue, where total revenue across all RA contract scenarios approached approximately $18 million.

Introduction

As California's energy grid becomes increasingly reliant on renewables and storage, ensuring reliable year-round electricity availability remains critical. One of CAISO's primary tools for maintaining grid reliability is the RA program. Under this program, load serving entities (LSEs) are responsible for securing sufficient capacity to meet their share of peak demand. To demonstrate compliance, LSEs must contract for firm capacity with resource owners in advance to guarantee they have enough energy resources available when needed.

RA contracts require resource owners to submit offers to CAISO's energy and ancillary services markets to fulfill "Must-Offer Obligations" (MOO), representing their availability for grid dispatch. Although these contracts provide a reliable and stable revenue stream, they also impose operational constraints, including mandatory offers and the risk of financial penalties for non-compliance.

This whitepaper explores how bidding optimization software can help asset owners and toll off-takers maximize merchant revenue (which our study finds constitutes 58% of total project revenues) while ensuring compliance with their RA obligations. Leveraging Stem's digital twin bid simulator, Stem provides insight into how various RA contract configurations impact the merchant revenue potential of a simulated energy storage asset in CAISO.

Understanding Resource Adequacy

The California Public Utilities Commission (CPUC) determines each LSE's RA requirements and requires them to procure each type of RA according to their standards. These mandated quantities are secured periodically through bilateral contracts between resources and LSEs. The three main categories of RA CAISO requires are summarized in the table below.

RA Category	Description
System	Ensures sufficient CAISO system-wide capacity to meet projected demand
Local	Ensures sufficient capacity to meet projected demand in local areas
Flexible	Ensures that there is enough capacity with operational flexibility to ramp quickly. It is further broken down into three sub-categories: · Flexible Base Ramping: Adjusting power output to meet gradual changes in low-demand periods · Flexible Peak Ramping: Adjusting power output to handle sudden spikes in high-demand periods · Flexible Super-Peak Ramping: Managing power output during extreme demand peaks

Table 1: *CAISO RA Categories*

Resources meeting RA requirements in these categories have specific MOO, necessitating that they offer various market products at different times of the day. While the must-offer hours are uniform within each RA category, they can vary seasonally and are updated periodically.

Resources designated as System, Local, or Flexible RA capacity are subject to resource adequacy availability incentive mechanism (RAAIM), which incentivizes them to meet bidding obligations and submit energy and ancillary service bids. Their monthly performance is evaluated based on bid availability during specific assessment hours. Depending on their average capacity availability, resources may be charged or paid each month.

Like System and Local RA, Flexible RA must submit energy and ancillary services bids to both the day-ahead and real-time markets, and participate in the residual unit commitment process after the day-ahead market closes to address gaps between forecasted demand and scheduled generation. Flexible Base Ramping resources must submit economic bids for 17 hours per day and be available 7 days per week. Flexible Peak Ramping must submit economic bids for 5 hours on all days. Flexible Super-Peak Ramping must submit economic bids 5 hours per day on non-holiday weekdays. In CAISO, most of the resources procured to provide Flexible Base Ramping are gas-fired resources, while Flexible Peak and Flexible Super Peak Ramping RA capacity is largely dominated by energy storage resources.

The tables below outline the 2023 schedule for RAAIM assessment hours and the MOO each type of RA carries.

RA Category	Winter (Nov - Feb)	Spring (Mar - May)	Summer (Jun - Oct)
System/Local	All Days: 4pm – 9pm	All Days: 5pm – 10pm	All Days: 4pm – 9pm

2023 Availability Schedule

	Winter (Nov - Feb)	Spring/Summer (Mar - Aug)	Fall (Sept - Oct)
Flexible - Base	All Days: 5am – 10pm	All Days: 5am – 10pm	All Days: 5am – 10pm
Flexible - Peak	All Days: 2pm – 7pm	All Days: 4pm – 9pm	All Days: 3pm – 8pm
Flexible - Super Peak	NERC Weekdays: 2pm – 7pm	NERC Weekdays: 4pm – 9pm	NERC Weekdays: 3pm – 8pm

Table 2: *Schedules for submitting bids and offers by RA category*

Must-Offer Obligations

RA Category	Must-Offer Obligations
System/Local	**Day-Ahead Market** · An energy offer (discharge side) at qualified capacity · Offer one or more ancillary services at qualified capacity **Real-Time Market** · An energy offer (discharge side) at qualified capacity · Offer one or more ancillary services at qualified capacity
Flexible - Base **Flexible - Peak** **Flexible - Super Peak**	**Day-Ahead Market** · An energy offer (discharge side) & a bid (charge side) at qualified capacity · Offer one or more ancillary services at qualified capacity **Real-Time Market** · An energy offer (discharge side) & a bid (charge side) at qualified capacity · Offer both Regulation Up and Regulation Down at qualified capacity

Table 3: *Bid/Offer obligations by RA category*

How Stem's Software Delivers Revenue Insights

Digital Twin Simulations

The goal of this study is to understand the revenue impact of various RA constraints by simulating operations of an energy storage resource in 2023. To achieve this, we use Stem's digital twin bid simulator which creates realistic simulations that mimic the market operational procedure every hour and reflect how Stem manages storage bidding operations.

The simulation process involves taking energy price forecasts and optimizing over a multi-day horizon, allowing us to enhance battery performance and generate bids and offers that maximize revenue across various energy market products. In our analysis, we use Stem's price forecast to reflect a realistic estimate of an asset's potential performance of fully automated managed bidding operations without any human intervention.

