Special Report on Battery Storage

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California Independent System Operator

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1 Summary

1.1 Background

As energy markets switch from fossil fuels to intermittent renewable resources, the market has added a growing fleet of battery storage resources to maintain the flexibility and resilience of the power grid. This is especially true in the Western U.S., where states like California, Washington, and Oregon have ambitious decarbonization goals. California is projected to need 79 GW of new renewable generation and around 50 GW of battery storage to meet its 2045 greenhouse gas reduction goals. [1]

The integration of large amounts of battery storage poses new challenges and opportunities, as battery technology is fundamentally different from that of more traditional power generators like gas and hydroelectric resources. Most large-scale storage systems in operation use lithium-ion technology, which is currently preferred over other battery technology because it provides fast response times and high-cycle efficiency (low energy loss between charging and discharging), while still being cost-effective. In addition to providing flexible generating capacity during critical hours, the fleet of battery storage resources now represents a significant amount of additional demand during other hours of the day.

Batteries do not generate energy, but rather store energy and move it from one time of day to another. Batteries can profit with this strategy—called arbitrage—so long as the price difference between charging and discharging is large enough to make up for efficiency losses in storage and variable operation costs. Batteries can purchase energy during midday hours when solar is plentiful and system prices are lowest, then sell it back to the grid in the evening when power is in high demand, solar output is low, and prices are much higher.

Batteries contribute other services and benefits to the grid besides energy. Because of their fast response times, batteries are ideal for providing services used to balance very short-term differences in supply and demand, such as frequency regulation and flexible ramping product. In addition, batteries can moderate the extremes in daily price swings through arbitrage, by increasing demand for renewables during the very low-priced hours of the day and increasing supply in the evening to bring prices down.

This report provides a description of the state of battery storage resources in the California ISO and Western Energy Imbalance Market. We evaluate the performance of batteries using several key metrics, and assess the recent market enhancements for battery resources.

1 California ISO, *20-Year Transmission Outlook*, May 2022, p. 2: http://www.caiso.com/InitiativeDocuments/20-YearTransmissionOutlook-May2022.pdf

1.2 Key findings

- **Battery storage capacity grew from about 500 MW in 2020 to 5,000 MW in May 2023** in the CAISO balancing area. Over half of this capacity is physically paired with other generation technologies, especially renewables, either sharing a point of interconnection under the co-located model or as a single hybrid resource.
- **The Western Energy Imbalance Market (WEIM) includes about 1,000 MW of participating battery capacity**. This is a nearly four-fold increase from the active battery capacity in the WEIM at the end of 2022.
- **During the 2022 September heat wave, batteries provided valuable net peak capacity and energy**. Batteries provided 2.4 percent of generation for the CAISO balancing area in hours-ending 17 to 21 from August 31 to September 9.
- **Batteries now account for a significant portion of load during peak solar hours**. From hours-ending 10 to 13 in 2022, battery charging represented nearly 5 percent of load. During these hours, batteries help reduce the need to curtail or export surplus solar energy at very low prices.
- **Batteries now provide over half of CAISO's regulation up and regulation down requirements**. However, the percentage of total battery storage capacity being scheduled for ancillary services has decreased as batteries have transitioned to providing more energy during the net peak hours.
- **Net market revenue for batteries increased from about $73/kW-yr in 2021 to $103/kW-yr in 2022.** This increase was driven largely by higher peak energy prices.
- **Bid cost recovery payments for batteries increased significantly in 2022**. In 2022 battery resources received 10 percent of all bid cost recovery, while accounting for about 5 percent of capacity in the CAISO market. These payments represent about 7.6 percent of net market revenue for batteries. However, DMM estimates that up to 28 percent of these bid cost recovery payments (approximately $8.4 million) will ultimately be rescinded as the result of a market rule change approved in November 2022. DMM continues to recommend enhancements to the market design of bid cost recovery for batteries.
- **Automated bid mitigation has had minimal impact of the dispatch of batteries.** Although an average of about 200 MW of battery capacity was subject to bid mitigation per hour in summer 2022, changes in bids due to mitigation very rarely had any impact on the level at which batteries were dispatched.
- **A special minimum state-of-charge constraint was used by operators to ensure the availability of batteries in peak net demand hours on most days during the 2022 summer heat wave**. These requirements were nonbinding during most intervals when they were in effect.
- **Batteries were frequently issued manual (or exceptional) dispatches throughout the 2022 summer heatwave**. Most of these exceptional dispatches were to hold charge in anticipation of net peak demand hours. Exceptional dispatches to charge were used largely in response to a software issue that prevented storage resources from bidding to charge at a higher price than $150/MWh, which resulted in those resources not being able to charge even when in merit.
- **Most battery capacity used to meet resource adequacy (RA) requirements during emergency alert hours of the September 2022 heat wave was scheduled or offered as energy or ancillary services.** However, about 20 percent of the total RA capacity being provided by batteries was bid as energy but not dispatched during these periods. Previous analysis by DMM indicates that in practice much of this undispatched capacity may have been unavailable due to various operational constraints related to state-of-charge and other issues.

2 Battery storage market participation

In the CAISO market, storage resources participate under the non-generator resource (NGR) model. NGRs are resources that operate as either generation or load (demand), and bid into the market using a single supply curve with prices for negative capacity (charging) and positive capacity (discharging).

NGRs are constrained by an energy limit to generate or consume energy on a continuous basis. They can produce at any point in their operating range, and can switch immediately between generating and consuming energy. In order to reflect the physical operational capabilities of batteries, the CAISO models minimum and maximum storage capability, upper and lower operating limits, and round-trip efficiency for each storage resource.

For their day-to-day operations, NGRs have the option to use several biddable parameters to manage their state-of-charge. They can submit upper and lower charge limits for each trading day which represent the highest and lowest stored energy values (in MWh) that must be maintained in the resource. For greater control in how their state-of-charge changes throughout the day, resources may use the end-of-hour state-of-charge parameter, described in more detail below in Section 2.1.

NGRs can also submit an initial state-of-charge value to indicate the available energy on the first participation interval of the trading day in the day-ahead market. The market software will default this value to the ending state-of-charge from the previous day if market participants do not submit an initial state-of-charge, or zero MWh if neither are available. One reason that the initial state-of-charge on a given day would differ from the ending state-of-charge from a previous market run is that the market software currently does not model state-of-charge changes due to a battery providing frequency regulation services.

Currently there are two participation frameworks that allow CAISO resources to combine batteries with other generation technologies in their operations: the hybrid and co-located models. However, many resources operate as stand-alone batteries. In this report we define a stand-alone resource as one that does not share a point of interconnection with other resources and does not use multiple generation technologies.

2.1 Multi-interval optimization

The California ISO uses a multi-settlement market design where bidding and dispatch are managed in a set of successive market runs—first in the day-ahead market, then in the real-time market. Each of these markets use a *multi-interval optimization* to effectively dispatch resources such that they are positioned to anticipate future conditions. The day-ahead market optimizes over a 24-hour horizon to determine the least cost way of dispatching resources to meet load.

As part of the CAISO's real-time processes, the fifteen-minute market generates optimal dispatch solutions for up to two hours into the future, and the five-minute market develops solutions for 65 minutes, or up to 13 five-minute intervals. Because of the computational complexity inherent with a large optimization, the length of these time horizons is limited. The CAISO real-time market design includes the settlement of one financially binding interval in the time horizon, leaving remaining intervals as advisory.

Given that storage resources are energy limited, the multi-interval optimization is essential to ensuring that inter-temporal conditions are factored into battery schedules. For example, the multi-interval optimization allows the market to hold state-of-charge, or even dispatch batteries to charge uneconomically in a given interval, in anticipation of higher future prices — so long as those high prices occur within the optimization horizon of its respective market.

In light of the challenges of having a limited optimization horizon, the CAISO proposed measures to help prevent sub-optimal market outcomes as part of its Energy Storage and Distributed Energy Resources (ESDER) Phase 4 stakeholder initiative. The solution proposed in this initiative, and eventually approved by the Federal Energy Regulatory Commission (FERC) in May of 2021, was the end-of-hour state-of-charge (EOH SOC) bid parameter.

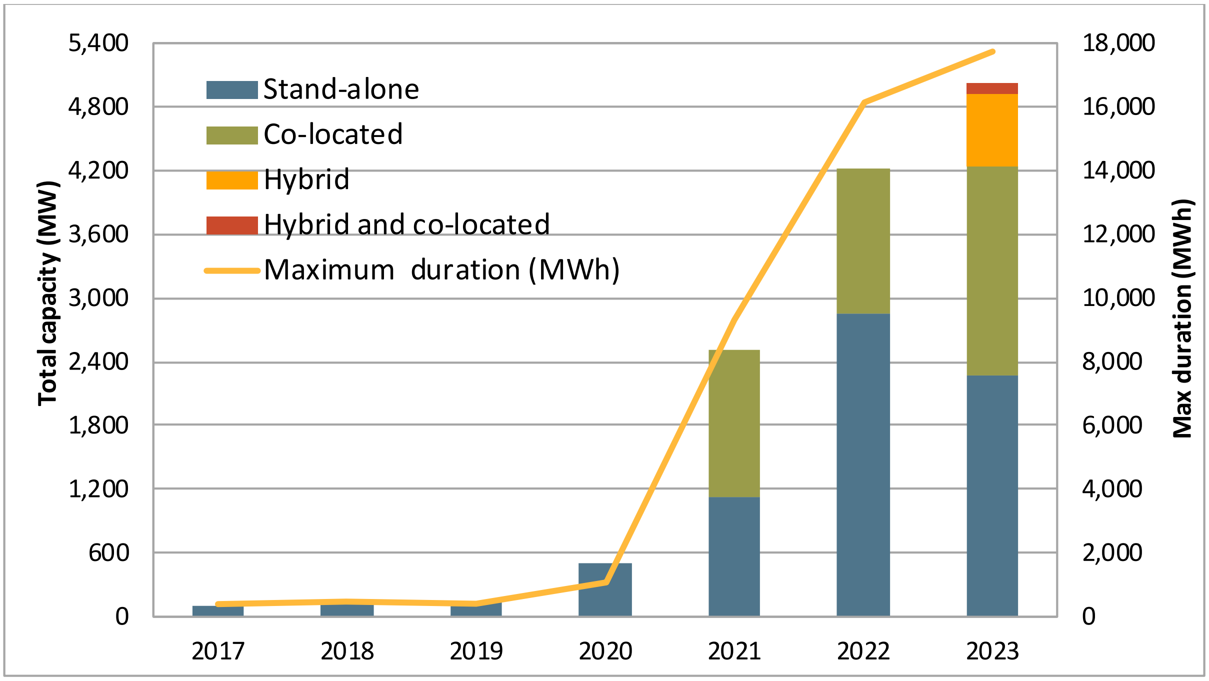
The EOH SOC bid parameter is an optional, real-time-only bid parameter for NGR resources which scheduling coordinators submit hourly as a range with an upper and lower state-of-charge limit. The market dispatches resources such that their states-of-charge end the hour within the submitted range, while respecting minimum and maximum energy bid limits. As noted in the heat wave section of this report, the limited time horizon of the real-time market optimization horizon has still led to undesirable results since the implementation of the EOH SOC bid parameter.

2.2 Capacity

Battery storage capacity has increased dramatically in the CAISO market in recent years. Figure 2.2.1 shows the total capacity of CAISO-participating battery storage as of May 2023, represented in terms of maximum output (MW) and maximum duration (MWh).[2] In May 2023, active battery capacity totaled 5,000 MW—2,200 MW from stand-alone projects, 2,000 MW from co-located projects, 700 MW from the storage components of hybrid resources, and 100 MW from the storage components of co-located hybrids. Total active hybrid capacity, including generation components, was 2,300 MW. For individual battery resources, the minimum power output tends to be the negative value of its maximum power output. The aggregate maximum duration of CAISO's battery fleet reached about 17,700 MWh. The size of active batteries varies widely, ranging from 1 MW to 260 MW. Figure 2.2.2 shows the size distribution of active battery resources. Most batteries in the CAISO market have a duration of four hours.

[2] These values may differ from other battery capacity measures. This metric only includes capacity of participating resources, defined as being scheduled at least once in the respective year. These data track co-located and hybrid status as of December 2021 and February 2023 respectively, though these types of capacity may have been participating sooner.

Figure 2.2.1 Active battery capacity in CAISO area (2017-2023)



Battery storage is the fastest growing type of resource in the CAISO market. As of May 1, 2023, NGR batteries make up 7.6 percent of CAISO's nameplate capacity. Figure 2.2.3 shows the steady growth in CAISO's battery capacity compared with other resource types.

In addition, the majority of projects waiting to connect to the grid contain a battery component. The CAISO requires projects to undergo a series of impact studies before they can be connected to the grid. The list of projects in this process is known as the "interconnection queue." On May 1, 2023, the interconnection queue included nearly 127 GW of planned capacity, 46 percent of which comes from batteries. 55 percent of planned new capacity comes from mixed-fuel projects, which collectively include nearly 11 GW of batteries. Historically, many planned resources drop out before the interconnection process is finished, so much of the capacity currently in the queue is expected to never come online.

