ATTACHMENT E: END USES AND MULTIPLE APPLICATIONS[1]

Energy storage technologies are emerging as highly flexible resources that can provide a wide variety of services and value to the grid and customers. In this attachment, we provide a brief overview of these services and applications, summarize key state activities that aimed to unlock access to associated value streams, and discuss the progress made towards value stacking based on the results of our historical analysis of storage operations in California.

The storage resources included in our historical analysis are predominantly standalone lithium-ion batteries with durations of up to 4 hours, so we supplement our discussion based on industry research on hybrid storage resources, alternative technologies and long-duration storage, and transmission deferral use cases.

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Energy Storage Services and Value

Energy storage can offer a wide range of services and values depending on where it is interconnected on the grid, as shown in Figure 1. Electrically, when a resource gets closer to the end use customer, it can *potentially* provide more services and value. Storage resources interconnected directly to transmission system can provide wholesale market, resource adequacy and transmission services. Distribution-connected resources can provide the same set of services, plus distribution system services. Customer-sited resources could provide all of the above, plus a suite of customer-specific services, like bill management. This is consistent with the CPUC decision D.18-01-003 which adopted several rules to govern multiple-use storage applications.

	Services to Grid and Cust.	Grid Domains: Tran.	Dist.	Cust.
Energy & AS Markets and Products	Energy	✓	✓	✓
	Frequency Regulation	✓	✓	✓
	Spin/Non-Spin Reserve	✓	✓	✓
	Flexible Ramping	✓	✓	✓
	Voltage Support	✓	✓	✓
	Blackstart	✓	✓	✓
Resource Adequacy	System RA Capacity	✓	✓	✓
	Local RA Capacity	✓	✓	✓
	Flexible RA Capacity	✓	✓	✓
T & D Related	Transmission Investment Deferral	✓	✓	✓
	Distribution Investment Deferral		✓	✓
	Microgrid/Islanding		✓	✓
Site-Specific & Local Services	TOU Bill Management			✓
	Demand Charge Management			✓
	Increased Use of Self-Generation			✓
	Backup Power			✓

Figure 1: Scope of possible services for transmission-, distribution-, and customer-sited resources.

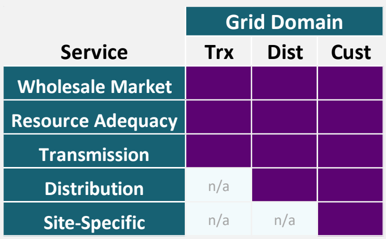
Potential storage services and associated value streams in California include:

- **Energy, or energy arbitrage:** Storage can move energy from one time to another by charging in off-peak periods when the prices are low and discharging during peak periods when high.
- **Ancillary services:** Storage can provide various ancillary services in the CAISO market, including frequency regulation by automatically responding to CAISO's control signals to address small random variations in supply and demand, and contingency reserves (spin and non-spin) to quickly respond in case of an unexpected loss of supply on the system. Storage resources can also provide voltage support to help dynamically maintain stable voltage levels in distribution or transmission systems, and blackstart to self-start without an external power supply and help the grid recover from a local or system-level blackout.
- **Flexible ramping:** Storage resources provide upward and downward ramping capability to help CAISO manage rapid changes in the system due to demand and renewable forecasting errors.
- **Resource adequacy (RA):** Storage resources can be available to discharge during peak periods to help with meeting system RA, local RA, and flexible RA requirements to ensure system reliability in California.
- **Transmission investment deferral:** Storage can defer the need for new transmission investments by charging during periods with low transmission use and discharging when local transmission system is constrained.
- **Distribution investment deferral:** If interconnected to the distribution system, storage can defer the need for new distribution investments by reducing local peak loading on the distribution grid.
- **Microgrid/islanding:** Distributed storage resources can improve resilience by supporting islanding and microgrid capabilities for sections of the distribution grid and thus help to mitigate the risk of power interruptions at the community level.

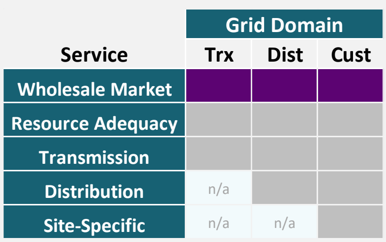
- **Site-specific customer services:** Storage resources that are interconnected behind the utility meter can help customers reduce their electric bills through time-of-use (TOU) bill management by charging when their retail rates are lowest and discharging when retail rates are highest, and demand charge management by reducing customer's net peak usage. Customer-sited resources can also provide backup power to mitigate impacts of power outages. If paired with solar PV, storage can increase use of self-generation by storing excess PV output during the day to use after the sunset.

Key Activities and Initiatives to Unlock Storage Value

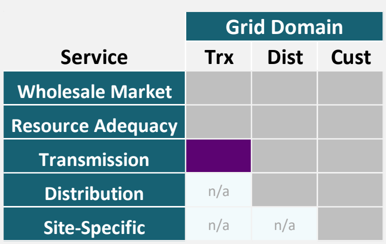
There has been a significant effort in the industry over the past decade to achieve full economic potential of energy storage resources by unlocking access to a variety of value streams. Key activities in California are summarized below. The purple color on the charts highlights types of services and value streams explored for energy storage at various grid domains.



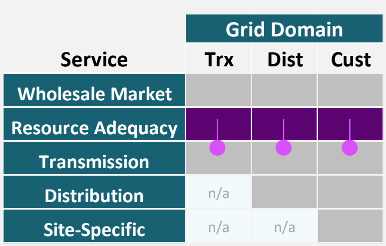
In 2018, CPUC approved D.18-01-003 which marked an important step towards enabling "value stacking" of energy storage systems that can provide multiple services to the grid. The decision adopted a joint staff proposal of the CPUC and CAISO to develop 11 stacking rules to govern multi-use-application (MUA) for grid-scale and distributed energy storage.



CAISO's energy storage and distributed energy resource (ESDER) initiative over the 2015–2021 period focused on various ways to improve ability of transmission-connected and distributed energy resources to participate in the wholesale markets. Separately, CAISO's ongoing energy storage enhancements initiative aims to improve optimization, dispatch, and settlement of energy storage resources through bid enhancements.



CAISO's storage as transmission asset (SATA) initiative kicked off in 2018 to explore how to enable storage provide transmission services while also participating in the wholesale markets, but the initiative is temporarily suspended until storage market participation model is further refined. CAISO transmission planning process (TPP) considers energy storage alternatives to transmission buildout and approved two projects in its 2017/18 TPP cycle.



Several storage procurements driven by local RA needs, including 2013-2016 LCR solicitations due to OTC and SONGS plant retirements in LA Basin and San Diego, 2016-2018 ACES solicitations to address reliability needs due to Aliso Canyon gas leak, 2018 LCR solicitations to meet local needs in Moorpark and Moss Landing. Local needs are determined based on CAISO LCR studies, which can be addressed local RA resources or transmission upgrades.

	Grid Domain		
Service	Trx	Dist	Cust
Wholesale Market			
Resource Adequacy			
Transmission			
Distribution	n/a		
Site-Specific	n/a	n/a	

CPUC's Integrated Resource Planning (IRP) efforts led to two procurement orders to address system reliability needs: D.19-11-016 and D.21-06-035 requiring a combined 14,800 MW of net qualifying capacity (NQC) by 2026. Under the IRP procurement track, most of the resource need so far is met by standalone energy storage and storage paired with solar.

	Grid Domain		
Service	Trx	Dist	Cust
Wholesale Market			
Resource Adequacy			
Transmission			
Distribution	n/a		
Site-Specific	n/a	n/a	

In 2016, CPUC adopted the Competitive Solicitation Framework under the Integrated Distribution Resources (IDER) proceedings and approved IDER incentive pilot to test distribution deferral. In 2018, CPUC established the Distribution Investment Deferral Framework (DIDF) to create an annual process to identify, review, and select opportunities for distributed energy resources to defer or avoid distribution investments.

	Grid Domain		
Service	Trx	Dist	Cust
Wholesale Market			
Resource Adequacy			
Transmission			
Distribution	n/a		
Site-Specific	n/a	n/a	

Several utility pilots and demonstration projects were installed at the distribution system to test various services and storage use cases, including CAISO wholesale market participation, resource adequacy, distribution deferral, microgrid/islanding. Oakland Clean Energy Initiative (OCEI) under utility-CCA partnership selected distribution-connected projects to facilitate gas peaker retirement, which would otherwise require transmission upgrade.

	Grid Domain		
Service	Trx	Dist	Cust
Wholesale Market			
Resource Adequacy			
Transmission			
Distribution	n/a		
Site-Specific	n/a	n/a	

Self-Generation Incentive Program (SGIP) was established in 2001 to provide financial incentives for distributed generation. Program is transformed in 2017 and allocated 75% of funds to storage. In 2019, CPUC adopted use of a GHG signal that reflects real-time emission intensity in wholesale markets to align performance with GHG goals. Same year, CPUC established Equity Resiliency budget for storage installations by vulnerable customers in high wildfire threat areas.