Generated bids and offers are "submitted" followed by a mock market clearing to assess whether the bids or offers are accepted or rejected. Subsequently, settlements are conducted using the cleared bids and actual 2023 energy prices for each respective product. While our simulations are designed to closely replicate actual operations, our analysis does not assume any outage or derate events.

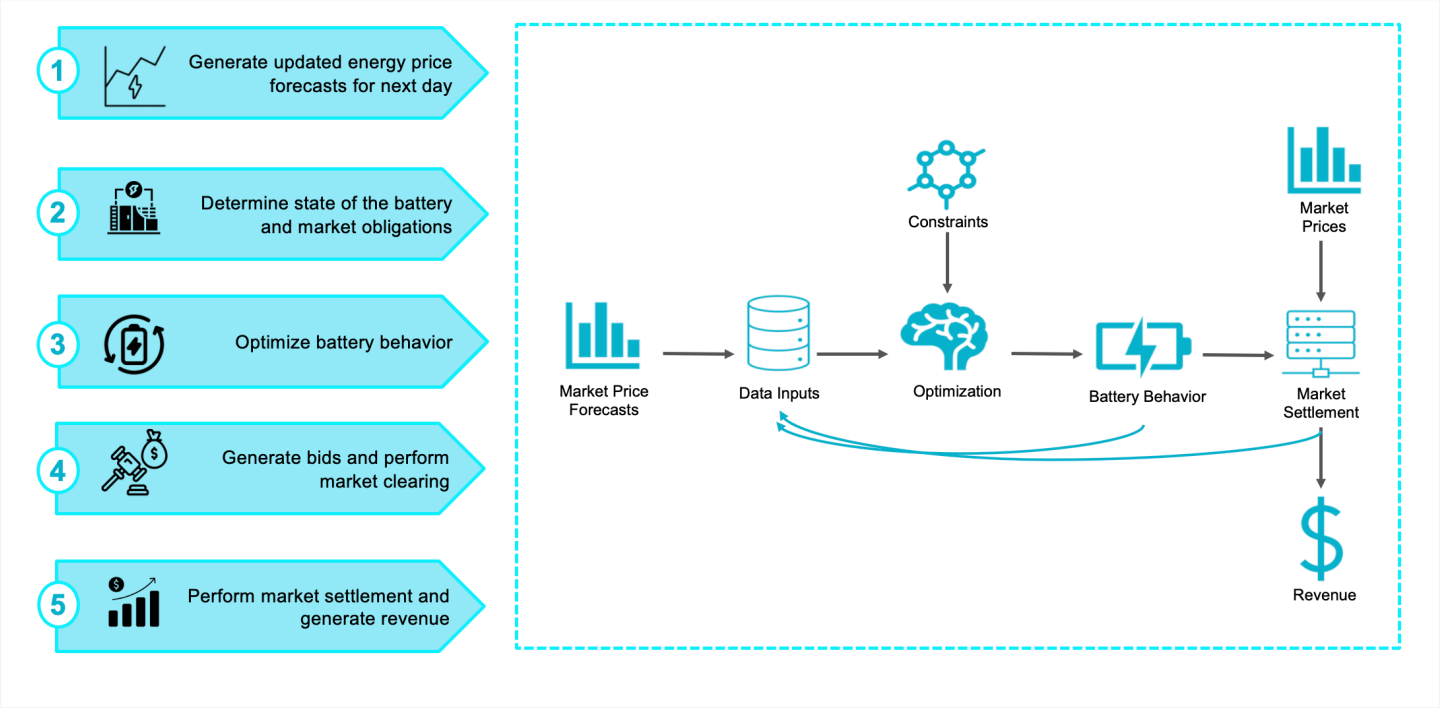

Figure 1: *Simulation Workflow*

Asset Configuration

For this analysis, we simulated different RA combinations for a standalone storage asset in CAISO using the following configurations:

- A stand alone Battery Energy Storage System (BESS) with a capacity of 100 MW and a 4-hour duration, situated in Southern California, with market revenue settlements based on the 2023 SP15 zone prices.

Asset Type	Capacity (MW)	Duration (Hours)	Local Area	Zone
System/Local	100	4	LA-Basin	SP15

Table 4: *Attributes for Simulated Asset Scenarios*

RA Configuration Scenarios

- We evaluate this asset across four distinct scenarios, each with fixed RA obligations throughout the months of 2023. In these scenarios, we assume that 80% of the battery's capacity is contracted for a specific RA obligation category.

Scenario	System RA Capacity	Local RA Capacity	Flexible (Peak) RA Capacity
System	80 MW	0 MW	0 MW
Local	0 MW	80 MW	0 MW
Flexible	0 MW	0 MW	80 MW
No RA	0 MW	0 MW	0 MW

Table 5: *RA Responsibilities for Each Scenario*

2023 RA Capacity Prices

- To estimate the revenue from monthly capacity payments in 2023, we use the reported average RA capacity prices from 2022 (adjusted for inflation) as an estimate of 2023 capacity prices. 2023 capacity prices were not publicly available at the time of drafting. For local area pricing, we assume the LA Basin territory.