Figure 2.2.2 Histogram of battery sizes

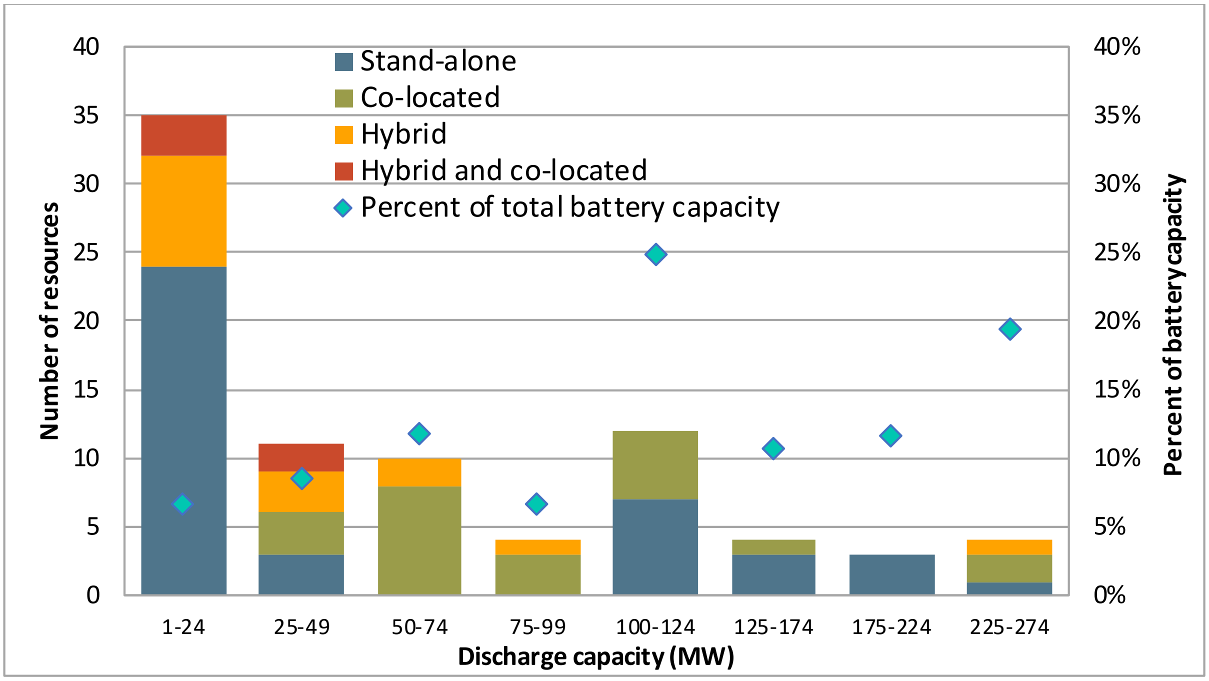
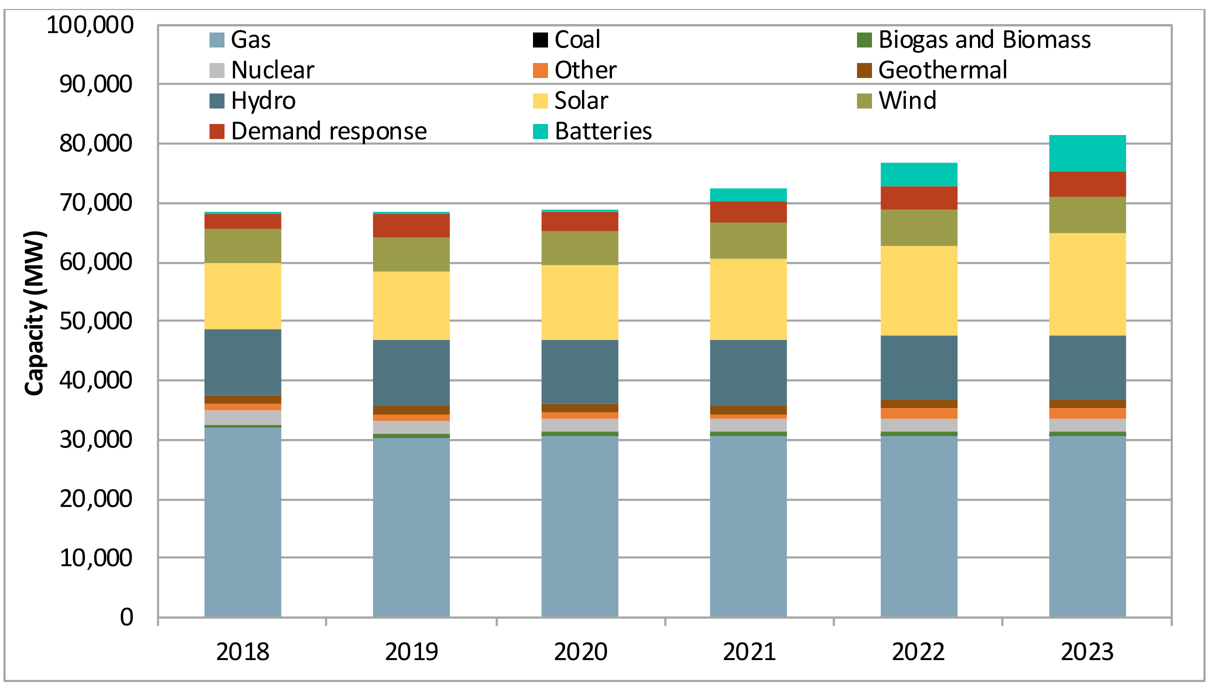


Figure 2.2.3 Total CAISO nameplate capacity by fuel type and year[3]



[3] The bars for 2018 through 2022 show capacity as of June 1. The bar for 2023 shows capacity as of May 1.

2.3 Energy bids and prices

With the CAISO's non-generator resource model, batteries submit a single energy bid curve, which reflects both willingness to charge and discharge. Battery resources do not submit energy price bids solely based on the actual costs of providing energy. Rather, they also consider the *opportunity costs* of discharging or charging in one particular part of the day. For example, discharging energy during low-demand hours may preclude batteries from discharging during high-demand hours. The difference in market prices between low demand and high demand hours can represent an opportunity cost of discharging in lower priced hours.

Batteries participating in the resource adequacy (RA) program—providing either system, local, or flexible resource adequacy capacity—are subject to must-offer obligations, meaning they are required to bid their entire upward RA capacity into the market. These resources tend to manage opportunity cost through their bid prices, rather than by limiting the quantity of their bids. For example, to avoid being dispatched when market prices are low, batteries may submit bid prices to discharge which greatly exceed the prices they paid to charge, especially in earlier hours of the day. Conversely, batteries may submit excessively low downward energy bids to avoid charging in certain hours. This bidding strategy contributes to the negative average charge bids shown in Figure 2.3.1 and Figure 2.3.2—though, currently, only batteries with flexible resource adequacy capacity are subject to must-offer requirements on their downward capacity.[4,5]

[4] California ISO, *Fifth Replacement Electronic Tariff, section 40.10.*6 *Flexible RA Capacity Must-Offer Obligation*, August 15, 2022, p. 102: http://www.caiso.com/Documents/Section40-ResourceAdequacyDemonstration-for-SchedulingCoordinatorsintheCaliforniaISOBalancingAuthorityArea-asof-Feb11-2023.pdf

[5] *California ISO, Fifth Replacement Electronic Tariff, section 40.10.4.1 (d) Energy Storage Resource*, August 15, 2022, p. 92: http://www.caiso.com/Documents/Section40-ResourceAdequacyDemonstration-for-SchedulingCoordinatorsintheCaliforniaISOBalancingAuthorityArea-asof-Feb11-2023.pdf

Figure 2.3.1 Hourly average day-ahead bids and nodal prices (by quarter)

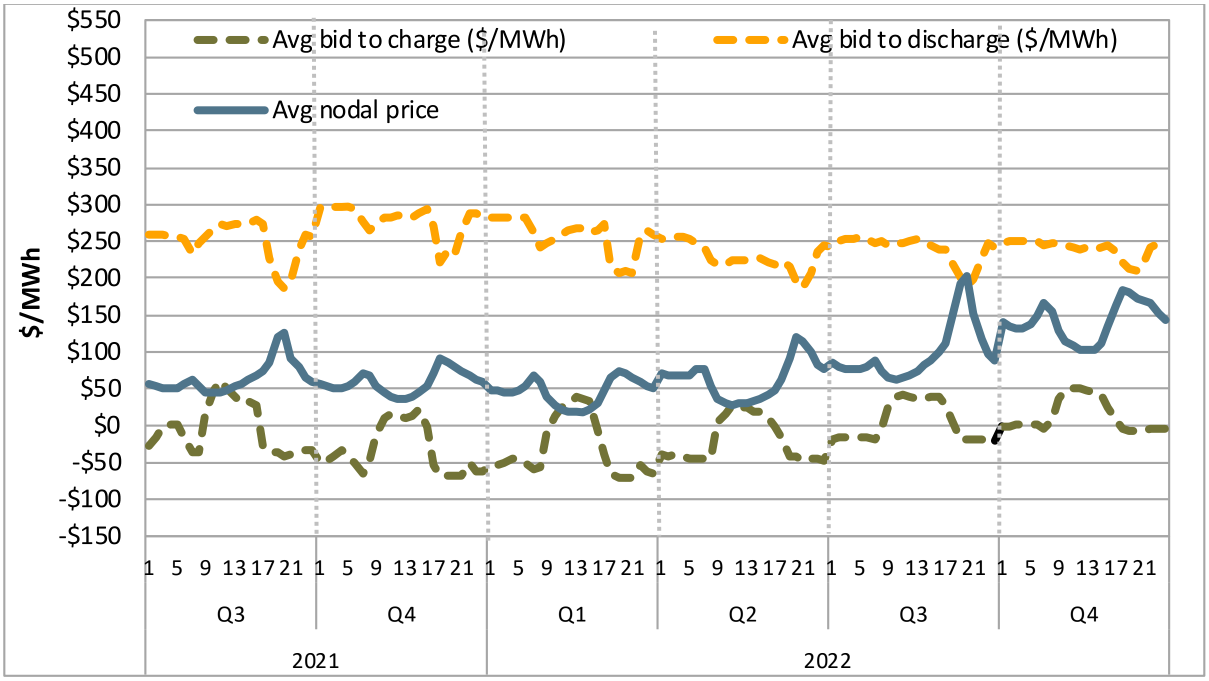


Figure 2.3.2 Hourly average real-time battery bids and nodal prices (by quarter)

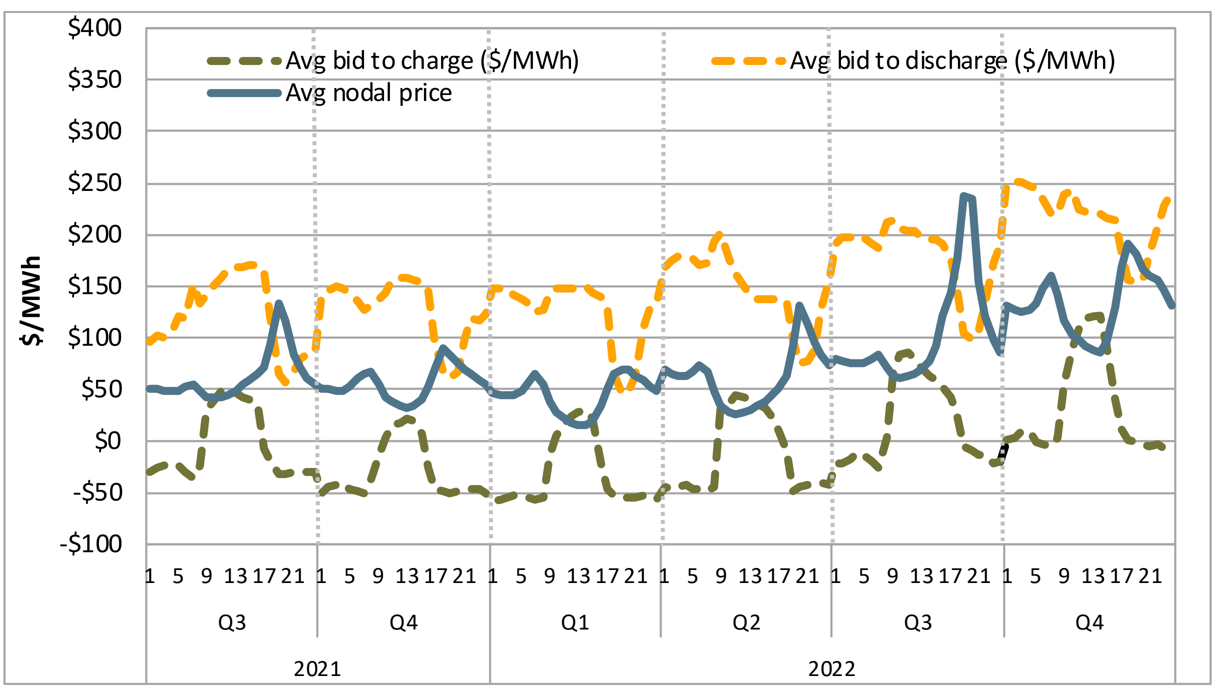


Figure 2.3.1 and Figure 2.3.2 show average energy bids of battery resources compared to average nodal prices by quarter in both the day-ahead and real-time market, respectively.[6] As shown in Figure 2.3.1, the spread of average energy bids remained high throughout 2022 in the day-ahead market. Average bid prices to charge were $96 lower and bids to discharge were $155 higher than the nodal price, with an average bid price spread of $251. The average bid price spread was $190 in 2021.

Figure 2.3.2 shows average real-time bids of battery resources for the portion of a resource dispatch range that is available to the real-time market (i.e., operating range that is not covered by real-time self-schedules or day-ahead ancillary service awards held in real-time). The average price spread in battery bids in the real-time market increased from $119 in 2021 to $167 in 2022. The increasing real-time nodal prices in 2022 coincide with an increase in both charging and discharging bids.

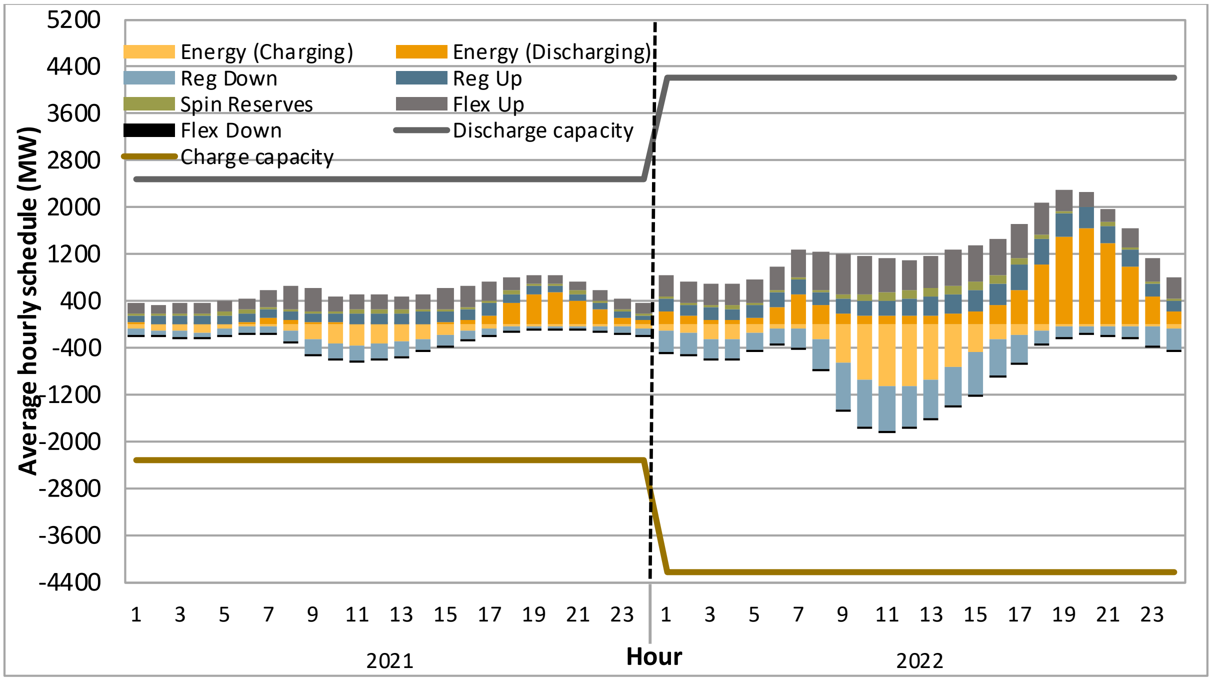
In both the real-time and day-ahead markets, batteries expressed their highest willingness to charge in the afternoon during peak solar production hours, when nodal prices are lowest on average. Batteries submitted their lowest discharging bids for peak demand hours, when their opportunity cost for discharging is lowest.