	Grid Domain		
Service	Trx	Dist	Cust
Wholesale Market			
Resource Adequacy			
Transmission			
Distribution	n/a		
Site-Specific	n/a	n/a	

In 2021, CPUC created the Emergency Load Reduction Program (ELRP) as a new Demand Response pilot to compensate electricity customers for voluntarily reducing their demand or increasing supply during periods of grid emergencies. This is a 5-year pilot program, started with commercial customers and extended in December 2021 to include residential customers.

At the federal level, there were two key FERC orders affecting wholesale market integration of storage:

- In 2018, FERC's Order 841 required the regional transmission organizations (RTOs) and independent system operators (ISOs) to enable participation of energy storage resources in wholesale energy, ancillary services, and capacity markets.
- Later in 2020, under a similar but broader scope, FERC's Order 2222 required RTOs and ISOs to open up wholesale markets to distributed energy resource (DER) aggregations, which includes distribution-connected and customer-sited energy storage, among other technologies.

Multiple-Use Applications and Value Stacking

In 2018, CPUC approved D.18-01-003 which marked an important step towards enabling "value stacking" of energy storage systems that can provide multiple services to the grid. The decision adopted a joint staff proposal of the CPUC and CAISO to develop 11 stacking rules to govern multi-use-application (MUA) for grid-scale and distributed energy storage.

These rules are summarized below.

1. Customer-sited storage can provide all services in any domain
2. Distribution-connected storage can provide all services except services in the customer domain, except for community storage
3. Transmission-connected storage can provide all services except services in the customer and distribution domains
4. All resources can provide resource adequacy, transmission, and wholesale market services
5. Reliability services must be prioritized
6. If multiple reliability services provided, reliability obligations must not conflict with each other
7. When contracting for reliability services, storage provides must demonstrate distinct capacity dedicated and available to that reliability service
8. Program rules, contract, or tariff relevant to each service provided must specify how the rules will be enforced, including through penalties for non-performance
9. In response to a utility request for offer, storage providers must list any services provided outside of the solicitation and update the list over time
10. Storage resources must comply with all applicable availability and performance requirements
11. Compensation is permitted only for services which are incremental and distinct; The same service must be counted and compensated only once

Figure 2: Summary of CPUC-adopted rules on multiple use applications.

For the historical benefit-cost analysis of energy storage projects in California, we evaluated projects across all grid domains based on their actual operations during 2017–2021. See **Attachment A (Benefit/Cost and Project Scoring of Historical Operations)** for details. Figure 3 shows estimated societal benefits averaged over operating period and normalized for MW capacity of the projects. Top chart shows the aggregate benefits color coded by project group or cluster. Bottom chart shows stacking of individual benefit metrics. Most bars represent individual resources with their widths showing relative MW capacity. Customer-sited storage installations are aggregated into utility contracts or clusters.

The top-ranked resources provided $20–$35 per kW-month of average benefits over the 5-year period. These resources all participated in the CAISO wholesale markets and they did relatively well in stacking of energy, ancillary services, and RA capacity value. Many of them are distribution-connected projects that were procured to address various local RA and reliability needs.

Many of the recent large transmission-connected storage projects ranked in the middle, with higher focus on energy time-shift and little/no ancillary services value. Their estimated RA capacity benefits were lower than the early projects procured for high-value local RA needs.

Customer-sited resources generally provided very low benefits due to lack of service to the transmission grid. However, one of the clusters of nonresidential SGIP projects provided relatively high resilience value by mitigating impacts of customer outages (shown in gray). Storage projects in this cluster are mostly paired with rooftop solar and located in areas that faced several Public Safety Power Shutoff (PSPS) events historically.

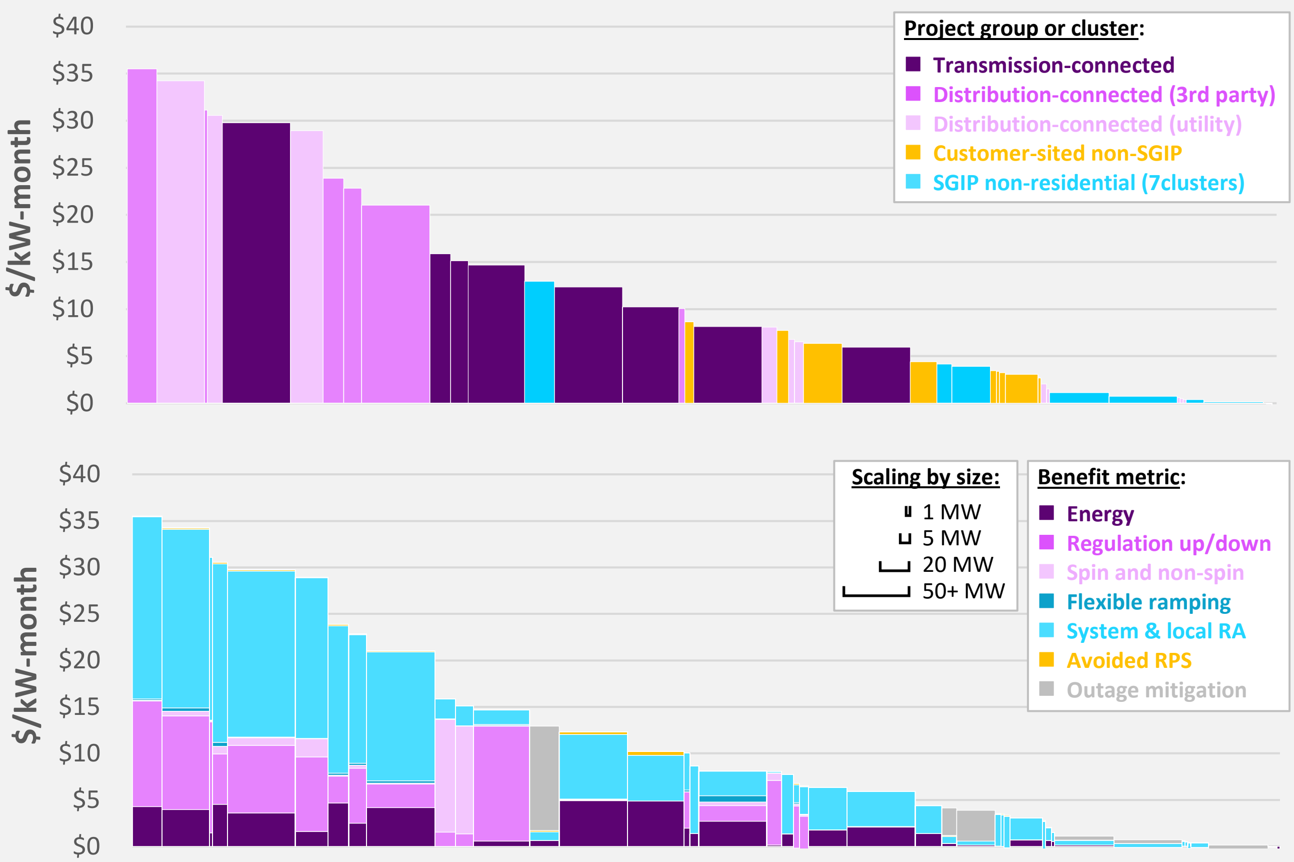


Figure 3: Summary of estimated societal benefits by project group (top) and benefit metric (bottom) (2022 $).

The storage projects with the highest levels of historical benefits are mostly distribution-connected resources that were procured to meet various local capacity needs driven by generation retirements (i.e., once-through cooling, San Onofre nuclear generators, Moss Landing generators) and issues related to Aliso Canyon. **Attachment A (Benefit/Cost and Project Scoring of Historical Operations)** describes the individual procurement tracks and the counterfactual cases developed based on specific circumstances of these procurement tracks, which we use to estimate local RA capacity values. Since these energy storage resources were procured under generation RA capacity procurement, where the resource alternative is a generation or load resource, we allocate these services and benefits towards local RA capacity rather than transmission deferral. However, local RA capacity value intersects with transmission deferral because without cost-effective local generation or storage, the alternative would be a transmission upgrade to reduce or eliminate local RA capacity need in the area.

None of these high-value local RA capacity distribution-connected projects provide distribution level services. As discussed in **Chapter 2 (Realized Benefits and Challenges)** of the main report, energy storage developed to defer specific distribution investments faced major challenges as the size and timing of identified needs changed over time. At least 9 projects earmarked for distribution investment deferral were canceled. One storage project originally procured for distribution deferral (under IDER) achieved commercial operations within the timeframe considered in our study. However, the distribution need driving the procurement of this resource disappeared due to a reduction in the utility's demand forecast. This resource participates in the CAISO marketplace and is able to provide benefits to the grid despite fluctuating needs on the distribution system. This highlights that the modularity of storage to "stack" a wide range of services, and to do so flexibly, may be beneficial to the distribution investment deferral use cases.