Date	System ($/KW-Month)*	Local (LA Basin) ($/KW-Month)*	Flexible ($/KW-Month)*
January 1, 2023	$5.95	$5.94	$5.76
February 1, 2023	$5.22	$5.64	$5.47
March 1, 2023	$5.32	$5.73	$5.55
April 1, 2023	$5.73	$7.26	$7.03
May 1, 2023	$6.10	$7.39	$7.16
June 1, 2023	$7.33	$7.81	$7.57
July 1, 2023	$10.64	$9.10	$8.82
August 1, 2023	$14.20	$10.73	$10.40
September 1, 2023	$14.98	$11.14	$10.80
October 1, 2023	$9.22	$8.70	$8.43
November 1, 2023	$5.66	$7.01	$6.79
December 1, 2023	$5.90	$7.12	$6.90

Table 6: *Assumed 2023 Capacity Prices*

**2023 RA capacity prices reflect reported average 2022 RA capacity prices, adjusted for inflation.*

The Revenue Impact of RA on Storage Assets

RA Obligation Impacts

Having an existing RA contract does not inherently restrict the opportunity to capture merchant revenue. By using optimization software that accounts for RA bidding requirements while managing a storage asset's opportunity costs, operators can preserve limited stored energy for the highest-valued hours.

Examining the total revenue breakdown for 2023 by product, we observe that the RA bidding constraints have minimal impact – less than 0.1% difference – on final revenue outcomes. In other words, properly optimized resources can pursue substantial merchant uplift, potentially more than doubling their contracted RA values.

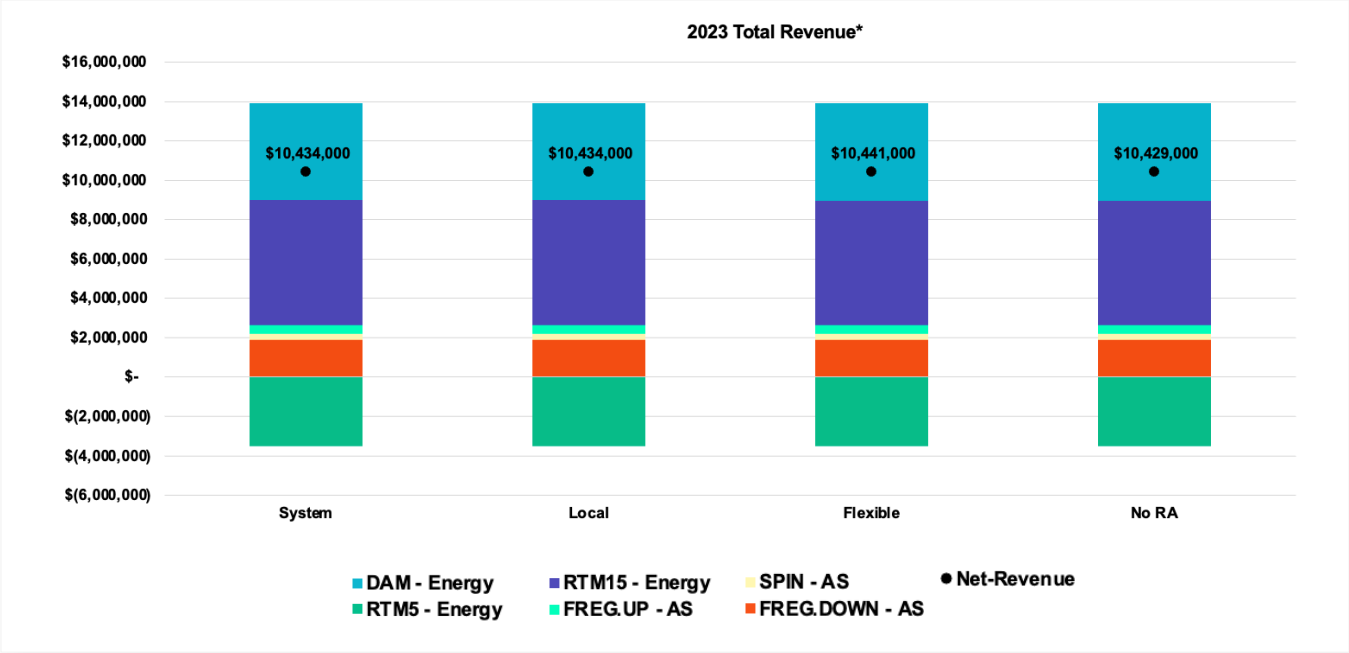

Figure 2: *2023 Annual Revenue Breakdown Across Scenarios*

**Note: Revenue figures above do not include revenue from RA capacity or incentive payments*

This stability is the result of Stem's RA compliance implementation, which is designed to be modular and adaptable to evolving RA must offer requirements. The optimization engine is "aware" of RA obligations and market compliance rules and is able to co-optimize revenue maximizing bid-offer quantities while ensuring compliance with the must-offer criteria for RA. By identifying strategic markets to place the RA obligation bid-offers while maximizing economic opportunities in others leads to consistent revenue performance across our RA scenarios and ensures that RA obligations are met without significantly impacting overall revenue.

The example below illustrates a typical bidding submission day for both the "No RA" and "Flexible" scenarios on August 16, which stands out as the highest revenue day in our results. In the Flexible RA scenario, our engine is required to submit offers for one or more ancillary services, participate in both the day-ahead and real-time markets at qualified capacity, and place bids for both regulation up and regulation down during the evening peak hours (4pm – 9pm). In contrast, the No RA scenario operates without such obligations, allowing for the submission of bids and offers aimed purely at maximizing revenue.

Looking into the results for the submitted 15-minute energy market quantities we observe that our optimization registers that there is an 80 MW flexible peak obligation that requires both bids and offers be submitted during (4pm – 9pm).