2.4 Schedules

Figure 2.4.1 shows average hourly real-time (15-minute market) schedules of all battery storage resources in 2021 compared to 2022, as well as aggregate charge and discharge capacity at year-end. Historically, batteries have been scheduled primarily to provide ancillary services. However, the increase in energy provided by batteries has outpaced the growth in their ancillary service schedules since 2021. In peak demand hours, batteries contributed up to 73 percent of their scheduled output to discharging energy on average.

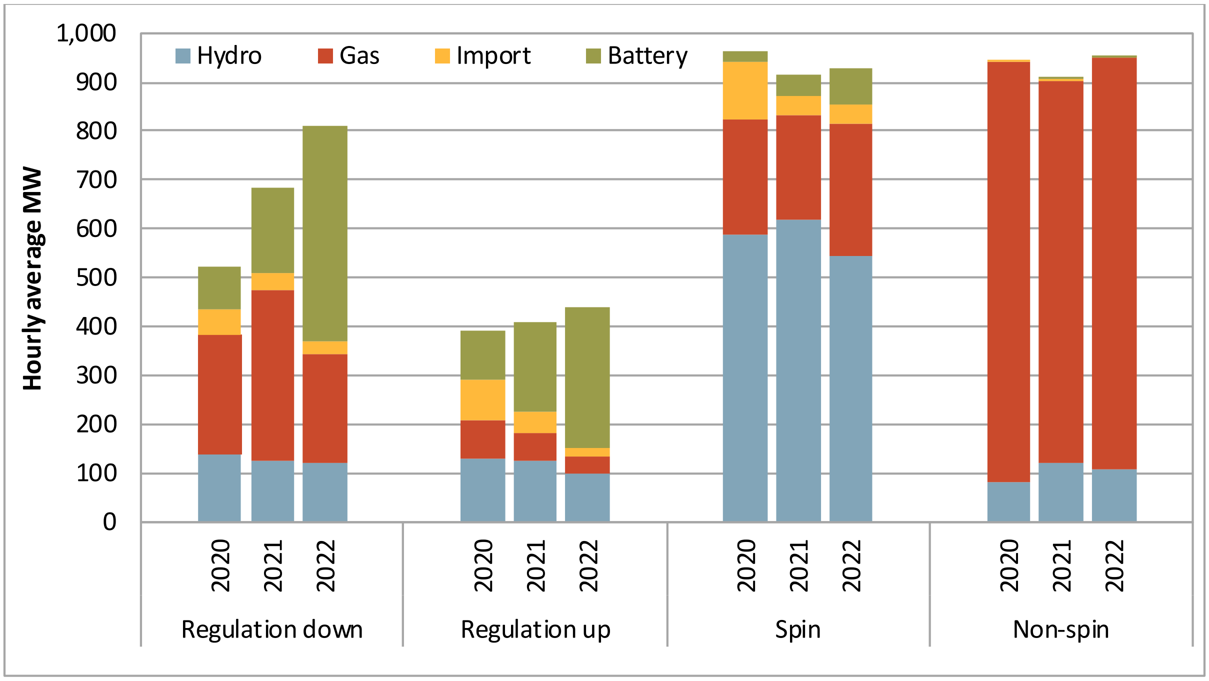
[6] Both bids and nodal prices are weighted average values, weighted by the bid quantity at each price and location.

Figure 2.4.1 Average hourly battery schedules (2021-2022)



While batteries represent a small proportion of CAISO's capacity, these resources provide a relatively large amount of its ancillary services. Figure 2.4.2 shows the portion of ancillary services procured by fuel type from 2020 through 2022. In this period, average hourly procurement of ancillary services served by batteries increased from 212 MW to 802 MW. In 2022, batteries averaged providing the majority of CAISO's regulation requirements for the first time.

Figure 2.4.2 Ancillary service procurement by resource type



Storage resources are also frequently scheduled to provide upward flexible ramping capacity, a product designed to manage volatility and uncertainty of real-time imbalance demand. Both upward and downward flexible capacity are readily available across the CAISO system, and prices for these products rarely go above $0/MWh.[7] Consequently, flexible ramping product contributes only a small proportion of storage resources' market revenue.

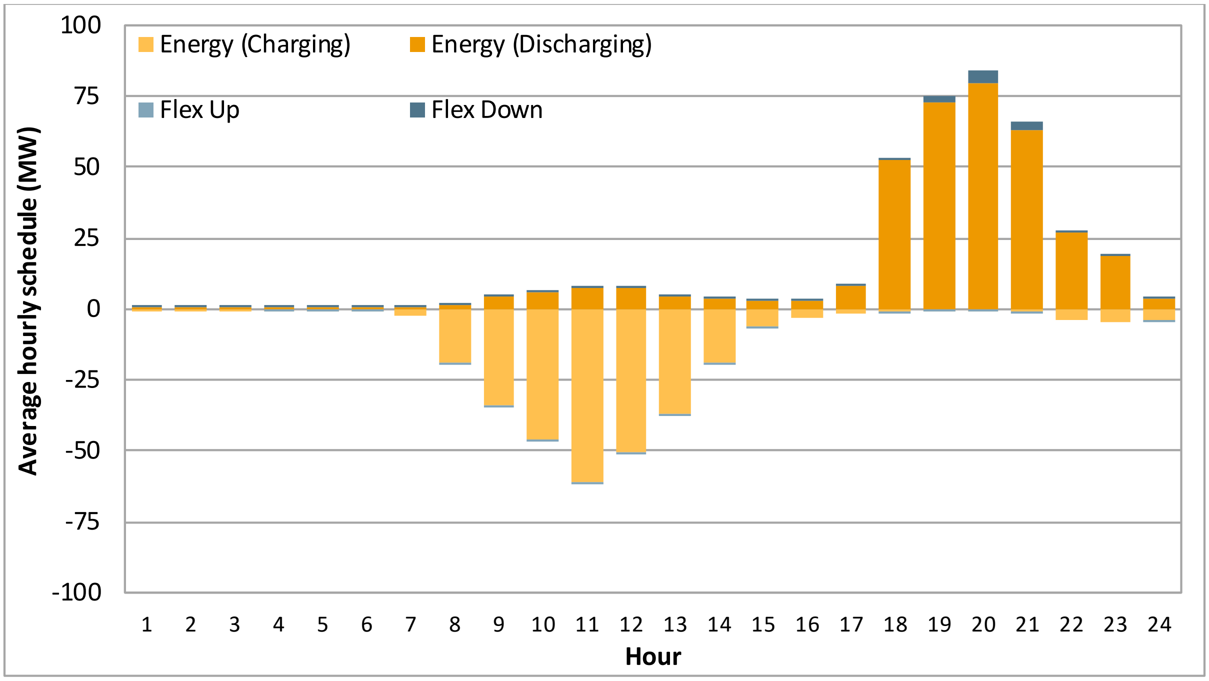
2.5 WEIM capacity and schedules

As of May 1, 2023, there were 20 actively-participating non-CAISO battery storage resources in the Western Energy Imbalance Market (WEIM) with around 1,000 MW of discharge capacity collectively. In comparison, WEIM battery capacity totaled 286 MW in December 2022. Figure 2.5.1 shows that WEIM batteries have somewhat similar schedules to CAISO batteries: primarily charging in morning and early afternoon hours, then discharging in the evening. However WEIM batteries do not have ancillary service schedules, since CAISO does not set ancillary service requirements outside of its balancing area.

In 2022, batteries accounted for less than one percent of generation in the WEIM.

[7] Department of Market Monitoring, *Q2 2022 Report on Market Issues and Performance*, *Section 1.4.2 Flexible ramping product prices*, October 14, 2022, pp. 24-25: http://www.caiso.com/Documents/2022-Second-Quarter-Report-on-Market-Issues-and-Performance-2022-10-14.pdf

Figure 2.5.1 WEIM average hourly battery schedules (2022)



2.6 Mixed-fuel resources

The CAISO accommodates multiple generation technologies at a single point of interconnection using the hybrid model and the co-located model. The primary difference between these designations is that hybrids are modeled as a single resource, whereas the CAISO treats the different components of co-located facilities as separate resources. Resources co-located together do not necessarily need to use different generation technologies—although, as of May 2023, only two out of 22 sets of co-located resources have a single generation technology. There is only one co-located point of interconnection that does not have at least one battery storage component. The CAISO expects significant deployment of *mixed-fuel* resources in its balancing authority area and balancing authority areas participating in the Western Energy Imbalance Market over the next several years, comprised primarily of solar photovoltaic and battery storage or wind and battery storage.

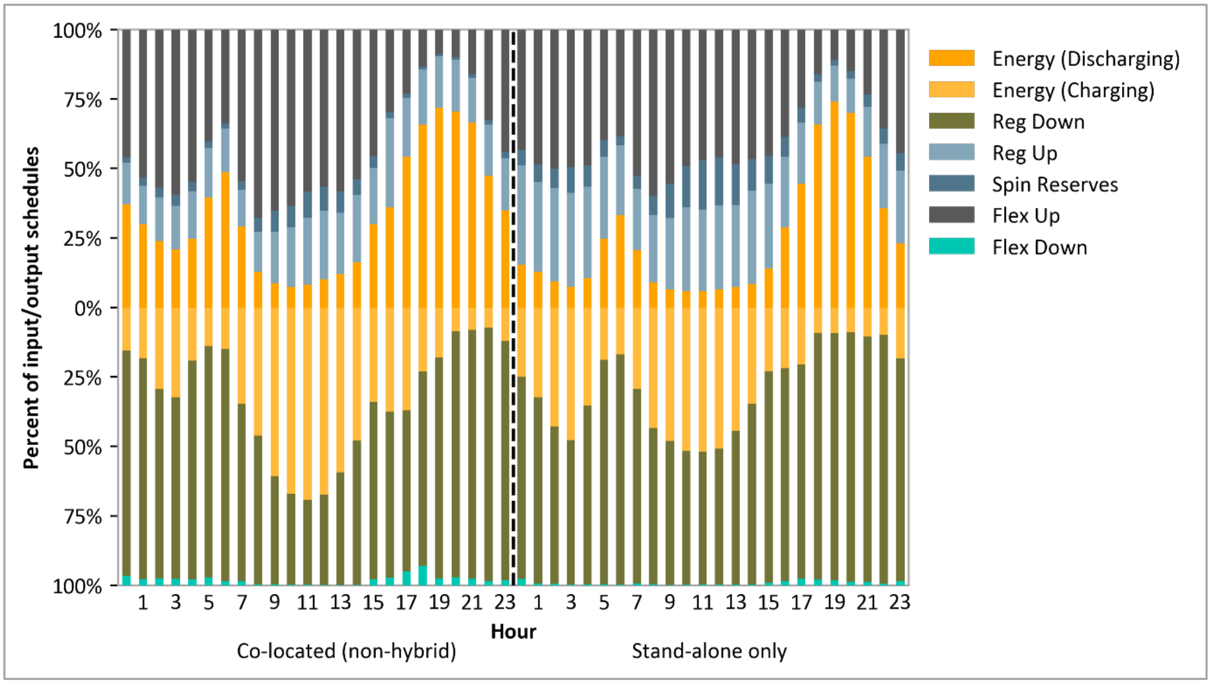
2.6.1 Co-located resources

The most common type of mixed-fuel resources are those participating in CAISO's co-located model. Since they are modeled as separate resources, co-located facilities have separate metering arrangements, submit separate outages, receive separate dispatch instructions, and may be operated by different entities.

The co-located resource model provides several benefits, especially to resources with batteries and renewable generation. By pairing batteries with renewable generation, co-located resources can take advantage of tax incentives, such as the Investment Tax Credit (ITC) which is common in solar projects. In addition, this configuration requires smaller assets for the physical interconnection onto the grid than stand-alone projects, resulting in significant capital savings during project development.

Figure 2.6.1 shows average hourly schedules for active co-located batteries (not including hybrids with battery components) compared to that of active stand-alone battery resources, both in proportion to total average hourly output. Co-located batteries tend to have similar schedules to stand-alone batteries. One difference is that co-located resources tend to have higher charging schedules during midday peak solar hours on average.

Figure 2.6.1 Average hourly schedules: co-located versus stand-alone batteries



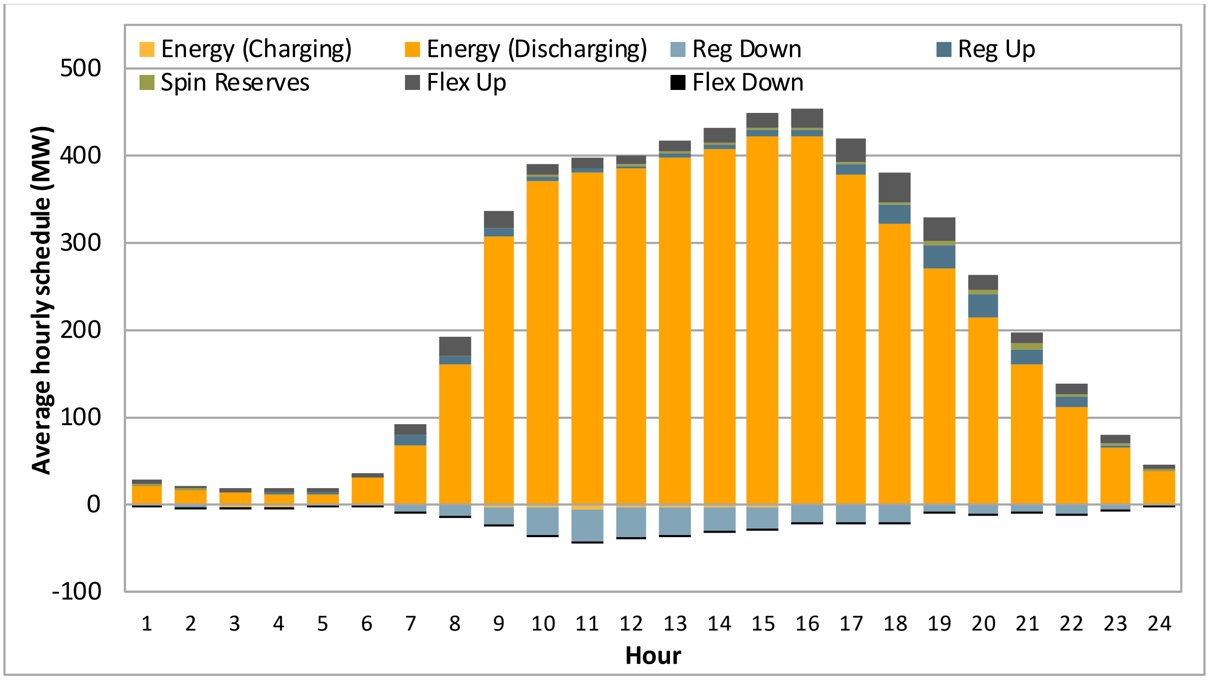
The CAISO has adopted several policy changes to help manage co-located resources participating in the market. In 2021, CAISO implemented the aggregate capability constraint (ACC) functionality to ensure that dispatch instructions to co-located resources behind a common point of interconnection do not exceed interconnection limits. The ACC can also restrict a battery's regulation awards. The CAISO has adopted rules allowing co-located storage resources to deviate from dispatch instructions under certain circumstances in order to allow renewable resources at the same point of interconnection to produce as capable up to the ACC limit. Additional policy changes approved in 2022 will further support capture of ITC incentives by co-located storage resources. These changes will introduce electable functionality that will prevent storage resources from receiving instructions to charge that exceed the dispatch operating target of a renewable resource at the same point of interconnection. These changes will also allow co-located storage resources to deviate from a market charging instruction to avoid grid charging when the actual output of a renewable resource at the same point of interconnection is less than forecasted.