Customer outage mitigation is becoming an increasingly crucial component of resilient electricity service to meet essential loads and to protect vulnerable customers, communities, and critical facilities. Wildfire risks in California have accelerated and shifted rapidly in 2017–2021 along with utility use of extended planned outages of sections of the distribution system (Public Safety Power Shutoffs) as a mitigation tool. Accelerating weather and environmental risks point to higher future resilience needs at the community and customer levels that can only be addressed by distributed solutions. Transmission-connected resources cannot help when distribution sections are de-energized.

Distribution-connected microgrids can support community-level resilience, which is tested by the IOUs and stakeholders through several early pilots and demonstrations. Projects like SDG&E Borrego Springs microgrid brought this use case to technological maturity. But as described in the main report, these microgrid projects historically provided very little value to the grid as they were on standby for extended periods of time.

For customer-sited resources, outage mitigation was largely an untapped potential until recently. Most of the initial SGIP-funded energy storage capacity came from nonresidential customers who focused on bill management. Over past couple of years, however, residential installations started to drive the market growth. The Equity Resilience budget, established for vulnerable customers in high fire-threat areas and at risk of outages, accounted for over 50% of the new customer-sited installations funded by the SGIP in 2021.

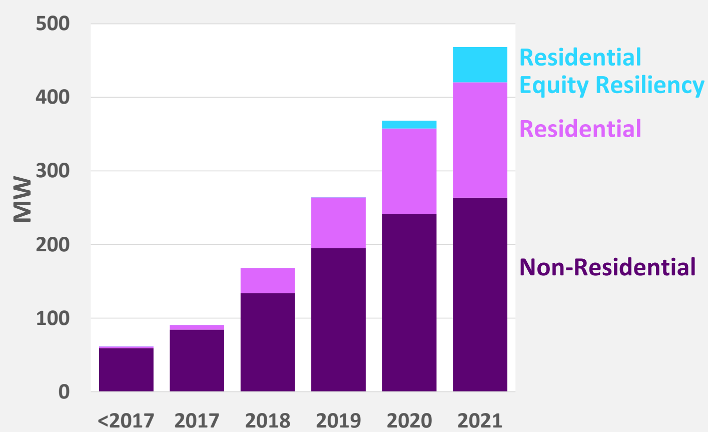
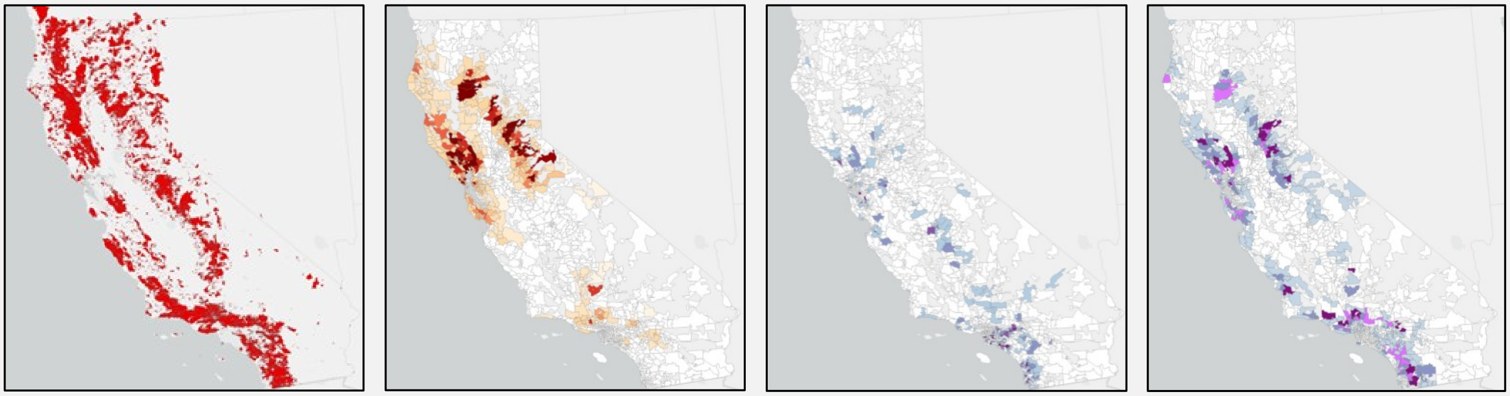


Figure 4: SGIP-funded installed storage capacity over time.



Historical fire perimeters

Relative PSPS severity in total customer-hours

Distribution of nonresidential SGIP-funded storage installations

Distribution of storage + solar installations under SGIP Equity Resiliency budget

Figure 5: Comparison of various SGIP installations to wildfire threat areas.

In Figure 5 above, historical wildfire perimeters and PSPS areas compared to the distribution of nonresidential projects shows low spatial correlation. Recent projects funded under the SGIP Equity Resiliency budget are primarily installations that are paired with solar and concentrated in high wildfire threat areas. SGIP projects in our historical analysis do not include these recent projects in high-risk areas, so the estimated customer outage mitigation values in our report are relatively low for most projects. Over the 2017–2021 period, we estimated the customer outage mitigation benefit to be $1.7/kW-month, when averaged across all nonresidential SGIP-funded projects. For the subset of these SGIP projects that are in PSPS areas and paired with solar PV, however, the average value is estimated to be in the range of $10–$20/kW-month (see **Attachment A (Benefit/Cost and Project Scoring of Historical Operations)** for details of this analysis). Going forward, we expect customer outage mitigation/resilience use case to be a primary driver of the future growth in distributed storage installations. The ability of these installations to stack grid benefits with customer resilience value is yet to be tested. The barriers are not technological. As discussed under **Chapter 3 (Moving Forward)** of the main report, it will be essential to bring stronger grid signals to customers and improve the analytical foundation for resilience-related investments.

Our study of future energy storage procurement in California (**Attachment B (Cost-Effectiveness of Future Procurement)**) investigated the need for and value of longer-duration storage (8–10 hours) over the next decade. The study found that creating a real option to add more duration to storage projects at the initial design and procurement phases could support a timely and cost-effective transition for a portfolio with longer duration storage. There are inherent uncertainties with future RA capacity needs and resource contributions, and procurement efforts may have to pivot quickly and adjust target portfolios based on unexpected changes and new information. Battery storage systems and site designs are highly modular and adding duration at existing sites can have a streamlined interconnection process that can be completed more quickly and at a lower cost. In our review of the actual grid-scale installations, we see that some developers are already taking advantage of this modularity in their market participation and development strategies by building the MW capacity first and increasing duration later when the need arises.

The 250 MW Gateway energy storage project is a great example for illustrating benefits of modular development when stacking multiple values. The project was initially deployed as a 1-hour battery in August 2020 and kept its duration at that level for almost a year, before adding more duration to meet its capacity obligations under multiple RA contracts starting in Q3 of 2021. During its first year of operations, the project remained primarily as a merchant resource participating in the CAISO's energy and ancillary services markets, and relying on wholesale market revenues. The project later increased its duration to provide RA capacity to various LSEs including PG&E, SCE, Direct Energy, and possibly other smaller entities. By the end of 2021, the project had an NQC of 175 MW, which implies 700 MWh energy capacity and 2.8 hours of duration. The project secured another RA contract with SCE for 75 MW starting in August 2023, and to meet that need, project's duration will likely reach 4 hours by the next year.

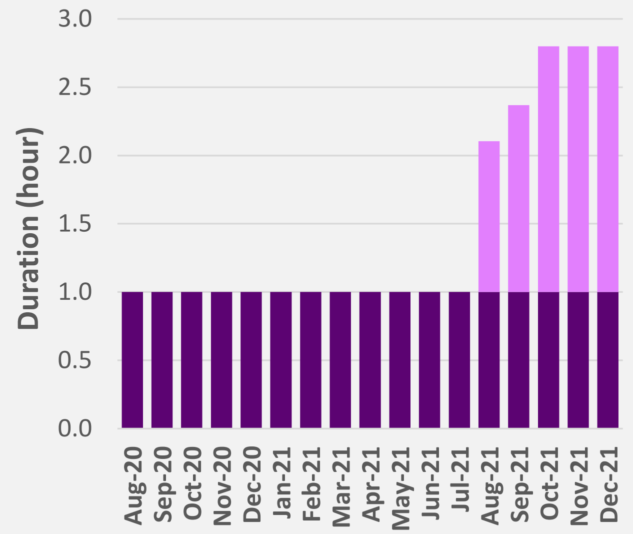


Figure 6: Estimated duration of the Gateway energy storage project over time.