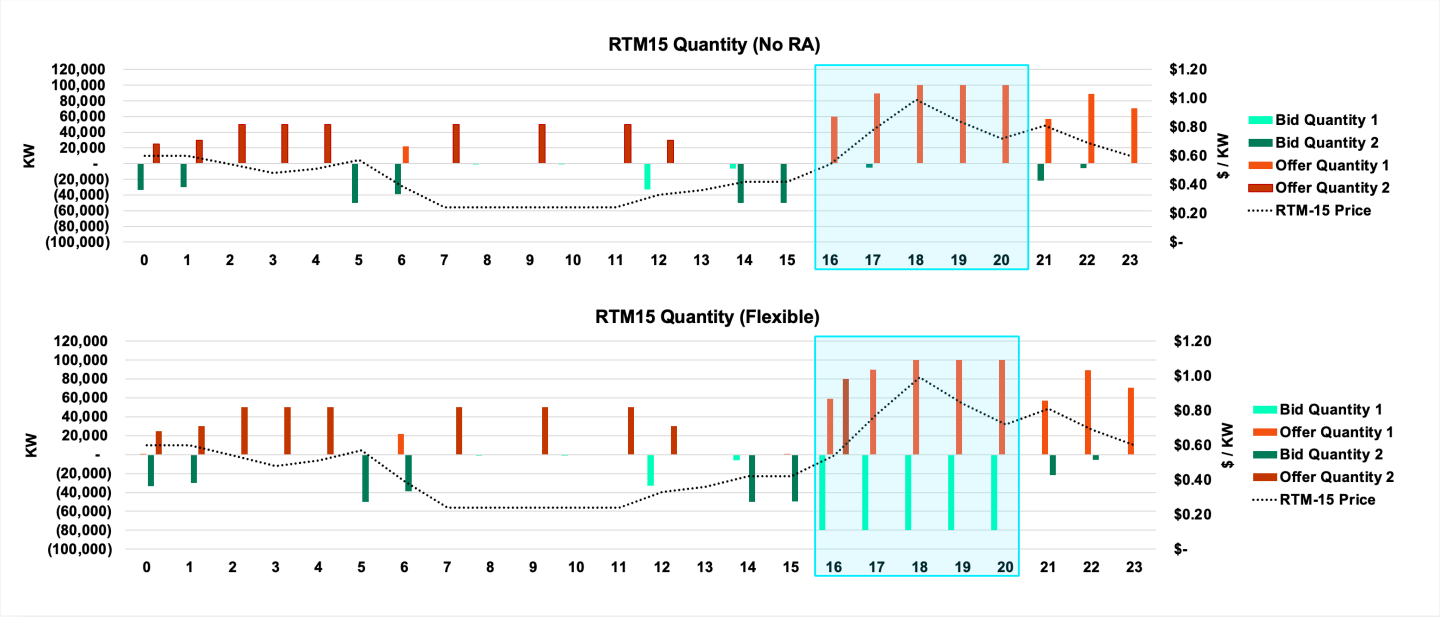

Figure 3: *Bid and Offer Quantities for RTM15 Submitted on August 16*

The No RA and Flexible scenario's submitted bid-offer pairs closely mimic each other in quantity and prices. The fundamental difference comes in the submitted quantities and prices during the peak hour window. To maximize revenue, our optimization seeks to clear offers during peak hours, when prices are at their highest and the grid is the most constrained. To avoid clearing the required 80 MW bids in the Flexible scenario, our engine submits a bid price that does not clear, while maintaining the same offer prices as the No RA scenario. As a result, the Flexible scenario is able to offer comparable revenue and bidding outcomes as the No RA, while complying with its flexible Peak RA contract obligations.

RA Capacity Revenue

Although the revenue results from our simulations do not include additional RA capacity revenues, we estimate the additional RA revenue breakdown for a 80 MW monthly obligation based on historical average RA prices. Based on our projected price assumptions, each RA scenario translates to $7.25+ million in additional revenue beyond what is generated through energy market optimization results alone.