2.6.2 Hybrid resources

Hybrids are modeled as single resources in that they have a single bid curve that applies to all their component parts and receive one dispatch instruction from the CAISO. The hybrid resource operator self-optimizes the components of its resource to meet that dispatch instruction. As of May 2023 there are 25 actively participating hybrid resources with battery technology in the CAISO market.

Figure 2.6.2 shows average hourly real-time (15-minute market) schedules of all active hybrid resources in 2022. Hybrids differ from battery-only resources in that most of their energy schedules occur during the afternoon when solar is abundant. Then, in the evening when solar is unavailable, hybrids can still discharge energy that they have stored in battery components during the day. Currently all registered hybrids participate as NGRs, though only around 30 percent of them have the operational capabilities which would make them eligible to charge from the grid. In 2022, hybrids generally did not receive market awards to charge—rather, they charged from on-site renewables.

Figure 2.6.2 Average hourly hybrid schedules



Whereas CAISO manages the efficient dispatch of individual co-located renewable and storage resources using tools such as renewable forecasts and state-of-charge tracking, the CAISO treats hybrid resources as a black box. Though this feature affords hybrid resources greater discretion in how they manage their generation, the resource operators are still required to respond to dispatch instructions from the CAISO.

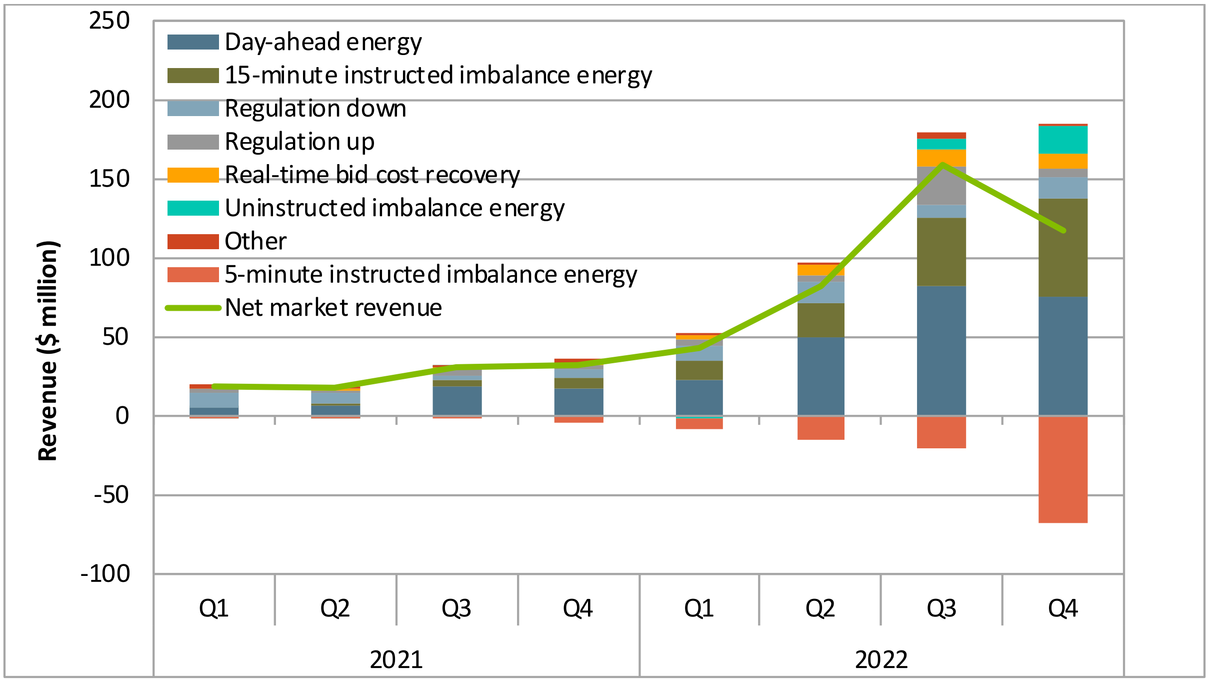
Recent markets enhancements for hybrid resources allow them to alert the CAISO to changes in available output capability in real-time. This allows the market to account for periods where renewable generation is volatile and when storage components are fully depleted or fully charged.

2.7 Market revenue

2.7.1 Overview of storage revenues

Market revenues earned by battery resources have increased in tandem with the rise in participating battery capacity. Figure 2.7.1 shows quarterly battery revenue sources from January 2021 through December 2022. The bars represent net payments to resources from the CAISO for each respective category.[8]

Figure 2.7.1 Quarterly revenues for battery resources (2021-2022)



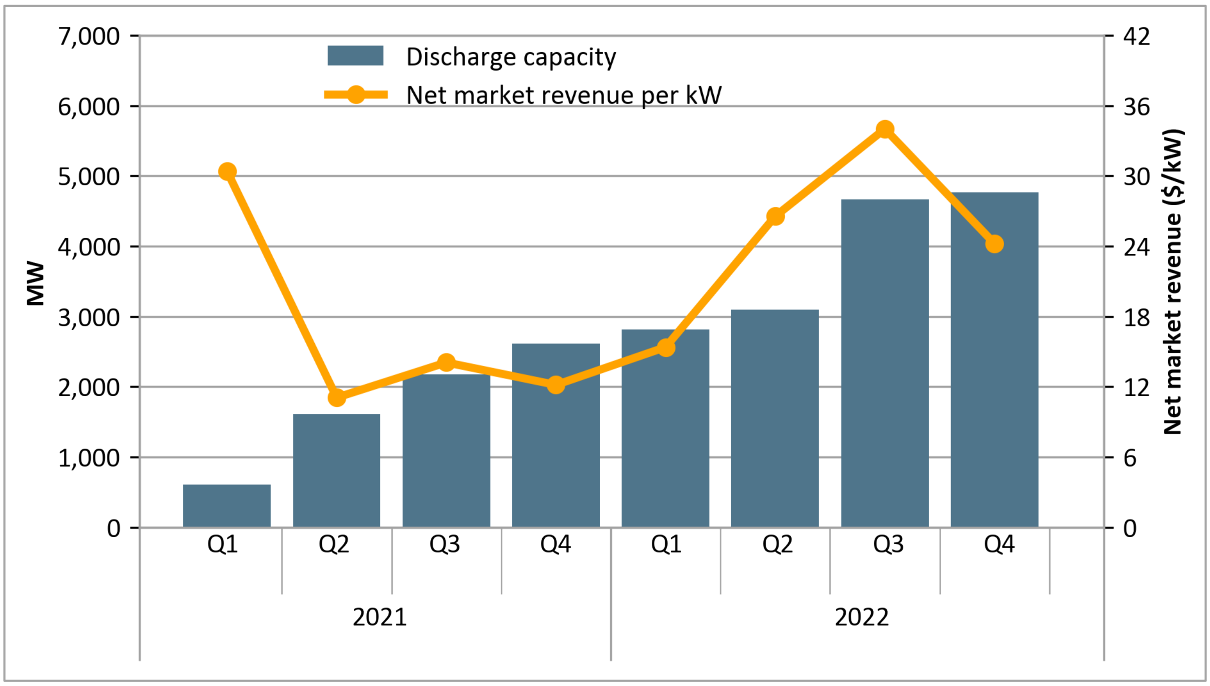
The largest positive revenue category in most recent quarters comes from day-ahead market energy schedules. The instructed imbalance energy (IIE) category includes all incremental and decremental energy from schedules that have either increased or decreased from one market to the next. For example, a resource may receive positive IIE revenue if it receives an award of 50 MW of energy in the fifteen-minute market, and then a 75 MW schedule for that same interval in the five-minute market.

Uninstructed imbalance energy (UIE) revenue results from deviations from energy schedules. In general, resources will not meet their dispatch operating target exactly, and any incremental and decremental imbalance energy is paid and charged at the 5-minute price.

[8] The regulation down category contains payments and charges from settlements codes 6600, 6624, 6670, and 7261. Regulation up includes 6500, 6524, 6570, and 7251. Other includes codes 6100, 6124, 6170, 6194, 6200, 6224, 6270, 6482, 6488, 7050, 7070, and 6630. All other categories consist of single charge codes. More details can be found on the CAISO settlements page: https://www.caiso.com/market/Pages/Settlements/Default.aspx

Figure 2.7.2 shows quarterly net market revenue per kW of capacity in a given quarter.[9] This figure shows net market revenue per kW decreased throughout 2021 and into the first half of 2022 due to the rapid increase in battery capacity. However in the third quarter of 2022, large gains in net market revenue outweighed the steep rise in capacity. This trend partly results from the increasing payments to batteries for frequency regulation, as well as the high energy prices during the 2022 summer heat wave. Net market revenue for batteries during the 10-day heat wave period from August 31 to September 9, 2022 totaled nearly $78 million, about 20 percent of all market revenue for batteries in 2022.

Figure 2.7.2 Net market revenues for batteries

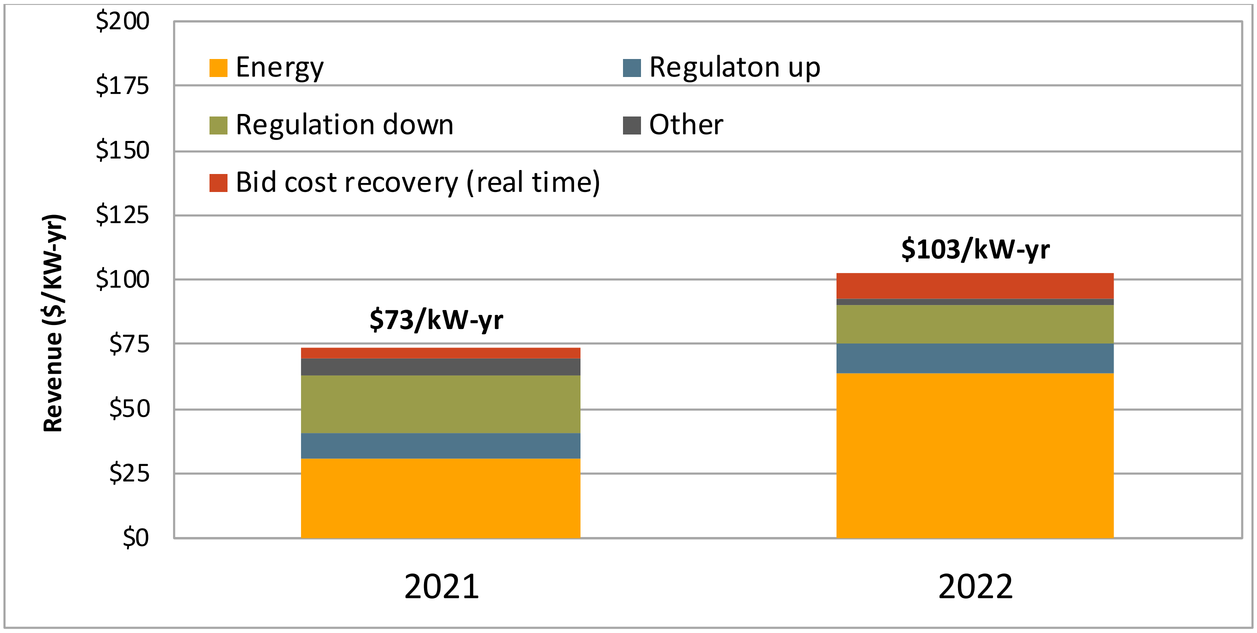


DMM periodically evaluates the performance of battery storage resources though simulations where hypothetical units charge and discharge optimally—subject to operational constraints—based on day-ahead prices.[10] Using 2022 day-ahead prices across 400 pricing nodes, DMM simulated revenues for hypothetical units in two scenarios: where they arbitrage energy only and where they provide both energy and regulation. On average, hypothetical units providing energy and regulation earned $114/kW-yr, with a range of outcomes from $80/kW-yr to $165/kW-yr. In comparison, existing battery resources with a full year of operation averaged $103/kW-yr in 2022, with a range of outcomes from $40/kW-yr to $239/kW-yr. Figure 2.7.3 shows weighted average revenue by category for batteries with a full year of operation.

9 WEIM batteries are included here. Data in some quarters may reflect capacity from resources which switched from LESR to hybrid.

10 The methodology is described in DMM's 2021 Annual report.
Department of Market Monitoring, *2021 Annual Report on Market Issues and Performance*, July 27, 2022, pp. 86-89 http://www.caiso.com/Documents/2021-Annual-Report-on-Market-Issues-Performance.pdf

Figure 2.7.3 Average revenue for batteries with a full year of operation



2.7.2 Bid cost recovery

Generating units are eligible to receive bid cost recovery (BCR) payments if total market revenues earned over the course of a day do not cover the sum of all the unit's accepted bids. This calculation includes bids for start-up, minimum load, ancillary services, residual unit commitment availability, day-ahead energy, and real-time energy.

In 2022, batteries received nearly $30.5 million of bid cost recovery, primarily from the real-time market. Despite the fact that batteries made up only 5 percent of the CAISO's capacity, batteries received nearly ten percent of all BCR settled in 2022. In 2022, real-time BCR per MW of active capacity increased year-over-year by 353 percent. Although BCR for batteries increased significantly in 2022, DMM estimates that as much as $8.4 million of this BCR will be rescinded in future settlements due to a tariff revision approved in November 2022.

Thermal resources face intertemporal constraints in an energy spot market because of certain traits inherent to their generation technology. Combined-cycle combustion turbines, for example, have longer ramping periods and longer minimum run times than other generation types. These resources incur a cost to turn their generator on and move it to the lower operating limit before their dispatch schedules, as well as a cost to serving light or zero loads during their minimum run time. However, only the cost of energy—not these *start-up* and *minimum load* costs—are considered in setting the locational marginal price (LMP) for a given market interval. One use of BCR for traditional generators is to alleviate the risk that the rents from the difference between the LMP and the resource's energy bid costs will provide insufficient revenue to compensate its start-up and minimum load costs. Operating constraints may contribute to energy dispatch at prices less than submitted energy bids as well. BCR is also intended to ensure recovery of these energy bid costs for traditional generators when the total of daily revenues is insufficient to cover the total of all bid costs for the operating day.