*Values approximated based on monthly NQC of the project

Pumped storage hydroelectric technology can offer a unique way of value stacking across multiple sectors. Lake Hodges, which is the only pumped storage project in our historical study, began operations in 2012. The project was built partly to provide up to 40 MW of on-demand electric capacity in San Diego. But the primary driver of the project was to store water for emergency use for the region. This multiple use case allowed San Diego County Water Authority (SDCWA) offer the project's electricity-related attributes at a price beneficial for the SDG&E ratepayers. The project not only provided local RA capacity in the CAISO-designated San Diego-Imperial Valley area, but it also achieved one of the top energy time-shift values across all energy storage resources analyzed in our study. Overall, Lake Hodges is among the best performing resources in terms of 2017–2021 electricity ratepayer benefit/cost ratio and overall scoring.

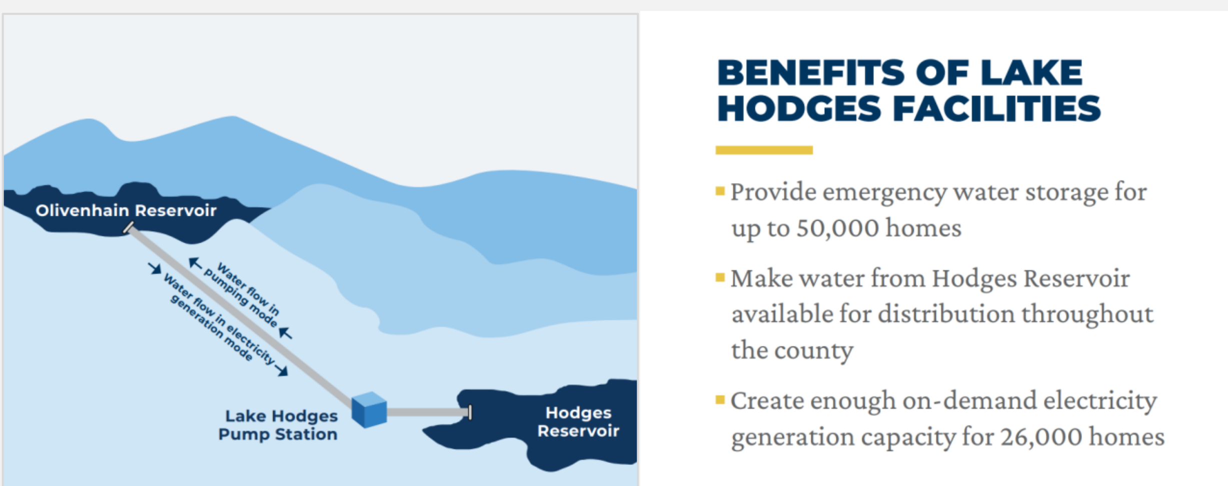


Figure 7: Overview of the Lake Hodges pumped storage project in San Diego.

Source: San Diego County Water Authority

Outside of California, the West Kauaʻi Energy Project (WKEP) in Hawaiʻi is on track to become the nation's first solar + pumped hydro project. Kaua'i Island Utility Cooperative signed a long-term PPA for the project, which is expected to serve 25% of the island's load. When completed, the WKEP will be an integrated renewable energy, storage, and irrigation project with two segments:

- Upper segment will include a traditional hydroelectric facility to generate electricity (up to 4 MW) and provide water for irrigation needed to support agricultural activities;
- Lower segment will include a 20 MW of pumped storage hydroelectric facility, a 35 MW solar PV, and a 35 MW/70MWh battery. The battery will be DC-coupled with the solar array to firm solar output and harvest otherwise clipped energy.

The project is expected have a combined 240 MWh (12 hours) of energy storage capability to be used for shifting solar energy to peak periods. Also, the project's development efforts will include rehabilitation of existing reservoirs for public use and recreational activities.

In recent years, industry has increasingly focused on value stacking related to electricity-related services, driven by many different and creative ways batteries can be utilized in the grid. While this is important for cost-effective clean energy transition, looking at value stacking opportunities outside of electric sector is equally important when pumped storage investments are considered. For example, recent ANL report prepared for the DOE's HydroWIRES initiative describe a methodology to quantify non-energy benefits of pumped storage projects, including flood control, recreation, water supply, environmental benefits during droughts, and irrigation.

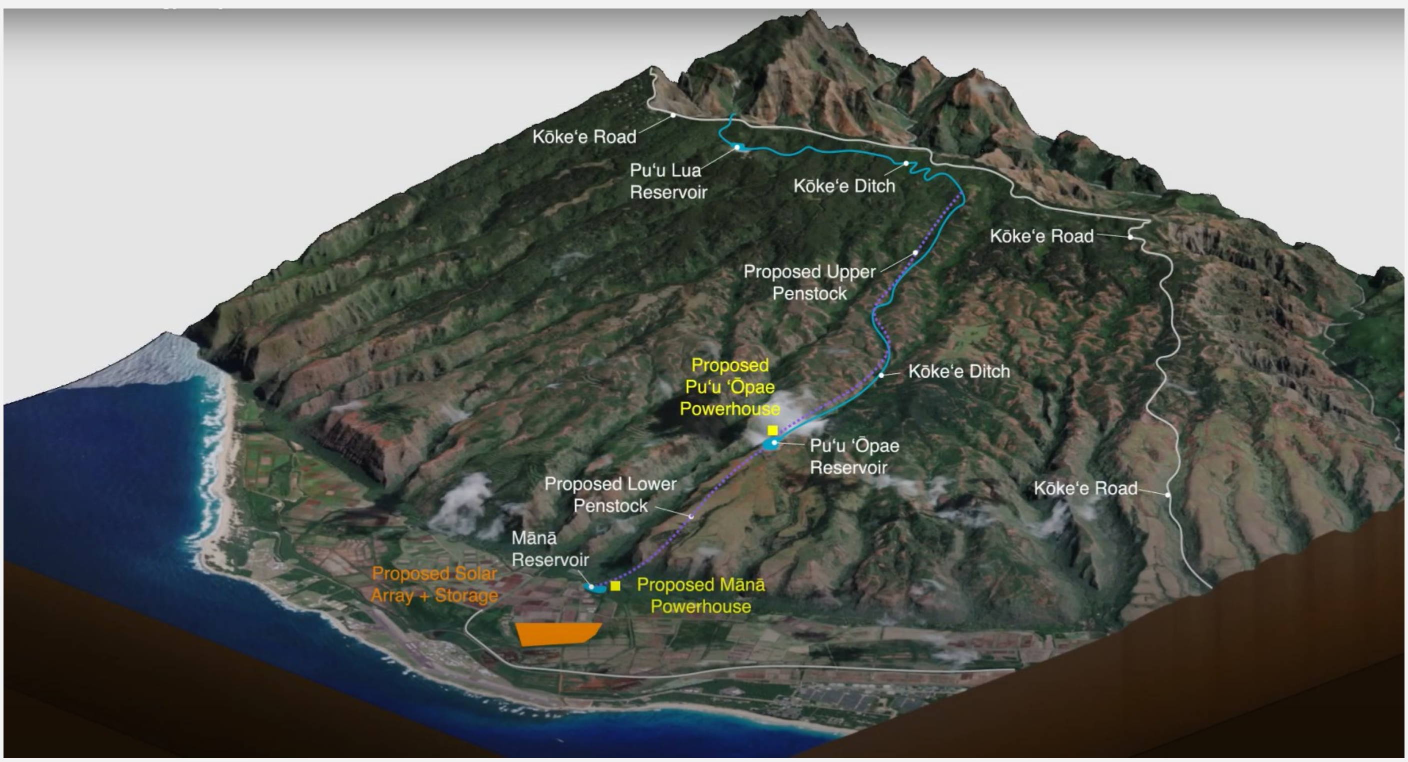


Figure 8: Overview of the proposed West Kauaʻi Energy Project in Hawaiʻi.

Source: Kaua'i Island Utility Cooperative

Hybrid Storage Resources

There has been a growing interest in developing energy storage resources paired with renewables, especially solar. This is a trend we see in most regions, but especially in California and rest of the West. Even though most of California's operational storage capacity as of early 2021 were from standalone projects, solar + storage accounts for approximately half of new energy storage capacity currently under development in California as shown in Figure 9 above. Procurement of grid-scale energy storage projects connected directly to the transmission system is split evenly between standalone vs. hybrid resources, while procurement of distribution-connected storage is primarily from standalone resources. Within customer-sited storage resources, almost all residential installations are batteries that are paired with rooftop solar. On the other hand, about one-fourth of nonresidential projects are paired with solar, most of which are installed at schools.

Our study of actual storage operations during 2017–2021 considered projects procured by California LSEs under the CPUC jurisdiction that reached commercial operations by April 2021 for sufficient history to analyze. At the grid-scale, our historical study includes only a few hybrid projects, in which short-duration batteries (< 0.5 hours) were integrated with gas turbines to provide the fast response needed for spinning reserves in CAISO ancillary services market. All large solar + storage projects were still under development as of April 2021. Given that, our discussion of grid-scale hybrid resources is primarily research based. We also summarize relevant findings from our peaker replacement study, which is described in detail in **Attachment C (Cost-Effectiveness of Peaker Replacement)** of this report.