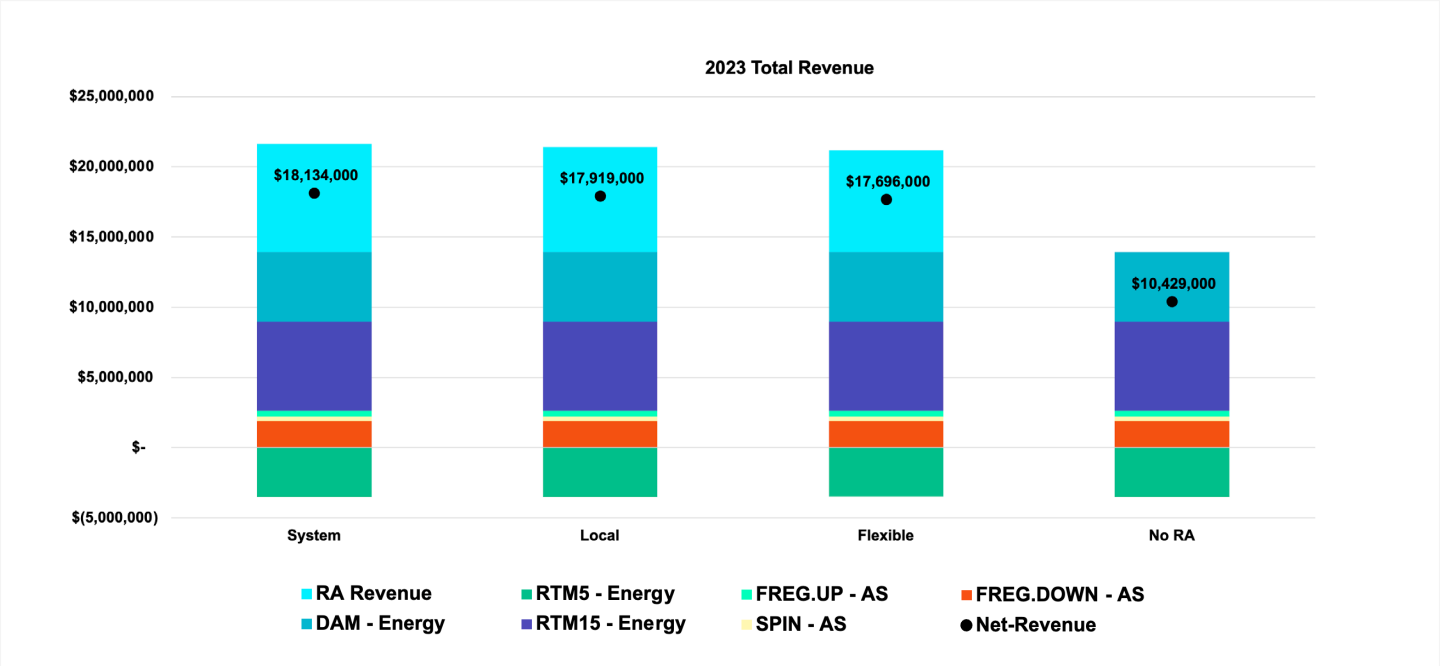

Figure 4: *Projected 2023 RA Revenue by Scenario*

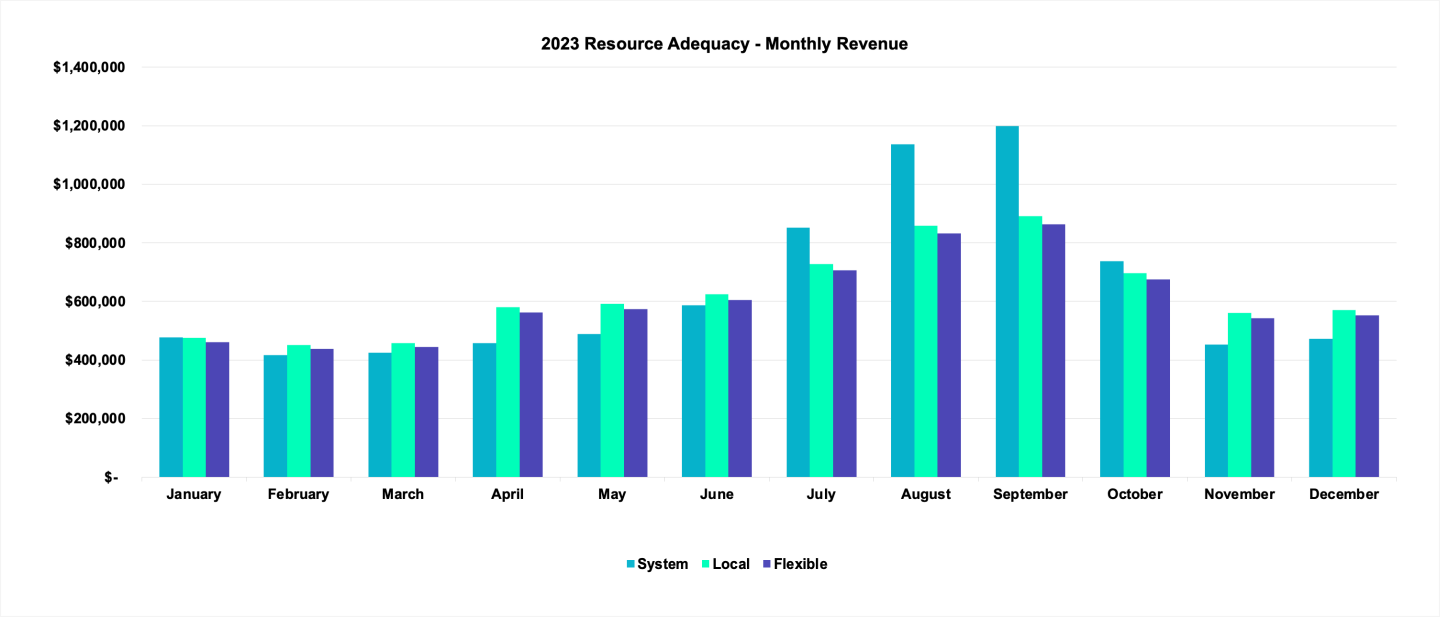

Figure 5: *Projected 2023 Monthly RA Revenue by Scenario*

System RA scenario obtains the highest project capacity payment revenue with $7.7 million, as prices for system RA capacity have increased dramatically over the past few years, especially in summer months. These price increases are largely driven by tight supply conditions stemming from resource retirements, increasing load forecasts, and changes in counting conventions that have reduced the RA value of certain resources. Please note that these revenue estimates are illustrative and may not account for factors like financial penalties from outages or unmodeled market products (e.g., Flex Ramp), which could significantly impact the amounts shown in the charts.

2023 Annual Revenue

Comparing annual performance across the RA scenarios, we find that the Stem operations achieved a total net revenue of $10.4 million for 2023. Notably, over 80% of market revenue comes from energy products in both CAISO's day-ahead and real-time markets. Ancillary services account for a smaller portion of our overall revenue, which is in line with a trend observed in CAISO. As the number of battery resources increases, the contribution of batteries to ancillary services has diminished relative to their total capacity. The 5-minute real-time (RT) market revenues are negative due to the disparity between our energy market commitments and AS dispatches. Overall, we engage in more charging through AS - specifically by participating in Regulation Down - since we can offset the cost of charging in RT with capacity revenue. This is primarily due to the Regulation Down capacity payment, which acts as an effective cost mitigation, making it more economically advantageous to charge in this way. This highlights the vital role of automated bidding and optimization software in crafting optimal bid/offer submissions for maximum revenue attainment across energy market products.