Batteries participating as NGRs do not have startup, shutdown, minimum load, or transition costs—and thus lack the traditional drivers of BCR. However, like traditional generators, batteries do incur energy bid costs that may be subject to bid cost recovery. These energy bid costs may include opportunity costs associated with future dispatch intervals. Under the current BCR design, batteries can recover their energy bid costs in various situations where they are uneconomically dispatched.

Many of the limitations on battery dispatch that lead to BCR payments derive from state-of-charge limitations. These state-of-charge limitations can result in uneconomic market dispatches that are eligible for bid cost recovery payments. For example, when a battery does not have sufficient real-time state-of-charge to deliver a day-ahead market award, the real-time market may force an uneconomic buyback of the day-ahead market award. This can lead to payment of real-time BCR. Additionally, batteries may submit limitations on stored energy through minimum or maximum state-of-charge daily bid parameters or through outage cards. When these limitations bind and result in uneconomic dispatch, the resource may be eligible for bid cost recovery payments.

Because current BCR rules were designed for traditional generators and do not consider state-of-charge limitations or other physical characteristics of batteries, some BCR payments to batteries may be inappropriate. For example, in the case of outages, traditional generators are ineligible for bid cost recovery of costs associated with a derate or outage. However, batteries can effectuate outages through minimum or maximum stored energy values, without the use of any megawatt derate. In this situation, the battery may remain eligible to recover bid costs associated with the outage because the resource does not have a megawatt derate and the rules to exclude BCR under these circumstances do not consider state-of-charge. Other situations exist where a battery may directly impose state-of-charge limitations that can lead to bid cost recovery payments. Batteries may also take actions to prevent charging or discharging in earlier intervals to restrict state-of-charge in later intervals in a manner that leads to undeliverable day-ahead schedules. These scenarios can contribute to inefficient market outcomes and additional BCR payments, and may be susceptible to gaming.

DMM has recommended in earlier stakeholder comments, and continues to recommend, that the CAISO enhance bid cost recovery rules for storage resources to consider state-of-charge limitations and other attributes unique to storage resources. The CAISO has implemented one targeted market enhancement to eliminate one source of inappropriate BCR for batteries. In November of 2022, the Federal Energy Regulatory Commission (FERC) approved a market rule change that precludes batteries from receiving BCR in situations where they are uneconomically dispatched by the market software in order to maintain a sufficient state-of-charge to fulfill ancillary service awards. As DMM has noted previously, the primary purpose of BCR is not for general cost recovery in every situation.[11]

Though battery resources face an additional cost of providing regulation that traditional resources do not—that of real-time charging and discharging to maintain the capability to provide regulation given their limitations—DMM has argued that it is inappropriate for batteries to receive BCR in these circumstances and that it would lead to inefficient outcomes. DMM estimates that up to 75 percent of BCR paid out to storage resources in certain periods came from uneconomic dispatches related to ancillary service awards.[12] DMM further estimates that this cause may account for up to $19.6 million

11 Department of Market Monitoring, *Comments on Price Formation Enhancements Issue Paper*, August 11, 2022, p. 10: http://www.caiso.com/Documents/DMM-Comments-Price-Formation-Enhancements-Issue-Paper-Aug-11-2022.pdf

12 Department of Market Monitoring, *Motion to Intervene and Comments of the Departments of Market Monitoring of the California Independent System Operator Corporation*, September 19, 2022, pp. 3-4: http://www.caiso.com/Documents/Motion-to-Intervene-Comments-ER22-2881-Energy-Storage-Bid-Cost-Recovery-Sep-19-2022.pdf

(approximately 64 percent of total) BCR paid to batteries in 2022, although up to $8.4 million is subject to rescission at a later date. This rule change applies retroactively, effective September 20, 2022.

2.8 Ancillary services

The California ISO procures four ancillary services in the day-ahead and real-time markets: regulation up, regulation down, spinning reserve, and non-spinning reserve. The CAISO uses regulation up and regulation down to maintain system frequency by balancing generation and demand. Spinning and non-spinning resources, collectively known as operating reserves, are used to maintain system frequency stability during emergency operating conditions and major unexpected variations in load.

Hybrid and NGR resources may provide ancillary services. Hybrid resources are required to manage their state-of-charge such that they have sufficient headroom (either upward or downward) to fulfill their ancillary service awards. When batteries modeled as NGR are awarded ancillary services, the day-ahead and real-time markets enforce constraints to manage state-of-charge to ensure the deliverability of the awarded ancillary services for the duration required by the CAISO tariff. These constraints are referred to as the ancillary services state-of-charge constraints (ASSOC).

When a resource is providing either regulation up or regulation down it will respond to four-second automatic generator control (AGC) instructions, which impacts state-of-charge. This results in discrepancies between day-ahead and real-time state-of-charge, and can result in the ASSOC binding in real-time to charge or discharge storage resources so that they are able to fulfill regulation awards.

The impact of ancillary service awards is not currently reflected in market state-of-charge modeling. This can result in the ASSOC binding more frequently, and can contribute to many consecutive hours of day-ahead ancillary awards that may become infeasible in real-time. In 2022, the CAISO developed market enhancements designed to improve the modeling of ancillary service impacts on battery state-of-charge.[13]

Initially, batteries favored providing ancillary services, especially frequency regulation, because it allows them to avoid deep charging and discharging cycles which cause rapid cell degradation. In the last two years, regulation services offered by batteries have increased significantly. Figure 2.8.1 shows how batteries have consistently offered many times more regulation than the market requires since the start of 2022.

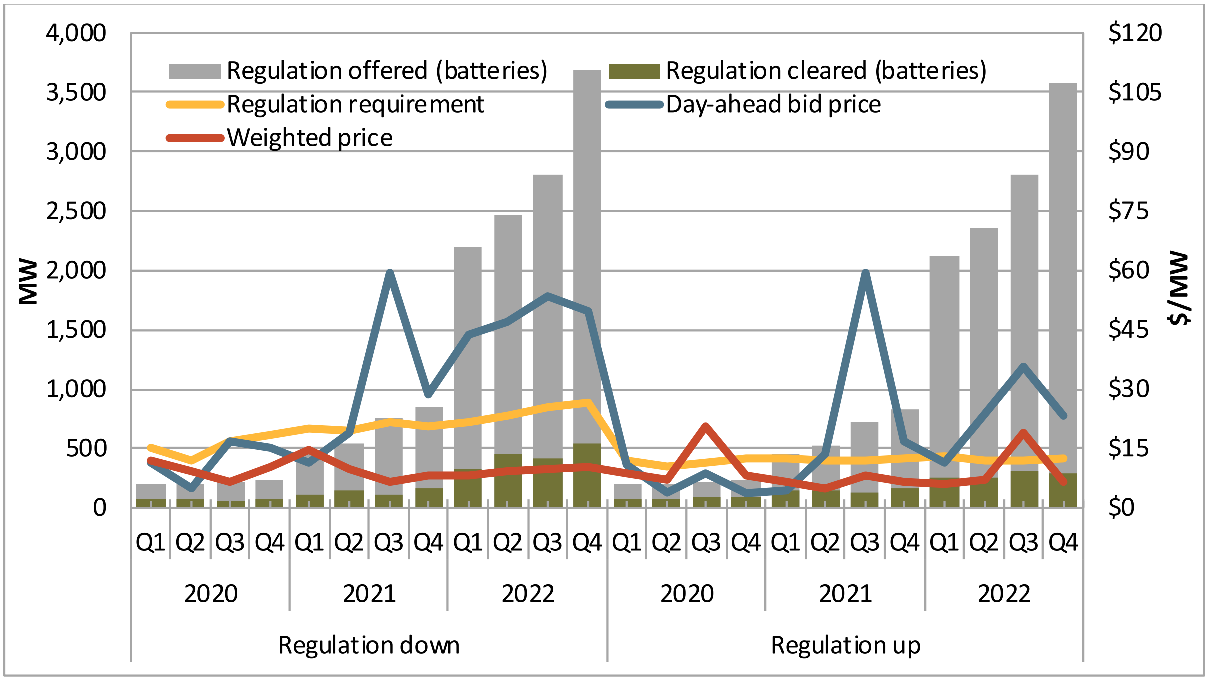
The CAISO has reported on an increasing frequency of resources—especially batteries—that fail to deliver awarded regulation in real-time.[14] In these instances, resources either fail to connect to AGC or do not follow the AGC signals. In February 2023, some scheduling coordinators failed to provide scheduled regulation down in over 20 percent of real-time intervals.[15]

13 California ISO, *Energy Storage Enhancements Final Proposal*, October 27, 2022: http://www.caiso.com/InitiativeDocuments/FinalProposal-EnergyStorageEnhancements.pdf

14 California ISO, *Market Performance and Planning Forum*, March 16, 2023, slides 42-47: Presentation-MarketPerformancePlanningForum-Mar16-2023.pdf (caiso.com)

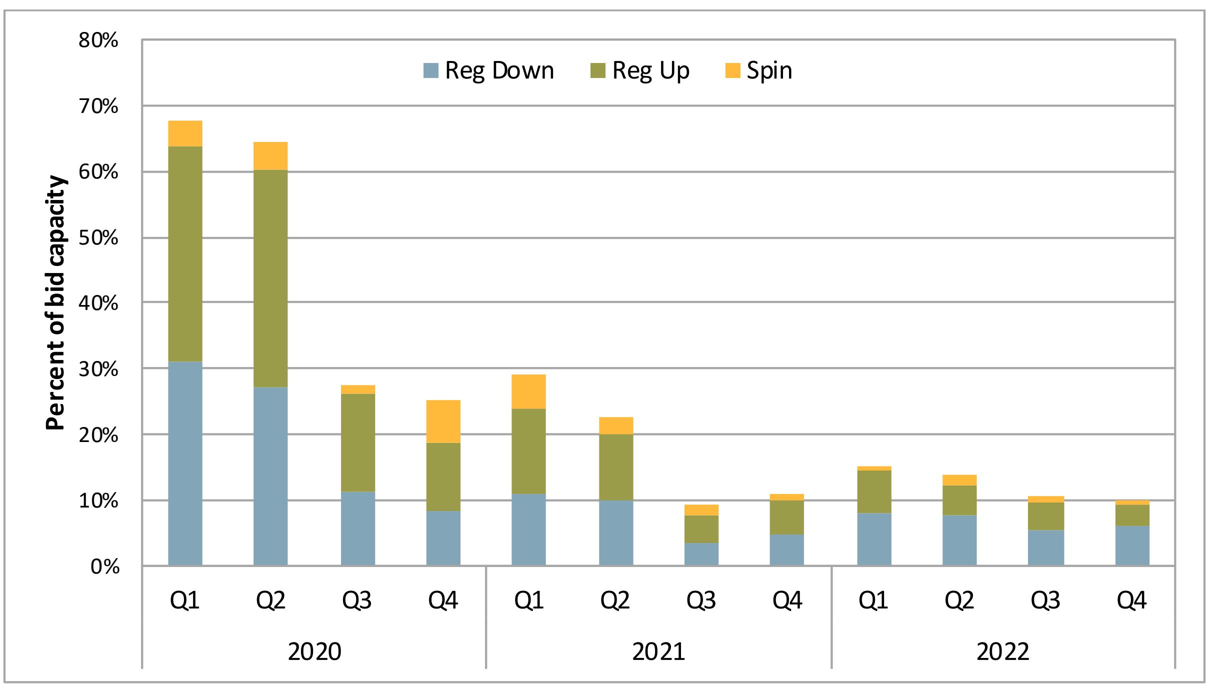
15 Ibid. p. 47.

Figure 2.8.1 Day-ahead regulation requirements met by battery storage



With many more battery resources online, ancillary services provided by batteries have actually decreased as a proportion of their total capacity. Figure 2.8.2 shows that ancillary services have gone from taking up the majority of battery capacity to only a small fraction.

Figure 2.8.2 Percent of battery capacity scheduled for ancillary services



2.9 Resource adequacy

California's resource adequacy program is designed to ensure the California ISO system has enough resources to operate the grid safely and reliably in real-time and to provide incentives for the siting and construction of new resources to operate the grid reliably in the future.

The state's resource adequacy (RA) program uses a metric called net qualifying capacity (NQC) to represent the maximum MW capacity that all resources—including batteries—can sell to an LSE to meet its resource adequacy obligations each month. The CPUC determines the NQC of batteries participating in the NGR model based on testing of their sustained output over a four-hour period. Batteries with a longer discharge duration do not receive a different amount of credit for RA capacity than those that can only provide energy for four hours.

The CPUC calculates capacity for hybrid and co-located resources differently than either stand-alone renewables or stand-alone storage resources.[16] Currently, the CPUC uses an electric load carrying capability (ELCC) methodology to assign resource adequacy values to solar and wind resources. This methodology applies an "effectiveness factor" to the nameplate value of the resource to determine the resource adequacy capacity value for which the renewable resources count.

According to the CPUC's methodology, the qualifying capacity value of the renewable component of the mixed-fuel resource is determined by applying the ELCC percentage to the difference between the renewable's nameplate capacity and the capacity needed to charge the battery at a constant rate over the available charging hours. As a result, hybrid and co-located resources receive less qualifying capacity than identically sized stand-alone resources. The qualifying capacity value of the storage component of mixed-fuel resources is based on the maximum deliverable capacity of the battery or the renewable charging energy transferred to the battery in the allotted time period divided by four if the battery is not expected to fully charge.