At the customer level, we analyzed actual operations of over 650 nonresidential SGIP-funded storage projects with a total capacity of 205 MW. About half of these installations (~35% of storage capacity) were paired with solar PV. We highlight key differences across project clusters with different levels of storage attachment rates.

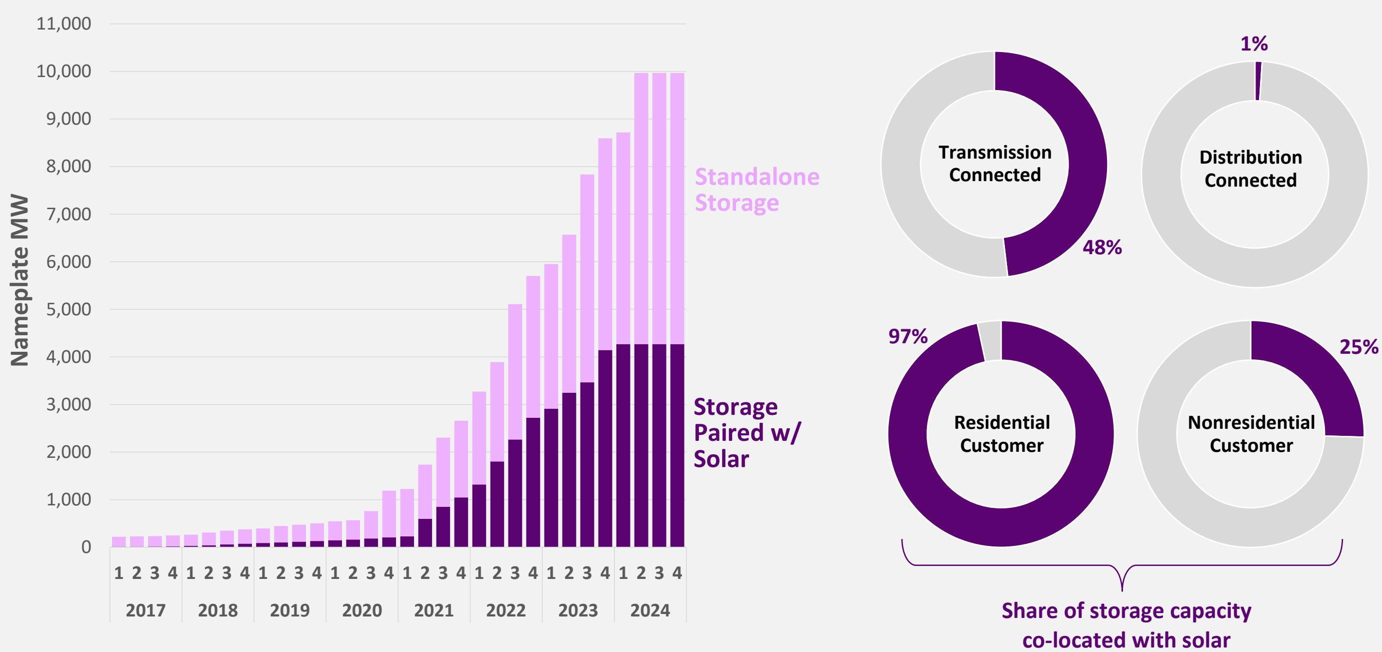


Figure 9: Standalone and co-located storage procurement in California as of summer 2022.

Relative to standalone development, co-located or hybrid projects can provide cost synergies and get additional tax incentives. A key benefit is the shared equipment and infrastructure that can help reduce equipment, interconnection, and permitting costs. A recent NREL report shows installed cost of grid-scale hybrid systems can be 6–7% lower than cost of solar and storage sited separately, which is illustrated in Figure 10 on the right.

While this cost difference may not seem large, it can be relatively important when the economics of incremental energy storage investments are considered in resource planning studies. In the example shown, marginal cost of adding storage would be around 12–14% lower under a hybrid configuration, compared to standalone projects (same $ delta, but divided by storage cost rather than total solar + storage cost).

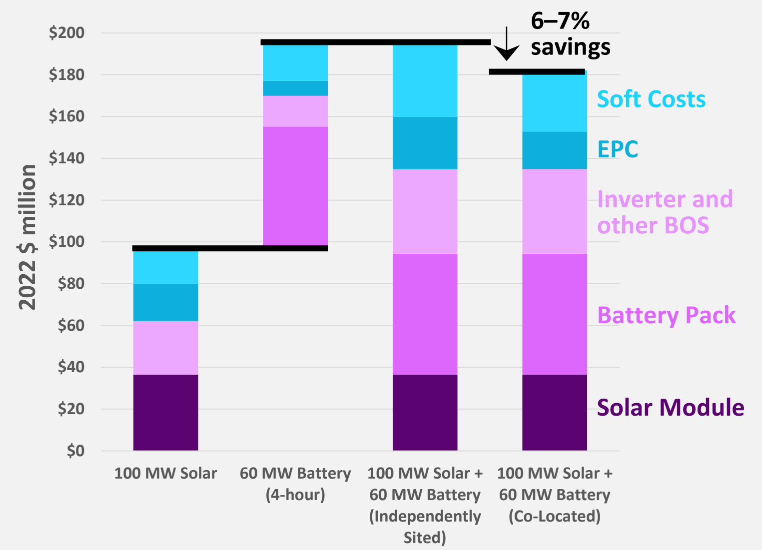


Figure 10: Cost savings of grid-scale hybrid systems relative to standalone development.

Based on data from (Ramasamy et al. 2021). Costs converted to 2022$ using GDP deflator and aggregated to broader categories.

Until recently, only energy storage co-located with solar would get federal investment tax credit (ITC) that could offset 26–30% of costs. The Inflation Reduction Act of 2022 extended the ITC to also standalone storage for up to 30% of their installed cost, which leveled the playing field for storage. If DC-coupled, co-locating solar and storage can also capture the solar energy that would otherwise be clipped and reduce the overall roundtrip energy losses. An important consideration is the interconnection process. Adding storage to an existing facility can reduce the cost and timeline for interconnection with the grid.

Taking advantage of co-location benefits also creates more restrictive operational constraints for storage, which reduces its value and needs to be weighed against benefits. For example, a recent LBNL study demonstrates that the lost value (called "coupling penalty" in the study) relative to independently-sited systems can offset most of the co-location benefits described above.

Until recently, a major constraint was the restrictions on grid charging to qualify for tax credits, but with the extension of tax credits to also standalone energy storage, this should no longer be an issue for new projects.

To realize cost synergies described above, co-located projects often share equipment such as inverters and keep their interconnection limit below the aggregate nameplate capacity of individual resources. This restricts the amount of energy that can be discharged by storage simultaneously when there is solar generation. Implications of this depends highly on solar penetration and can vary by region. For example, in Texas, where high-priced hours in the energy market often occur during daytime, limiting total energy from solar plus storage can be detrimental to economics of hybrid projects. On the other hand, in California, where storing solar output in the day and sending it to the grid later in the evening tends to be optimal, the lost value due to shared inverter or interconnection limit would be small. Total capacity of co-located or hybrid resources is capped at the interconnection limit, which may reduce their contribution towards RA needs. For solar + storage in California, this would have a limited impact. In the latest IRP studies, marginal ELCC for near-term resources is estimated at around 10% for solar and 90% for 4-hour battery. Solar + storage with an interconnection sized to solar MW would have the same NQC as resources sited and interconnected separately.

Co-location may potentially prevent storage resources to be placed at highest-value locations of the grid. For example, the same [LBNL study](#) mentioned above estimated that annual value of storage projects in CAISO at selected high-volatility nodes (top 20 percentile) is around $30/kW-year higher on average than the value of storage at solar nodes under 2012–2019 prices. While the exact value differential varies by the nodes selected and can change going forward, the overall magnitude of this result suggests that lost value due to siting constraints could offset a large portion of the cost savings from pairing storage with solar.

As a part of our study, we evaluated cost effectiveness of replacing the state's gas peakers with storage. For that evaluation, we analyzed historical operations of around 100 individual peakers under challenging system conditions of 2020. We found replacing peakers' output with standalone storage would require either significantly overbuilding storage MW or installing long-duration storage at a relatively high cost. If the site or local area has sufficient land that can be used to install solar capacity, developing storage paired with solar can reduce the need for overbuilding MW and/or duration, and result in lower net costs. Figure 11 shows the distribution of estimated net cost of replacing peaker capacity under various storage configurations. See **Attachment C (Cost-Effectiveness of Peaker Replacement)** of our report for study details and discussion of alternative storage configurations and scenarios analyzed.