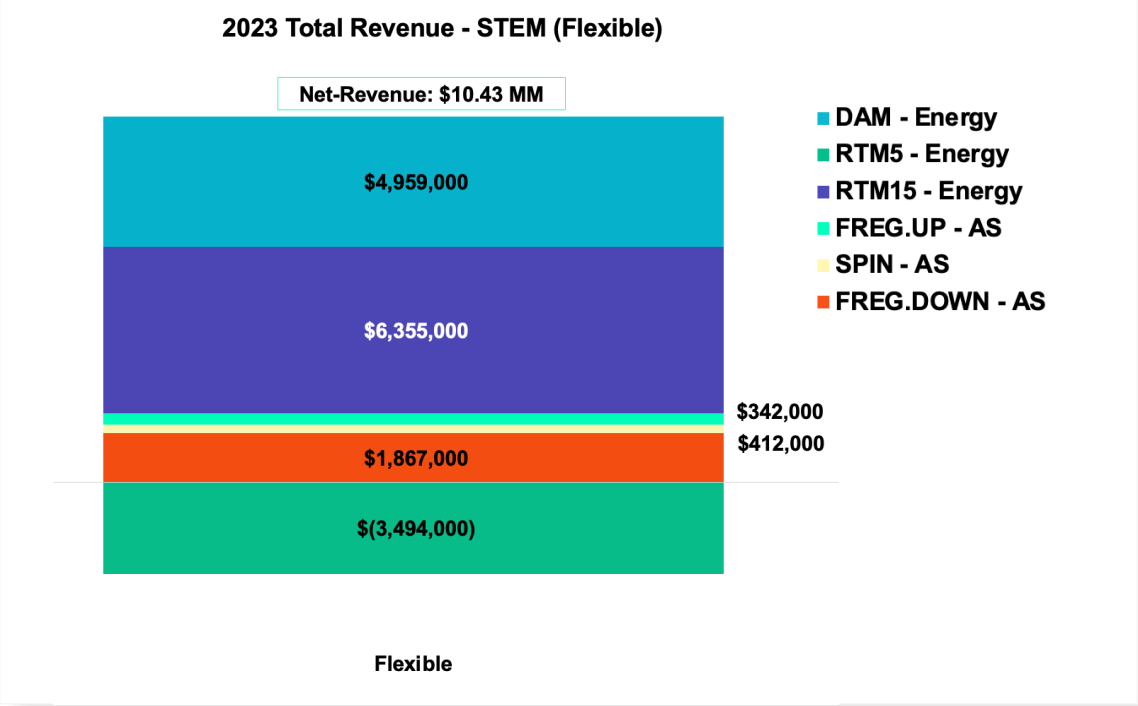

Figure 6: *Revenue Breakdown for Flexible RA Scenario*

2023 Monthly Revenue

When looking at revenue attainment on a monthly basis, an interesting breakdown emerges. Spring 2023 experienced two low-revenue months due to the 2023 snowpack reaching 245% of the long-term average, resulting in a 69% increase in hydroelectric production. This surplus of hydroelectric power from spring runoff diminished the need for baseload generation and imports, ultimately suppressing wholesale energy prices. In contrast, the top three revenue months occurred during the summer and winter seasons.