Resources benefit by participating in the RA program by getting capacity payments when they contract with LSEs. However, RA resources are subject to numerous additional requirements when participating in the CAISO market. For example, RA storage resources are subject to a minimum state-of-charge (MSOC) requirement on days with Residual Unit Commitment (RUC) infeasibilities, which is described in the heat wave section of this report.[17]

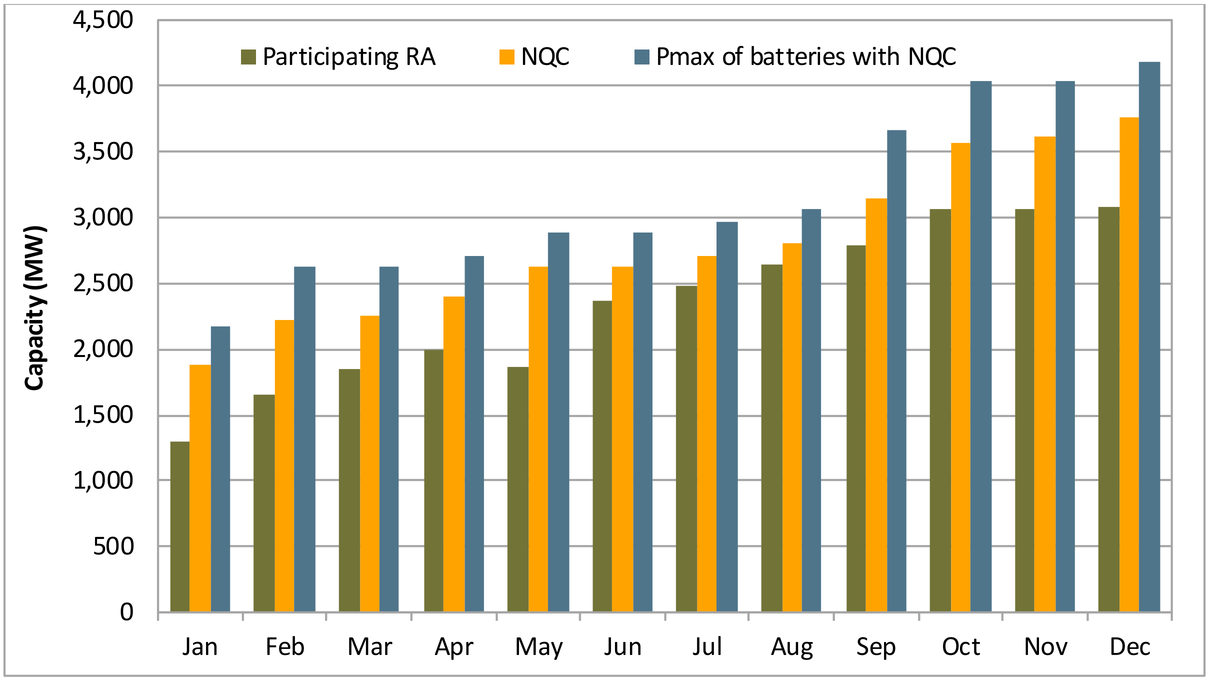
Figure 2.9.1 shows month-end participating RA capacity, aggregate battery NQC, and total nameplate battery capacity for 2022.[18] In total, batteries contributed 69 to 95 percent of their available NQC towards RA, depending on the month. In December 2022, 12 of the 64 active battery resources—with around 550 MW of total nameplate capacity—contributed no capacity towards RA.

[16] California Public Utilities Commission, *2020 Qualifying Capacity Methodology Manual*, November 2020, pp. 19-21: https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/q/6442466773-qc-manual-2020.pdf

[17] The Residual Unit Commitment (RUC) process is a reliability function for committing resources and procuring capacity in order to cover shortfalls between forecasted demand and day-ahead market schedules.

[18] For battery nameplate capacity we count any battery which has a NQC rating from the CPUC.

Figure 2.9.1 2022 RA battery capacity



The CAISO has proposed several market enhancements to improve RA battery performance which are currently undergoing a stakeholder process. One enhancement specifies that storage and hybrid resources would be subject to a must-offer obligation that reflects both the charging and discharging capabilities of the resource so that the market can fully optimize the resource's full range. Currently, batteries are not required to offer their charging capacity into the market in most circumstances.

The initial enhancement proposal includes a stipulation that hybrid resources have access to a dynamic limit tool to inform the CAISO about unavailability, since on-site generation or storage is often unavailable. Generation capacity may be unavailable while on-site storage components are being charged, when ambient temperatures impact generation equipment, or simply because of the intermittent nature of the hybrid's VER components. Likewise, hybrids may have conditions when storage components are completely charged or completely depleted, precluding the resource from dispatch in a portion of its operating range.

2.10 Local market power mitigation

As part of its day-ahead and real-time market processes, the CAISO includes local market power mitigation (LMPM), an automated procedure meant to ensure that resources are providing energy at or near their cost of production. Beginning in November 2021, battery resources using the non-generator resource (NGR) model became subject to mitigation. Storage resources with five MW or less of capacity and whose parent company is not a net-supplier in the CAISO market are exempt from mitigation. Hybrid resources are currently exempt from mitigation regardless of size. As with all resource types, batteries are subject to mitigation based on when they can provide counterflow to relieve congestion on a binding non-competitive transmission constraint.

Unlike other resource types, NGR storage resources may bid negative MW (for charging), and thus are subject to mitigation on their negative (charging) bids as well as their positive (discharging) bids. Assuming competitive market conditions exist, batteries are incentivized to charge during times that maximize energy arbitrage spread. Competitive energy bids on the charging portion of the bid curve should reflect the opportunity cost of forgoing charging at a given point in time. If a resource submits very low charging bids, the resource will be less likely to receive a charging award, and the low bid reflects a low cost of forgoing charging.

However, if a resource submits a very high charging bid, the resource will be more likely to receive a charging award, which reflects a high cost of foregone charging. A resource can potentially withhold counterflow to a non-competitive constraint by submitting a high charging bid to charge when it may be uneconomic to do so. When the resource is mitigated, the charging bid can be lowered, resulting in the battery not receiving a market charging award. When charging is not awarded, flow on the non-competitive constraint is reduced.[19]

Figure 2.3.1 and Figure 2.3.2 in Section 2.3 of this report show that, on average, charging bids are lower than nodal prices in most hours of the day. Consequently, as shown in Figure 2.10.1, charging bids were rarely changed by mitigation in either the day-ahead, fifteen-minute, or five-minute markets in 2022.

As with other resource types, bids are only changed during the LMPM processes if a resource has bid higher than their default energy bid (DEB) and the competitive LMP at the resource's location. NGR storage resources have the opportunity to choose a "storage option" for their DEB calculation.[20] Around 74 percent of active CAISO batteries that are subject to LMPM have opted for the storage DEB. The day-ahead and real-time market storage DEBs are calculated using Equation 2.10.1 and Equation 2.10.2, respectively.

Equation 2.10.1 Day-ahead market storage DEB

$$\boldsymbol{DAM\ DEB} = \left\{\boldsymbol{Max}\left(\boldsymbol{En}_{\frac{\delta}{\eta}}, \mathbf{0}\right) + \boldsymbol{\rho}\right\} * \mathbf{1.1}$$

Equation 2.10.2 Real-time market storage DEB

$$\boldsymbol{RTM\ DEB} = \boldsymbol{Max}\left\{\boldsymbol{Max}\left(\boldsymbol{En}_{\frac{\partial}{\eta}}, \mathbf{0}\right) + \boldsymbol{\rho},\ \boldsymbol{OC}_{\gamma}\right\} * \mathbf{1.1}$$

Where:

En: Energy cost

δ: Energy charging duration

[19] Battery storage resources could also potentially exercise market power in future intervals by submitting uneconomic low charging bids to withholding charging in the current interval. This could result in the battery being unable to discharge in a future interval when it has local market power in that interval. Mitigation of these bids would involve increasing charging bids to a level higher than submitted. This type of mitigation does not currently exist in the CAISO market.

[20] California ISO, *Business Practice Manual Change Management, Market Instruments, Appendix D.9, Storage Default Energy Bid*: https://bpmcm.caiso.com/Pages/BPMDetails.aspx?BPM=Market%20Instruments

γ: Energy discharge duration
η: Round-trip efficiency
ρ: Variable storage operation cost
OC: Price-based opportunity cost

The energy cost component of the storage DEB is calculated under the assumption that the resource performs one cycle of charging and discharging per day and that it will charge during the least expensive continuous block of time during the day. Resources may have individualized variable operation costs, which are validated by the CAISO. These costs often reflect a conservative estimate of potential cell degradation costs that may be incurred should the battery cycle multiple times per day.

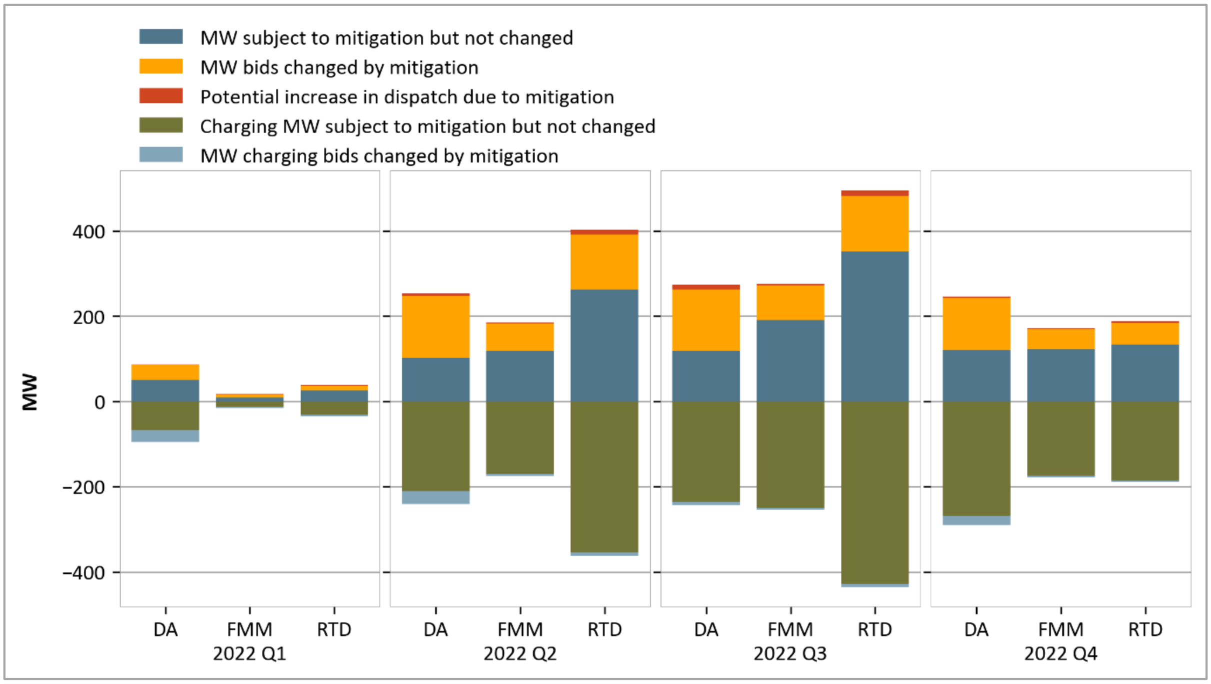
The real-time storage DEB includes a priced-based opportunity cost parameter which is meant to prevent mitigated batteries from being dispatched at a time that is not profit-maximizing over the day. The opportunity cost component for a given resource is set to the N^{th} highest day-ahead LMP, where N equals the discharge duration of the resource in hours. For example, if a storage resource has a four hour discharge duration, the opportunity cost will be the fourth highest day-ahead LMP.

Recent market enhancements proposed by the CAISO include adding an opportunity cost component to the day-ahead market storage DEB, using the same calculation as the real-time DEB.[21]

Figure 2.10.1 shows average quarterly battery mitigation by market in 2022. Batteries were subject to mitigation more often in the second and third quarters of 2022, especially in the five-minute market. In cases where resources' bids were changed by mitigation, the bids were most often changed to the DEB. Changed bids from batteries were mitigated to the DEB four times more often than to the competitive LMP in the five-minute market and five times more often than the competitive LMP in the fifteen-minute market. Bids changed by LMPM were switched to the DEB about 20 percent more than the LMP in the day-ahead market.

[21] These changes were approved by the CAISO Board of Governors in December 2022 and are currently pending FERC filing and acceptance. See *Energy Storage Enhancements - Final Proposal*, p. 27, California ISO, October 27, 2022: http://www.caiso.com/InitiativeDocuments/FinalProposal-EnergyStorageEnhancements.pdf

Figure 2.10.1 Quarterly battery mitigation



3 September 2022 heat wave

Between August 31 and September 9, 2022, the combined CAISO and WEIM system experienced a prolonged heat event. This period was marked by record setting extremely high temperature weather conditions across most of the Western United States. This section describes battery participation during and around the heat wave period and reviews previous findings related to battery storage from DMM and the California ISO.[22, 23]

3.1 Overview of storage participation

During the heat wave, batteries tended to offer a large portion of both their upward and downward capacity into the market. Figure 3.1.1 shows average hourly real-time (15-minute) schedules of NGR battery resources with battery capacity as of September 9. Table 3.1.1 shows how the average schedules for peak hours during the heat wave compared to peak-hour battery schedules in 2022 overall. Average output schedules—including energy discharging, regulation up, spinning reserves, and flex ramp up—tended to decrease (compared to 2022 overall) early in the day to allow batteries to charge.

As shown in Figure 3.1.1 and Table 3.1.1, charging and discharging schedules both increased during peak hours of the heat wave compared to the annualized trend, although charging schedules remained low overall in these intervals. Regulation up schedules increased significantly during peak hours of the heat wave, while regulation down schedules decreased on average. Batteries provided a significant share of the market's regulation during the heatwave, and even provided all of its regulation in some intervals.[24] On average, scheduled battery output was at most 82 percent of available capacity.

Figure 3.1.2 and Figure 3.1.3 show average energy bids of battery resources compared to average nodal prices during the heat wave in both the day-ahead and real-time market, respectively.[25] In both the real-time and day-ahead markets, storage resources had a higher willingness to charge during the morning and early afternoon hours. In the day-ahead market, bids to discharge remained fairly constant throughout the day. Although storage resources bid much higher than usual, on average batteries tended to bid below the average nodal price during peak demand hours. In fact, average discharge bids actually decreased during peak hours in the real-time market.