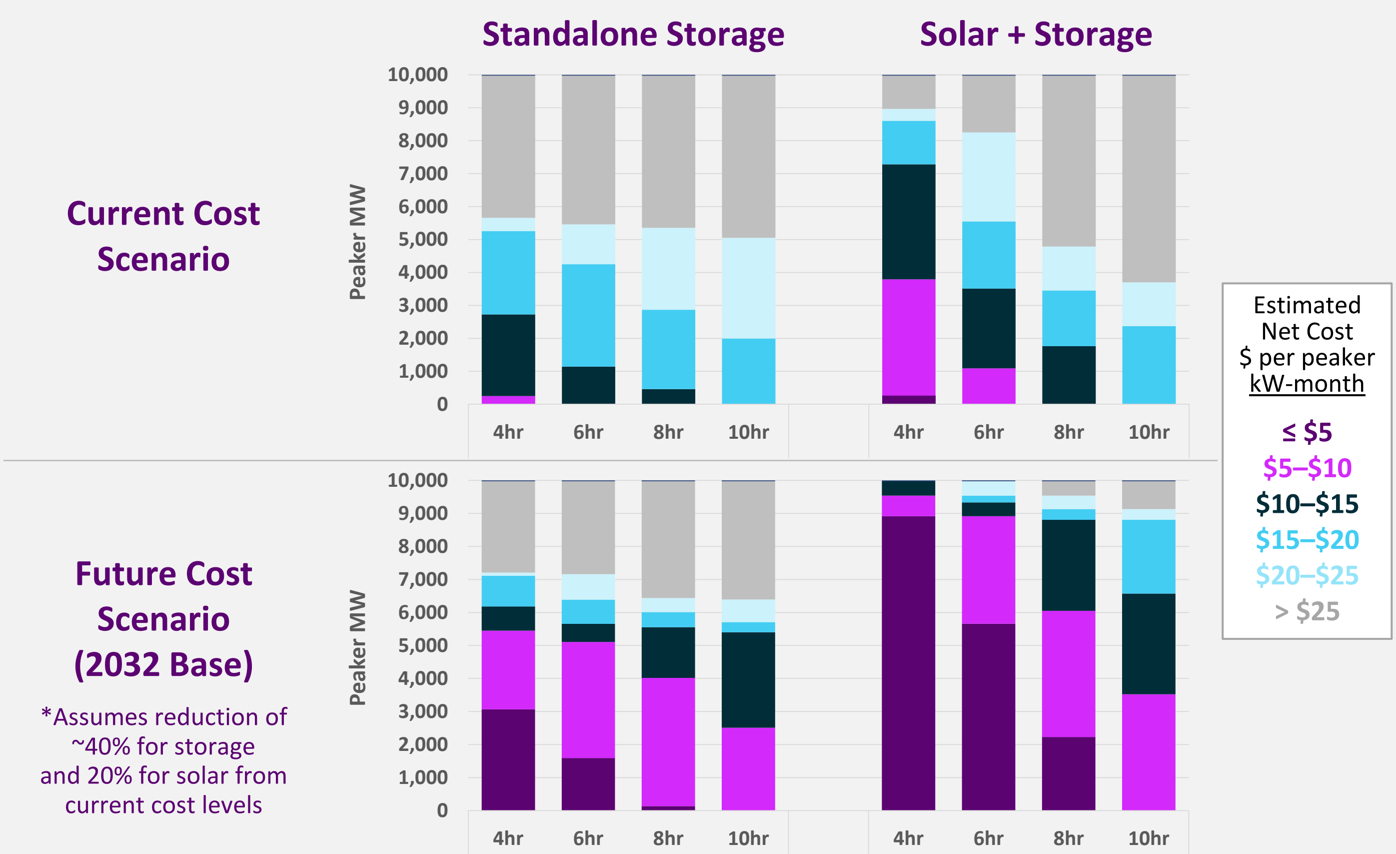
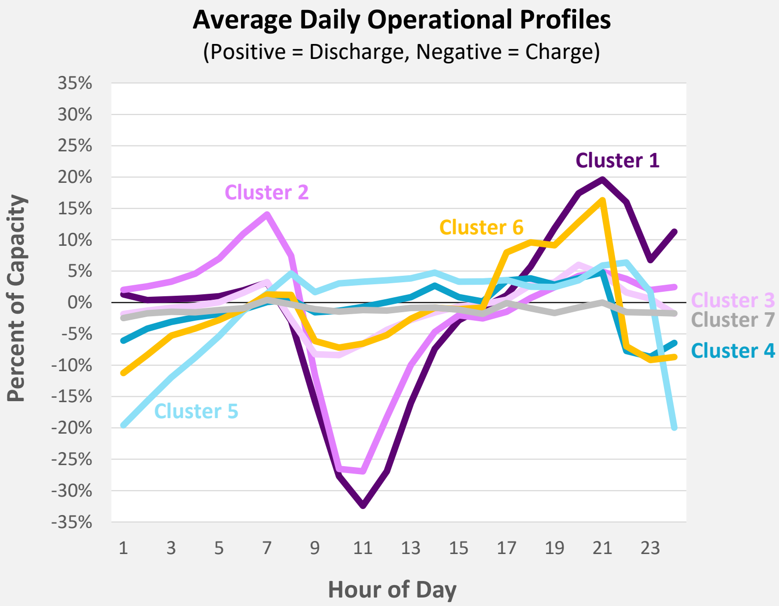


Figure 11: Distribution of peaker replacement net costs with no limitations on grid interconnection (2022 $).

* 4-hour storage configurations need to significantly oversize their MW (relative to peaker capacity) to meet total energy required during extended reliability events. Storage with longer duration needs less oversizing as it can provide same MWh with fewer MWs. See **Attachment C (Cost-Effectiveness of Peaker Replacement)** for study details and discussion of alternative storage configurations analyzed.

For non-residential SGIP-funded projects, we conducted an analysis to group 654 resources into 7 clusters based on each installation's interval-level operating behavior during 2017–2021. Projects in clusters 1–3 have operating patterns synergistic with the grid: they charge during the day and discharge during the grid's morning and evening ramps into and out of solar generation periods. These resources are mostly schools and colleges, and they have a high solar attachment rate. Projects in clusters 4–7 are mostly standalone batteries, and their use cases focus on demand charge management and does not align well with bulk grid needs. See **Attachment A (Benefit/Cost and Project Scoring of Historical Operations)** for details of our benefit/cost analysis and project scoring, including comparisons across SGIP clusters and grid-scale storage.



Cluster ID	Project Count (# of projects)	Energy Storage Capacity (MW)	Average Roundtrip Efficiency (%)	Average Daily Discharge (hours/day)
1	96	17.6	78%	1.3
2	56	9.1	75%	1.1
3	82	23.6	75%	0.6
4	164	60.6	77%	0.8
5	22	9.7	83%	1.1
6	102	41.6	77%	1.2
7	132	43.0	65%	0.6
Total	**654**	**205.3**	**74%**	**0.9**

Cluster 1
- Midday Charge
- Evening Peak Discharge

Cluster 2
- Midday Charge
- Morning Discharge

Cluster 3
- Midday Charge
- Morning+Evening Discharge
- Low Utilization

Cluster 4
- Night Charge
- Distributed Discharge
- Low Utilization

Cluster 5
- Extended Night Charge
- Distributed Discharge

Cluster 6
- Midday+Night Charge
- Evening Peak Discharge

Cluster 7
- No apparent charge/discharge pattern
- Low Utilization
- Low Efficiency

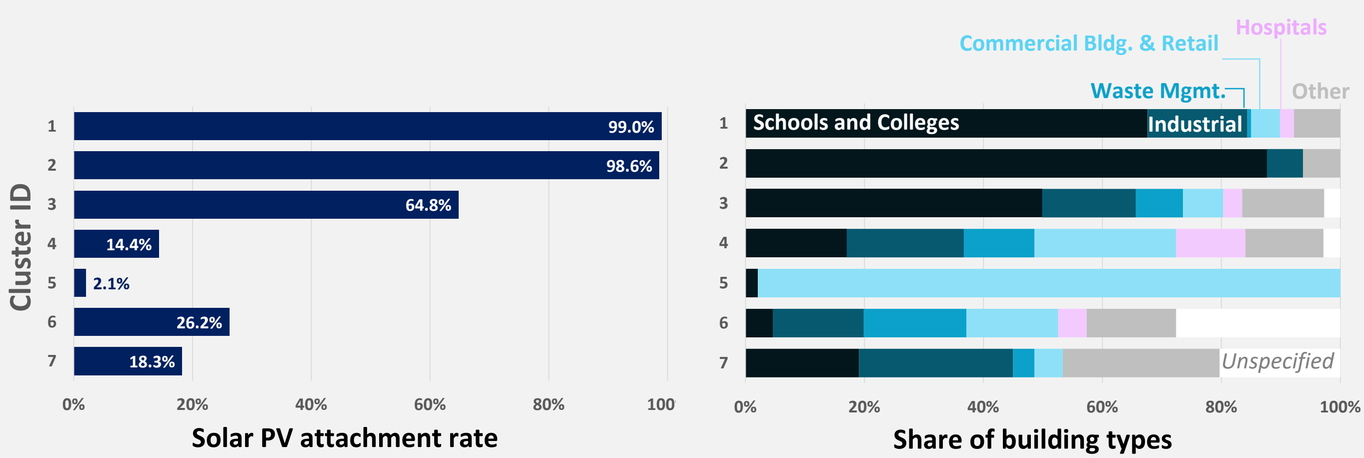


Figure 12: Observed characteristics of non-residential SGIP-funded installations (654 installations in 7 clusters).