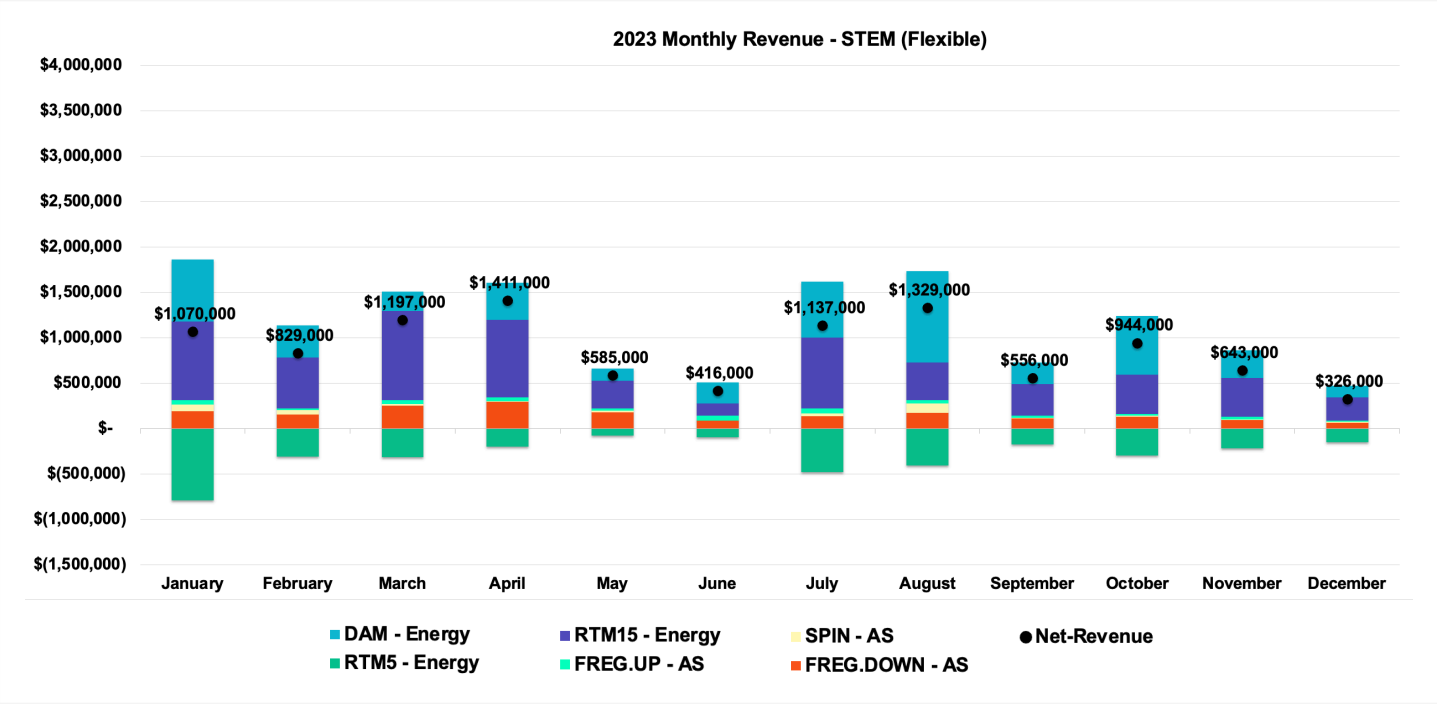

Figure 7: *Monthly Revenue Breakdown for Flexible RA Stem Forecast*

The following chart illustrates the hourly revenue from participation in energy markets in January 2023.

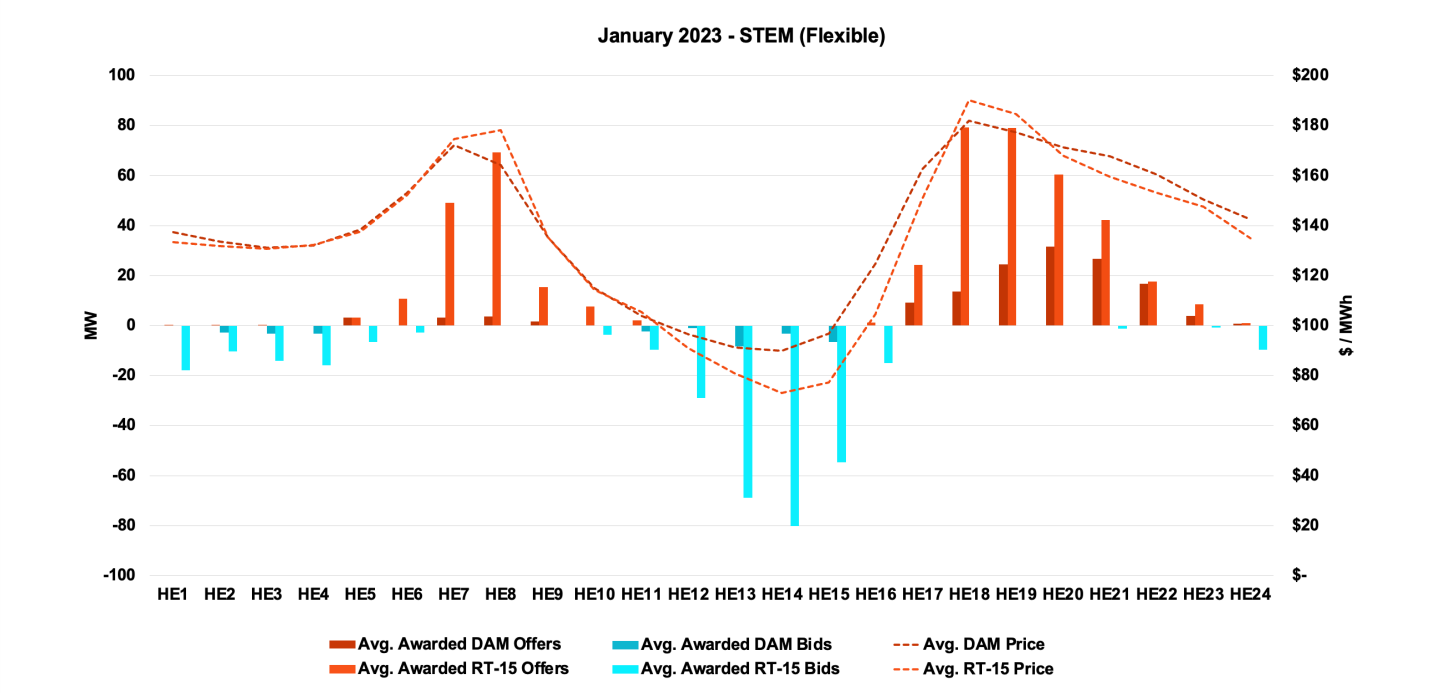

Figure 8: *January 2023 DAM and RT15 Energy Revenue Breakdown for Flexible RA Stem Forecast*

While CAISO storage resources typically capitalize on summer months for revenue by arbitraging low-priced mid-day solar production hours with high evening peak prices, January 2023 presented a different scenario. Following the major summer heat wave demand of 2022, gas inventories in California struggled to keep pace with replenishment, particularly in Southern California, where gas storage capacity is more limited compared to Northern California. Coupled with below-average temperatures, which led to increased gas consumption in the residential and electric sectors, this caused gas prices at western gas hubs to rise significantly. Since natural gas units frequently serve as the marginal source of generation in CAISO, their role in elevating energy prices led to a highly profitable January month for the simulated storage asset.