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22 Department of Market Monitoring, *Q3 2022 Report on Market Issues and Performance, Section 3 Western region heat wave*, December 14, 2022: http://www.caiso.com/Documents/2022-Third-Quarter-Report-Market-Issues-Performance-2022-12-14.pdf

23 California ISO, *Summer market performance report - Sept 2022*, November 2, 2022: http://www.caiso.com/Documents/SummerMarketPerformanceReportforSeptember2022.pdf

24 Ibid, p. 148.

25 Both bids and nodal prices are weighted average values, weighted by the bid quantity at each price and location.

Figure 3.1.1 Average hourly battery schedules (August 31-September 9, 2022)

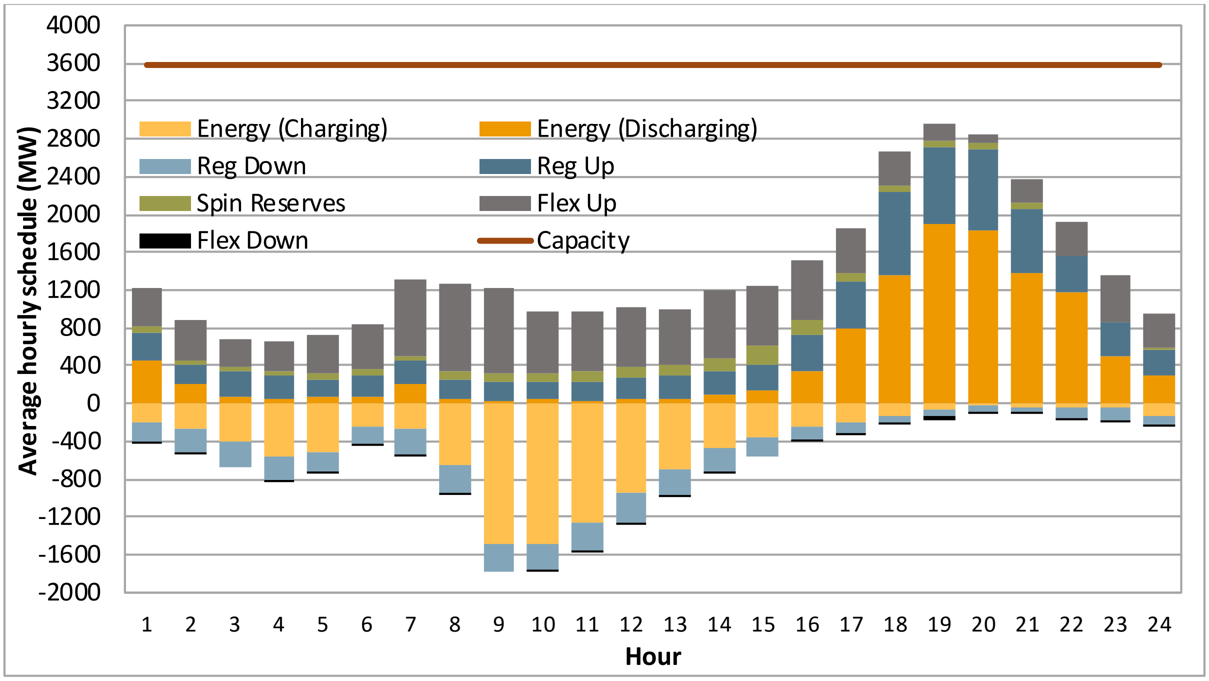


Table 3.1.1 Percentage difference between average heat wave schedules and average 2022 schedules

Hour	Energy (Charging)	Energy (Discharging)	Reg Down	Reg Up
16	6%	-0.7%	-79%	-0.4%
17	13%	37%	-74%	4%
18	45%	33%	-76%	100%
19	64%	26%	-61%	102%
20	12%	12%	-48%	137%
21	161%	-1%	-65%	119%

Figure 3.1.2 Average day-ahead battery bids and nodal prices (August 31 – September 9, 2022)

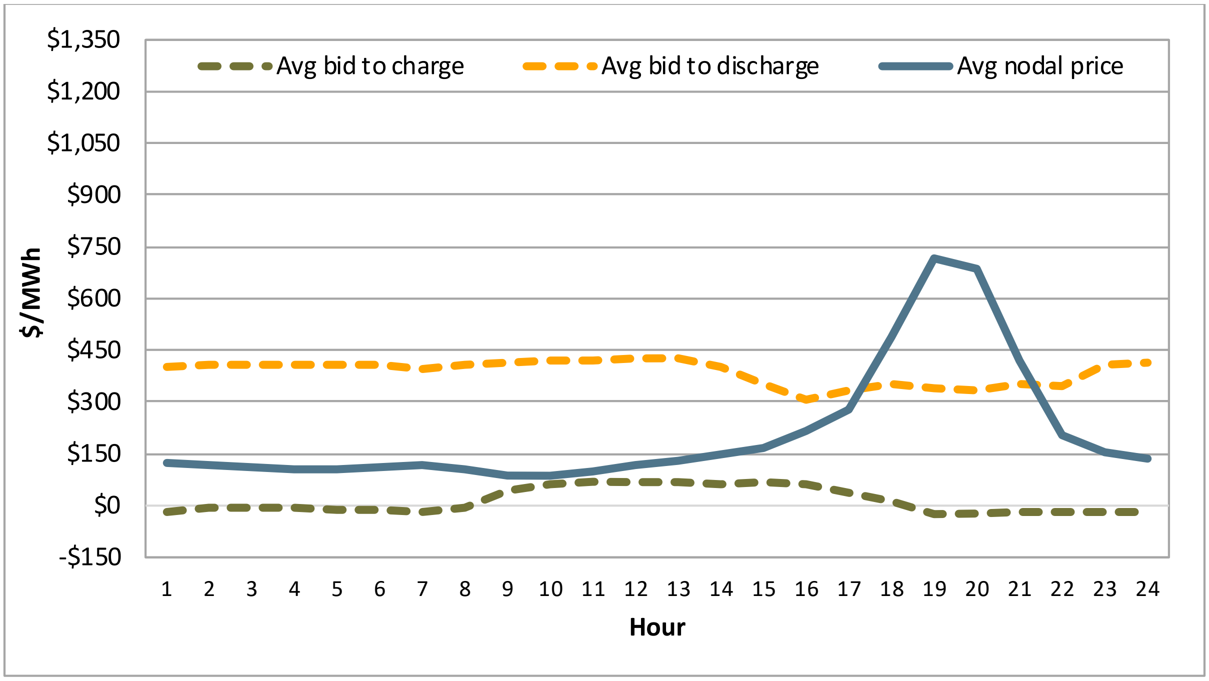
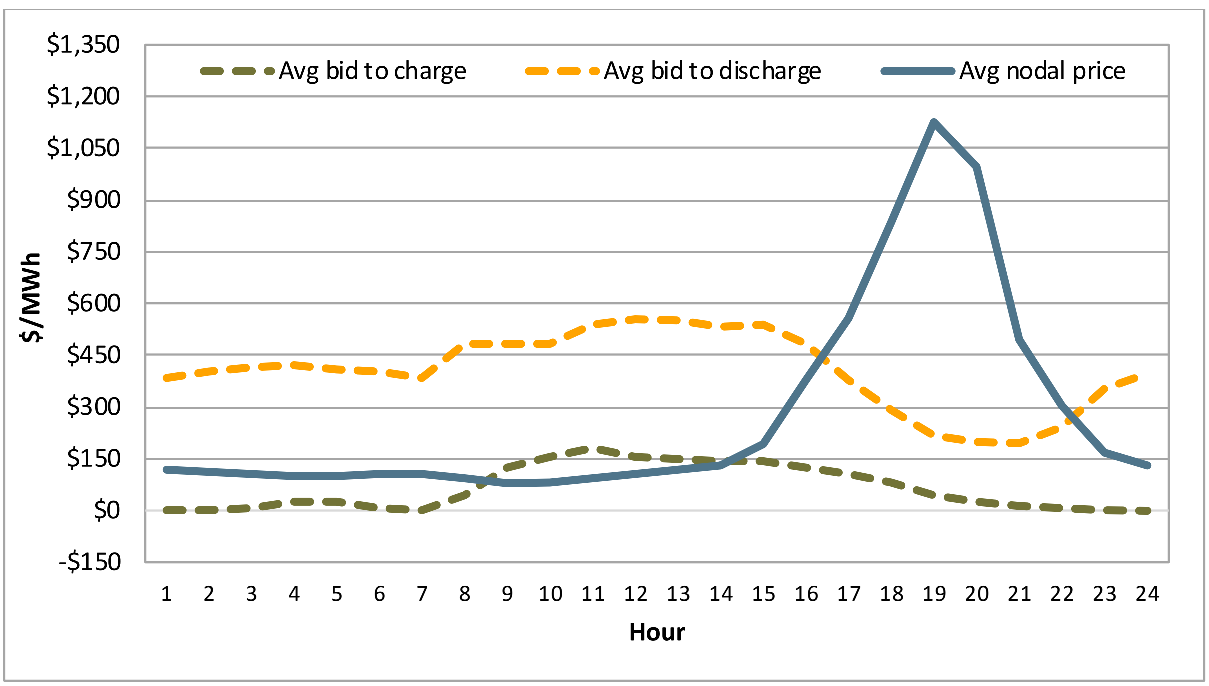
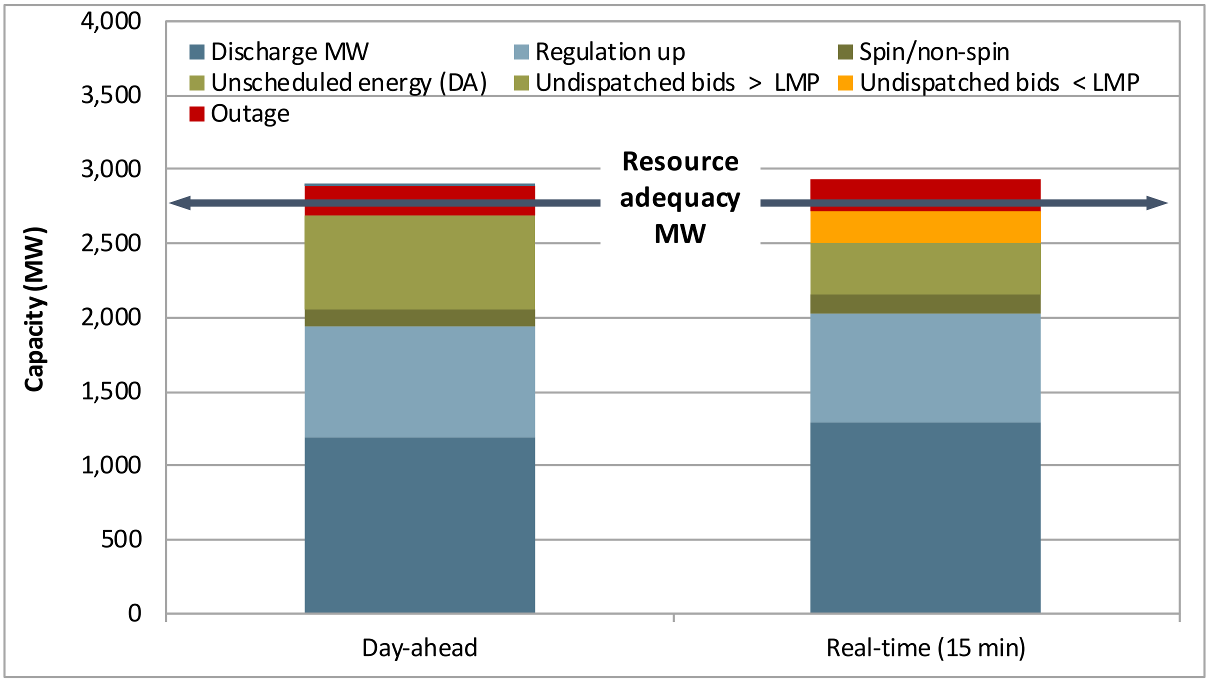


Figure 3.1.3 Average real-time battery bids and nodal prices (August 31 – September 9, 2022)



During the heat wave, the CAISO declared Energy Emergency Alerts (EEA) to keep the public and market participants informed about shortages. Figure 3.1.4 compares average hourly battery schedule in the day-ahead and fifteen-minute markets to total participating RA capacity during EEA events in the heat wave.[26] As shown in Figure 3.1.4, the total aggregate energy and ancillary service schedules and bids submitted by RA batteries in these hours exceeded these resources' RA obligations.

Figure 3.1.4 Average RA battery schedules during EEA events



However, as shown in Figure 3.1.4, during these hours there was an average of about 214 MW of undispatched bids at a price below the LMP and another 356 MW of energy offered at bids above the LMP. Thus, there was an average of about 570 MW of undispatched energy bids in these hours, or over 20 percent of the total RA capacity being provided by batteries.

Previous analysis by DMM indicates that in practice, much of this undispatched capacity may have been unavailable due to various operational constraints related to state-of-charge and other issues. These constraints include:

- **The minimum state-of-charge (MSOC) requirement**, which manages battery schedules during stressed conditions such that they are able to discharge during a set of operator-defined critical hours.
- **The ancillary services state-of-charge (ASSOC) constraint**, which can bind in the real-time market and cause batteries to either charge or discharge in order to give them sufficient headroom to fulfill their ancillary service awards.

[26] This analysis includes hours when either an EEA 1, 2, 3 or EEA Watch was in effect.

- **The aggregate capability constraint**, which ensures that the combined generation of co-located resources does not exceed interconnection limits.
- **Upper and lower charge limits**, optional biddable parameters which represent the highest and lowest stored energy values (in MWh) that should be maintained in the resource in a trading day.
- **The end-of-hour state-of-charge (EOH SOC) bid parameter**, which is an optional real-time only parameter for use by NGR resources to manage their state-of-charge.

3.2 Minimum state-of-charge requirement

As part of its 2021 market enhancements for summer readiness, the CAISO implemented a new tool to manage battery resources during tight system conditions called the minimum state-of-charge (MSOC) requirement. The MSOC is intended to maintain batteries' state-of-charge during stressed system conditions such that they can discharge energy throughout peak demand hours.

Originally, the CAISO intended this feature to be a stopgap measure to manage critical periods while refining rules for battery storage resources, and gave it a sunset date of two years after implementation. However, the CAISO noted that replacement measures approved in 2022 as part of the Energy Storage Enhancements initiative—including new rules for exceptional dispatches and tools to model state-of-charge—will not be implemented prior to summer 2023. Because of this, CAISO has proposed extending the MSOC requirement to no later than summer of 2024.[27] Only batteries providing resource adequacy capacity are subject to the MSOC requirement.

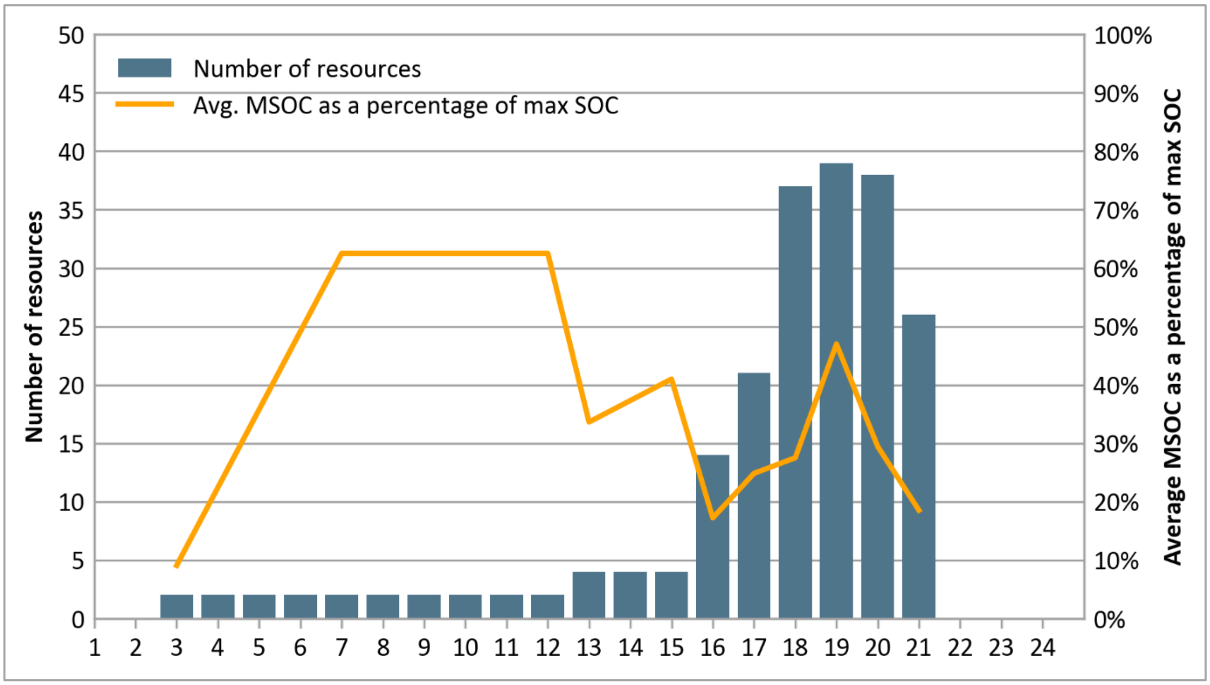
The market software only activates the MSOC when there is a shortfall between supply and forecasted demand in the day-ahead market, causing a Residual Unit Commitment (RUC) infeasibility. Before the MSOC is activated in the real-time market, market operators decide on a series of "critical hours," which determine when and how much charge individual resources are required to maintain in order to meet demand in peak periods. The market software calculates how resources can optimally preserve state-of-charge on an hourly basis for critical hours and the preceding hours. The EOH SOC biddable parameter will apply in preceding hours when it is more restrictive (causing a higher state-of-charge) than this MSOC calculation. However, the MSOC always takes priority during critical hours.