Alternative Technologies and Long-Duration Storage

While lithium-ion batteries have dominated the recent energy storage development in California, rest of the U.S, and world-wide, there are several other energy storage technologies that can also provide grid services and benefits. Broadly, energy storage technologies that can support electric grids fall under 4 categories:

1. **Electrochemical energy storage** involves batteries using various chemistries to charge and discharge electricity through electrochemical reactions (oxidation and reduction) on two separate electrodes that are electrically connected. E.g., Lithium-ion, sodium-sulfur, redox-flow, and metal-air batteries.
2. **Chemical energy storage** systems store electricity in chemical bonds. E.g., Hydrogen produced by electricity used to split water molecules (electrolysis), which can be stored in caverns or pipeline, and later sent to combustion turbines or fuel cells to generate electricity.
3. **Mechanical energy storage** converts electricity into kinetic or potential energy, and later reverses the process to recover stored energy. E.g., Pumped storage, flywheels, compressed air energy storage, liquid aid energy storage.
4. **Thermal energy storage** systems store electricity as thermal energy by heating or cooling a material, and keep it insulated until energy is needed. Thermal energy can later be converted back to electricity or used directly in heating and cooling applications. E.g., Molten salt TES systems coupled with concentrated solar power plants, ice or chilled water TES systems used for commercial or residential cooling.

Most of the grid-scale energy storage systems procured in California today have a 4-hour duration, which means they can continuously discharge up to 4 hours at full capacity. This is a result of the high initial value of 4-hour storage in addressing current system reliability needs and lithium-ion batteries dominated the market due to their lower costs. But going forward, as California continues to decarbonize its electric system by deploying more clean energy resources, system flexibility needs and role of storage will evolve and longer duration storage systems will be needed.

Batteries are highly modular and there are no technical barriers to configuring them with longer durations. But most of batteries' installed cost is from energy-related costs such as cost of battery pack, which increases with duration. For instance, a battery with 8-hour duration costs around 1.8 times the cost of a 4-hour battery with the same nameplate MW. This cost structure makes it difficult to scale lithium-ion batteries cost effectively at longer durations above a certain level. Figure 13 compares cost projections for selected long-duration energy storage technologies based on a recent E3 study, which illustrates several emerging technologies have the potential to support multi-day or seasonal storage needs at a much lower cost than lithium-ion battery as California gets closer to 100% clean energy target.

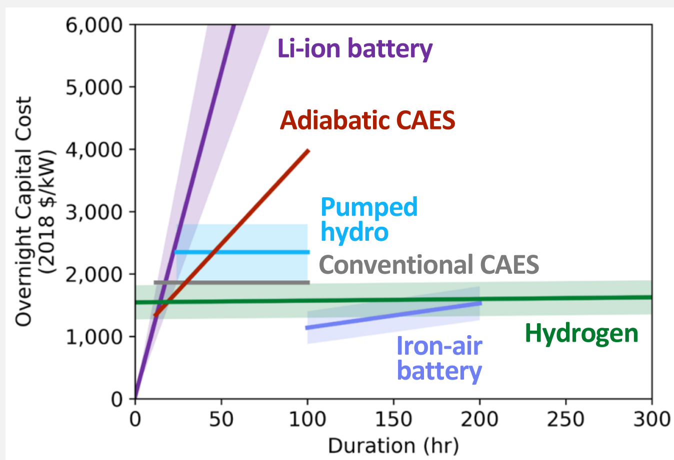


Figure 13: Long-duration storage cost projections for 2045.

(Go, Knapstein et al. 2022)

Future cost trajectories of these long-duration energy storage technologies are highly uncertain, as many of them are still in R&D or pilot phase, or they are subject to geological and site limitations. However, there have been major industry-wide efforts in the past couple of years to improve economic viability of long-duration storage technologies.

Some of the recent key activities are summarized below:

- In July 2021, the CPUC issued its midterm reliability decision D.21-06-035 ordering LSEs to procure 11.5 GW of capacity by 2026, with a 1 GW carve-out for long-duration storage.
- As a part of the 2022-2023 California spending plan, the state allocated $380 million of its budget for CEC to create a new program that provides financial incentives for emerging long-duration storage technologies, and $100 million to advance green hydrogen projects.
- At the federal level, in early 2020, DOE announced Energy Storage Grand Challenge program to accelerate development, commercialization, and utilization of next-generation energy storage technologies. Later in 2021, DOE also launched the Long Duration Storage Shot initiative aiming to reduce cost of grid-scale storage by 90% to a levelized cost of 5 cents/kWh in the next decade, for systems with 10+ hours of duration.
- Through the Bipartisan Infrastructure Law, which passed in November 2021, DOE is preparing to roll out the Long Duration Energy Storage for Everyone, Everywhere initiative with a $505 million of funding to support demonstration and pilot programs that can validate grid-scale long-duration storage technologies and address institutional barriers to technology adoption.

A key performance metric for storage resources is their roundtrip efficiency, which reflects the share of the energy used for charging that is retrieved during discharge. Lithium-ion batteries have a relatively high roundtrip efficiency in the range of 80–90% when they operate regularly, and they have a calendar life of 10–15 years.

Figure 14 compares efficiency and life of lithium-ion batteries against other storage technologies based on a PNNL report prepared for the DOE's ESGC effort. Long-duration storage is typically less efficient than lithium-ion batteries, which leads to higher charging costs. Redox-flow and zinc-based batteries have roundtrip efficiencies in the 65–70% range. Efficiency of thermal storage and conventional CAES systems is around 50% although adiabatic CAES technology can achieve a higher efficiency (55–65%) by capturing the heat during compression and using it later according to recent MIT study. Pumped storage hydro projects typically have 65–80% of roundtrip efficiency, and gravity-based storage systems at early pilot stages of development can potentially reach up to 80–90% of efficiency. Hydrogen storage (power-to-H_2-to-power) systems achieve a roundtrip efficiency of 30–40% after losses incurred during electrolysis, storage, and power generation.

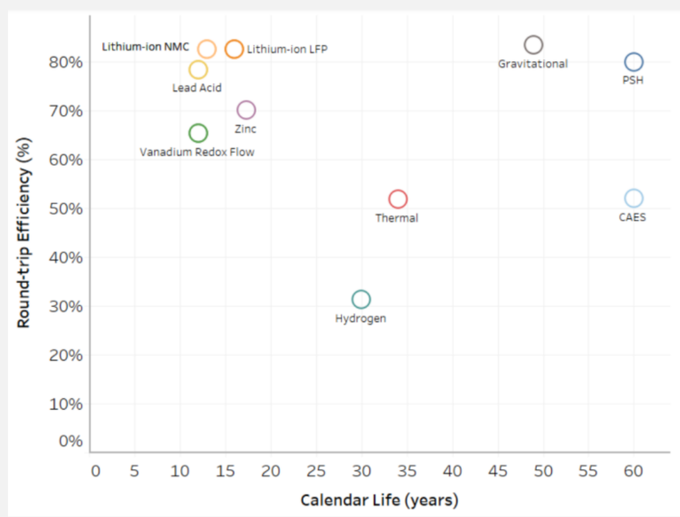


Figure 14: Long-duration storage efficiency and calendar life.

(Viswanathan et al. 2022)

Meeting deep decarbonization goals in California will require significant new solar and wind buildout relative to today's levels, which will inevitably create multiweek or seasonal mismatches between renewable energy supply and electricity demand. A major challenge will be to overcome high "charging" costs associated with very low efficiency levels of technologies that can provide such long durations of storage. For example, hydrogen storage has the potential to deliver fully dispatchable and highly flexible clean energy. But at 30–40% of roundtrip efficiency, it uses around 3 MWh for every MWh sent back to grid, which limits incremental benefits relative to overbuilding renewables and curtailing their output when there is excess supply.

The economic viability of very long-duration storage will partly depend on system needs for such durations of storage at deeper decarbonization levels, and how much of these needs can be addressed by resource and load diversification, and at what cost. The CEC recently adopted an ambitious 25 GW planning goal for offshore wind by 2045. A renewable portfolio with this much offshore wind would be more diverse and likely need less long-duration storage, relative to a solar-centric portfolio. Similarly, increased regional coordination and market development across Western states can better utilize the geographic diversity of both loads and resources, and accordingly reduce the need for long-duration storage. In the case of hydrogen storage, the economics also largely depend on future cost of green hydrogen production driven by economy-wide use cases for hydrogen. As discussed in an MIT study, hydrogen produced by electrolysis can be used directly as a fuel to support decarbonization of the industrial sector, which in turn can improve the utilization of electrolyzers and reduce per unit cost of hydrogen.