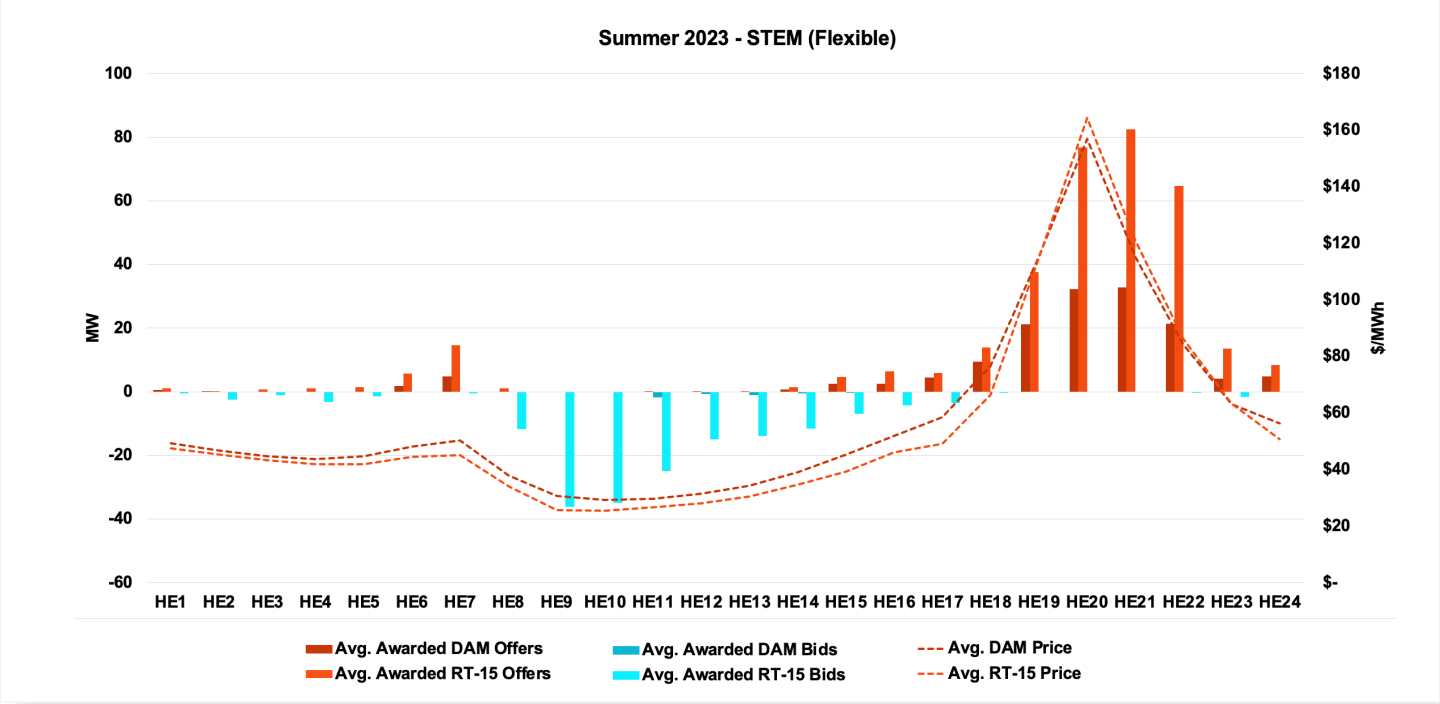

Figure 9: *Summer 2023 DAM and RT15 Energy Revenue Breakdown for Flexible RA Stem Forecast*

Summer energy prices closely follow the net-load curve due to the significant increase in solar production in California. During the day low-priced solar generation leads to substantial price reductions, while evening hours see a sharp rise in both energy prices and net load as demand remains high and solar production drops. These generation and load fluctuations create large price spreads, which is advantageous for storage resources as 9 of the the top 10 revenue days in our simulation results occur during summer months. In addition to supply and demand dynamics, transmission network congestion within CAISO also influences energy prices considerably based on location and time of day. Given that most solar capacity is located in Southern California, congestion typically flows from south to north during midday, driving up prices in Northern California. Conversely this pattern reverses in the evening, resulting in higher prices in Southern California.

Conclusion and Key Takeaways

Resource adequacy contracts are and will continue to be essential for CAISO storage assets, as they provide a stable contracted revenue stream. However, these contracts come with constraints, including requirements for availability during peak periods, performance standards, bid limits, and operational specifications that must be managed effectively. As demonstrated in this whitepaper, Stem's proprietary optimization engine manages various types of RA capacity contracts for storage assets. By leveraging a strategic combination of real-time and day ahead bids, it helps maximize revenue during specific periods of CAISO energy price fluctuations and unlocks merchant uplift. This more than doubles the estimated contracted RA revenue.

Our goal is to offer transparency regarding our analytical process, thereby reinforcing our commitment to reliability in managing BESS optimization for merchant markets. We invite stakeholders and interested parties to engage with us for a deeper exploration of the insights presented in this whitepaper. If you are an asset owner or toll off-taker and want to learn more about innovative software solutions to maximize your resource's revenue potential, contact a Stem energy expert.

About Stem, Inc.

Stem is a global leader in AI-enabled software and services that enable its customers to plan, deploy, and operate clean energy assets.

The company offers a complete set of solutions that transform how solar and energy storage projects are developed, built, and operated, including an integrated suite of software and edge products, and full lifecycle services from a team of leading experts.

More than 16,000 global customers rely on Stem to maximize the value of their clean energy projects and portfolios. Learn more at stem.com.

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