The MSOC requirement was active throughout the 2022 summer heat wave. MSOC requirements were often highest in the morning hours despite there being fewer batteries subject to the requirement at these times. The number of resources subject to MSOC requirements increased in evening hours, and the requirements spiked just before the start of the critical period on each day. Figure 3.2.1 provides an example of the MSOC requirement trends on September 6, 2022. The CAISO has noted that, during the heat wave, the MSOC requirement was binding most frequently during intervals leading up to critical hours, though economic bids generally kept batteries above the minimum requirements.[28]

[27] California ISO, *Minimum State-of-charge Straw Proposal*, February 2, 2023, p. 6: StrawProposal-Minimum-state-of-charge-extension.pdf

[28] California ISO, *Summer market performance report - Sept 2022*, November 2, 2022, p. 154: http://www.caiso.com/Documents/SummerMarketPerformanceReportforSeptember2022.pdf

Figure 3.2.1 Minimum state-of-charge requirement on September 6, 2022



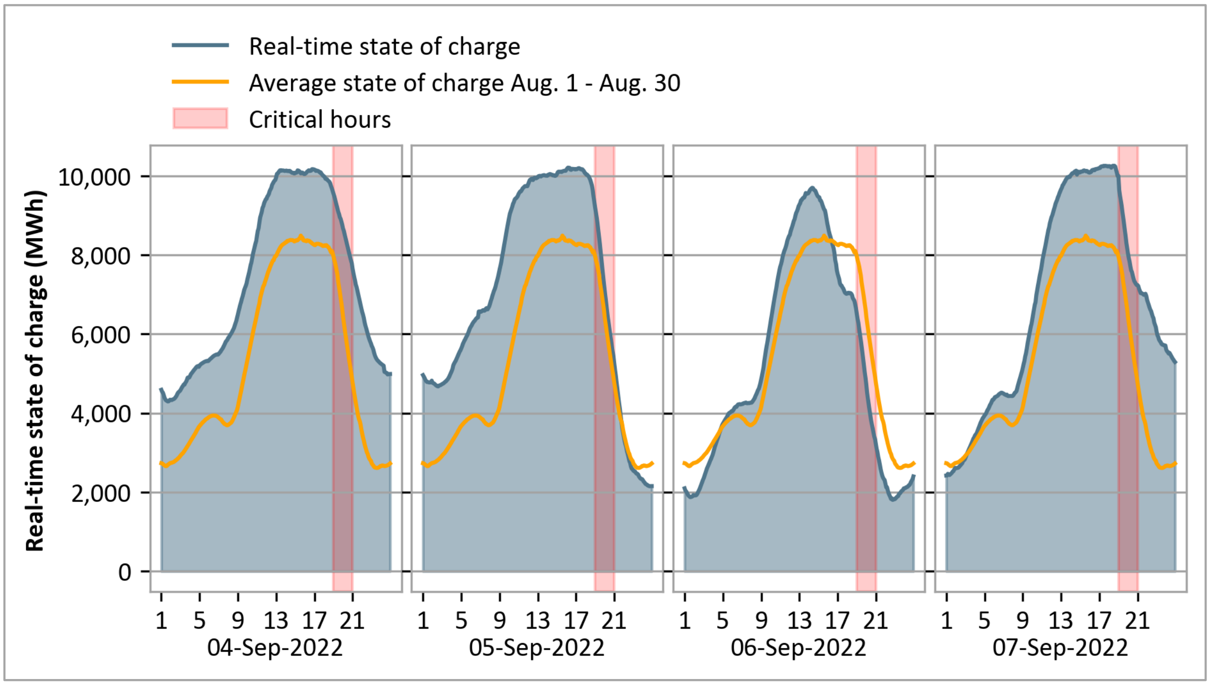
In some cases, price considerations overrode the MSOC requirements in determining batteries' state-of-charge. On September 6, high real-time prices in the beginning of the day caused batteries to discharge ealier than usual. Figure 3.2.2 compares the real-time state-of-charge of resource adequacy batteries on four of the heatwave days to the average state-of-charge of these batteries in the 30 days preceding the heatwave. During these days, critical hours were set to hours-ending 19 through 21. September 6 is perhaps the most notable day among these. Whereas these batteries tended to start discharging around hour-ending 19 before the heatwave, on this day they started discharging around hour-ending 14. DMM has noted that ealy discharging on this day can be explained in part by the $1000/MWh bid soft offer cap, which limits batteries' ability to reflect their opportunity cost on days with high real-time net load prices.[29]

During most days of the heat wave—including September 4, 5, and 7 shown in Figure 3.2.2—batteries maintained a much higher state-of-charge compared to the period directly before the heatwave. In addition, they preserved this high state-of-charge until the start of the MSOC critical hours. However, aggregate state-of-charge for the CAISO battery fleet tended to stay below 90 percent of total charge capacity (around 13,600 MWh) throughout the heat wave. Batteries would not be fully charged—even in the hours preceding peak load—as a result of any of the constraints listed in Section 3.1.

29 Department of Market Monitoring, *Comments on Minimum State-of-Charge Extension Straw Proposal*, February 24, 2023, p. 3: http://www.caiso.com/Documents/DMM-Comments-Minimum-State-of-Charge-Extension-Straw-Proposal-Feb24-2023.pdf

In general, the mimimum state-of-charge was maintained across the storage fleet throughout the heatwave, and batteries were able to provide energy at or greater than their day-ahead awards when prices were sufficient for economic dispatch.[30]

Figure 3.2.2 Resource adequacy state-of-charge (September 4-7, 2022)



3.3 Exceptional dispatch

CAISO operators use exceptional dispatches for unit commitments and energy dispatches when they determine that market optimization results may not sufficiently address a particular reliability issue or constraint. This type of dispatch is sometimes referred to as an *out-of-market* or *manual* dispatch.

Battery storage resources were exceptionally dispatched throughout the heatwave, primarily to charge in anticipation of peak demand hours. Figure 3.3.1 shows average hourly real-time exceptional dispatches during the heat wave. Exceptional dispatches to charge tended to peak in the early afternoon and continue until the start of peak demand hours.

Figure 3.3.2 shows average hourly real-time exceptional dispatch by day. Battery resources were not exceptionally dispatched on September 3 or September 5. The CAISO's Summer Market Performance Report notes that exceptional dispatches to charge were used largely in response to a software issue that prevented storage resources from bidding to charge at a higher price than $150/MWh, which resulted in those resources not being able to charge even when in merit.[31]

[30] California ISO, *Summer market performance report - Sept 2022*, *Section 9.8 Storage resources*, November 2, 2022, p. 152: http://www.caiso.com/Documents/SummerMarketPerformanceReportforSeptember2022.pdf

[31] California ISO, *Summer market performance report - Sept 2022*, *Section 10 Market Issues*, November 2, 2022, p. 170: http://www.caiso.com/Documents/SummerMarketPerformanceReportforSeptember2022.pdf

Figure 3.3.1 Average hourly energy for exceptional dispatch (August 31 – September 9, 2022)

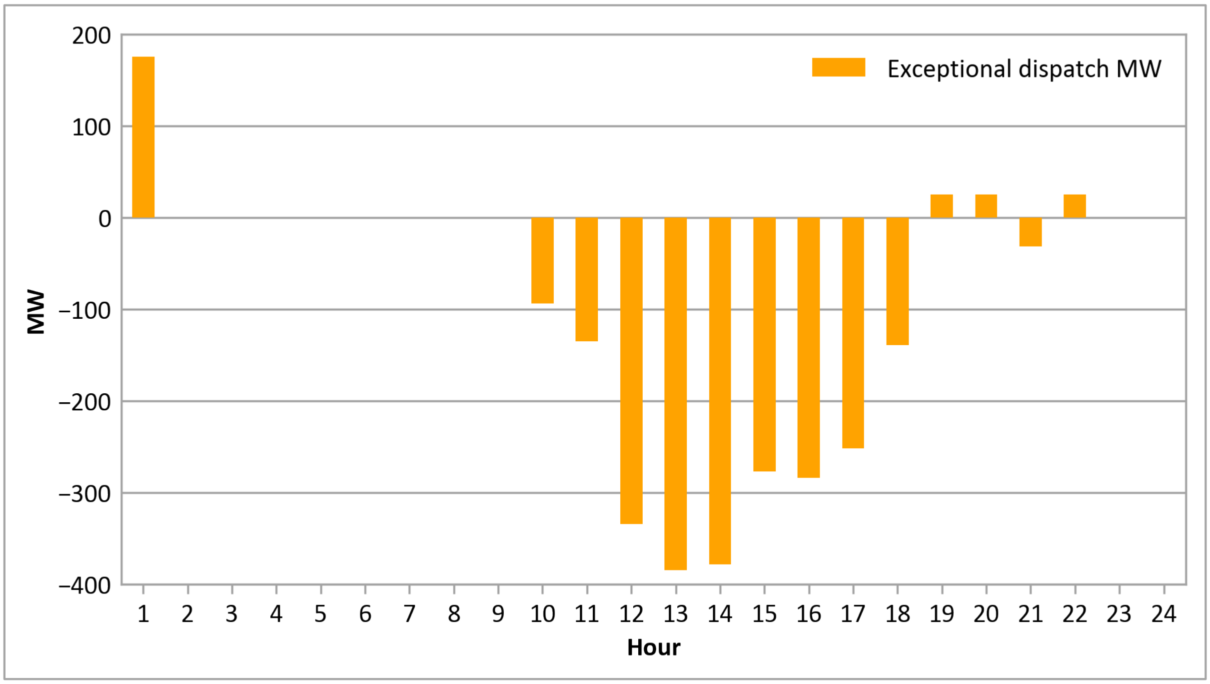
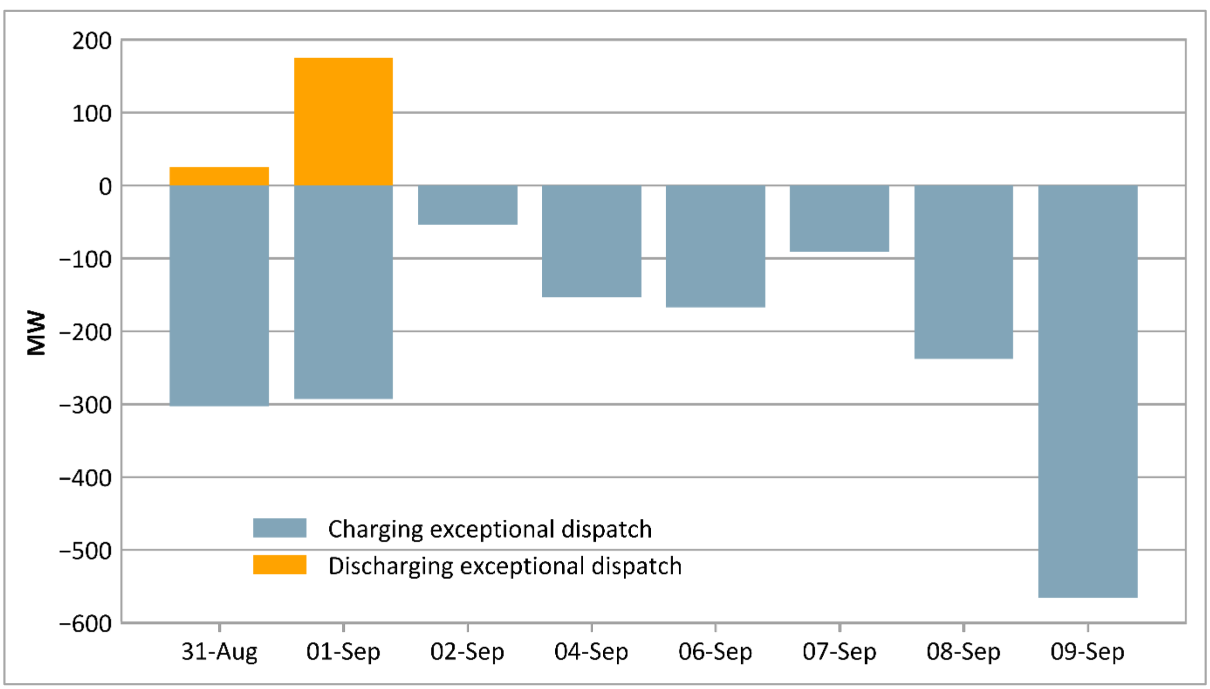


Figure 3.3.2 Average hourly energy for exceptional dispatch by day



Currently, batteries can only be exceptionally dispatched to charge or discharge to a MW target. If a resource is dispatched to discharge energy, then the resource will receive compensation at the higher of their bid or the prevailing price for the dispatched MW amount. Operators can also issue an exceptional dispatch at or near 0 MW to get a battery to hold its state-of-charge. This would result in no compensation for the opportunity cost of holding state-of-charge associated with the exceptional dispatch. About 64 percent of batteries' exceptional dispatch schedules were 0 MW during the summer 2022 heat wave.

The CAISO has developed several enhancements to market rules for exceptional dispatch of batteries, which are scheduled for implementation by fall 2023. One change, approved in December 2022 but not yet implemented, would allow operators to exceptionally dispatch batteries to hold a certain state-of-charge (MWh) until a target time.

The CAISO has also developed a new methodology to compensate batteries for this new type of exceptional dispatch. This new approach includes an opportunity cost methodology which would capture the revenues a resource would have received had it been optimally participating in the market during the time of its exceptional dispatch and the remainder of the operating day. The CAISO's Energy Storage Enhancements Final Proposal provides an example of how this proposed compensation framework would work.[32]

[32] California ISO, *Energy Storage Enhancements Final Proposal*, October 27, 2022: http://www.caiso.com/InitiativeDocuments/FinalProposal-EnergyStorageEnhancements.pdf