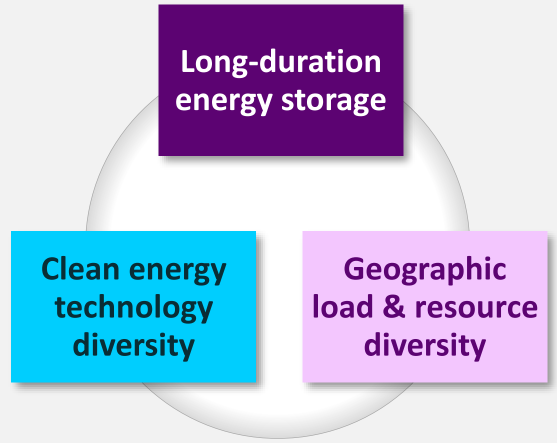


Figure 15: Pillars of deep decarbonization in the electric sector.

Most energy storage resources included in the CPUC Energy Storage Procurement Study's historical analysis utilize lithium-ion battery technology, but the set of resources analyzed includes pumped storage hydro, thermal energy storage, and alternative battery chemistries with durations up to 7 hours. See **Attachment A (Benefit/Cost and Project Scoring of Historical Operations)** of our report for details on our approach, assumptions, and key results of the benefit-cost analysis and project scoring.

Our evaluation also included two separate studies considering the role of longer durations (up to 10 hours) over the next decade:

- In the first study, we analyzed future energy storage procurement in California and found that the "cross-over" point for cost-effective longer-duration storage (8–10 hours) is in sight over the next 5–10 years driven by resource adequacy and reliability needs and value. See **Attachment B (Cost-Effectiveness of Future Procurement)** of our report for details of this study.
- In the second study, we screened the cost-effectiveness of around 100 individual gas peaker units' replacement with energy storage under the challenging system conditions observed in 2020 and found that replacing peakers' output with energy storage would require either significantly overbuilding storage MW or installing longer-duration storage. The study investigated economic trade-offs among various storage configurations, with durations of 4–10 hours and considering standalone development vs. pairing with solar. See **Attachment C (Cost-Effectiveness of Peaker Replacement)** of our report for details of this study.

As California approaches to carbon neutrality by 2045, the storage characteristics needed will evolve and shift towards durations above 10 hours. Through EPIC grants, the CEC has funded two parallel research efforts to develop a better understanding of the role and value of long-duration energy storage to support a zero-carbon future, with E3 and UC Merced leading these ongoing efforts.

Figure 16 below include preliminary results from the [E3 study] on value of long-duration storage, which shows how long-duration storage beyond 10 hours impact the future capacity mix and total portfolio costs by 2045. The study includes two core scenarios:

- The Reference Scenario builds on the CPUC's IRP Reference System Plan (RSP) and it assumes 100% of *retail sales* will be served by clean resources in 2045. In this scenario, the load associated with T&D and storage losses are not required to be served by clean resources. Accordingly, some of the gas plants are kept for reliability and they can run minimally.
- The SB100+ scenario has a more stringent target assuming 100% of *all loads* (including losses) are served by clean resources. Accordingly, all existing gas plants are forced to retire or retrofitted to use green hydrogen.

E3's initial results show vert limited amounts of long-duration storage built under the Reference Scenario, as the clean energy target less strict (100% of retail sales corresponds to around 75% of all loads served) and system needs can be sufficiently addressed by energy storage with up to 6 hours of duration. In the SB 100+ Scenario, however, the stringent clean energy target leads to substantial amount of long-duration storage, including multi-day and seasonal storage (shown in pink, yellow, and dark blue on the left chart). The study finds that achieving SB 100+ target in 2045 without long-duration storage would increase total portfolio resource costs significantly relative to the Reference Scenario, and availability of long-duration storage technologies can help avoid a large share of the incremental costs related to more stringent clean energy target (left chart).

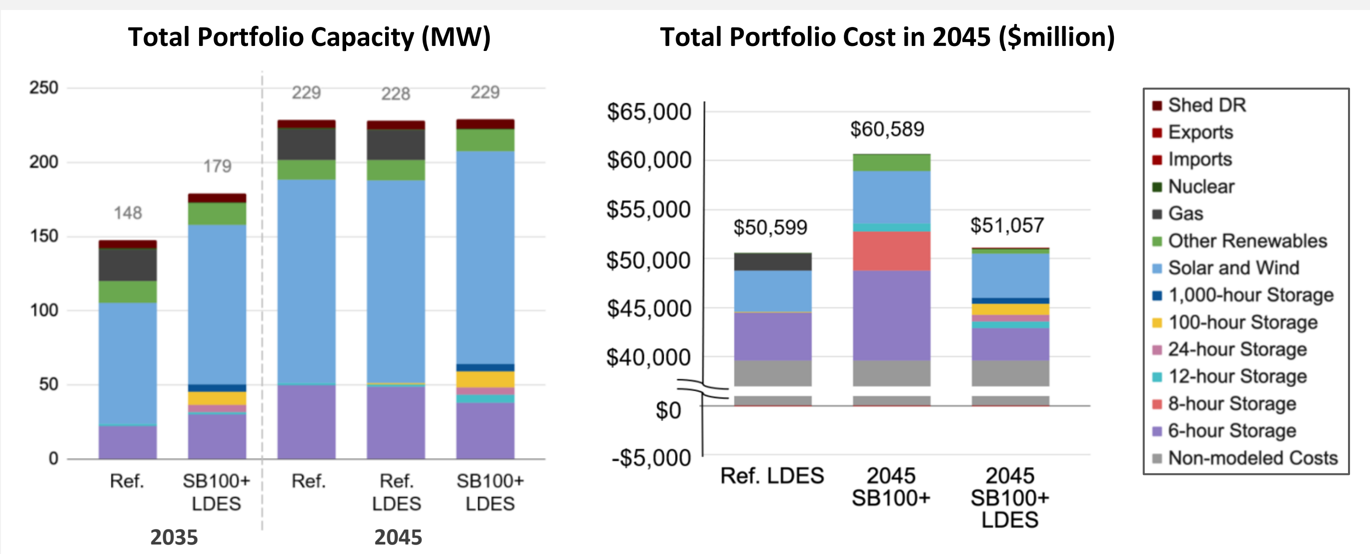


Figure 16: Impact of long-duration energy storage (LDES) on California's future resource portfolios and portfolio costs.

(Go, Knapstein et al. 2022)

Transmission Deferral Use Cases

The national discussion of transmission investment deferral indicates that energy storage can help to defer investments in the transmission system through two distinct use cases:

- In the first use case, energy storage acts as an energy resource, alters the load and generation balance in an area to relieve transmission bottlenecks (and/or provide ancillary services), and thus replaces transmission solutions that could do the same. A variety of generation and load resources could theoretically serve the same function.
- In the second use case, storage is used by the system operator like a controllable transmission asset. The resource could be operated, for example, to redirect power flow and prevent overloads on specific circuits. Since these use cases are deployed on either side of the legal and functional separation of generation and transmission (respectively), they are distinguished by who operates the energy storage resource, to what objective, and how the resource is paid for.

In California, energy storage has achieved scalability to help relieve transmission bottlenecks under the first use case. A total of 909 MW/3,579 MWh of energy storage resources operating in the 2017–2021 study period was procured to meet various local capacity needs driven by major generation retirements (i.e., once-through cooling, San Onofre nuclear generators, Moss Landing generators) and issues related to Aliso Canyon. Since these energy storage resources were procured under generation RA capacity procurement, where the resource alternative is a generation or load resource, we allocate these services and benefits towards local RA capacity rather than transmission deferral.

As part of the CAISO's Transmission Planning Process (TPP), generators and energy storage are considered directly as alternatives to transmission investments. In 2017-2018 TPP, the CAISO recommended approval a 10 MW of PG&E-owned energy storage project as part of a combined transmission/generation solution to prevent overloads in Oakland after the planned retirement of a gas peaker. The selected project under the Oakland Clean Energy Initiative (OCEI) had an estimated cost of $102 million. CAISO considered 3 other proposals including a new local generator, upgrades to existing transmission, and a new transmission line, with estimated costs ranging from $367 million to $574 million, well above the cost of the OCEI project. But the development of the project has apparently been hampered by changes in scope identified in subsequent TPPs and it is not clear if or when the project will be developed. Under the 2020–2021 TPP, CAISO identified two new 4-hour energy storage resources in the PG&E system as cost-effective solutions to mitigate local reliability needs in the Kern-Lament and Mesa 115 kV systems. As a result, two of the previously-approved transmission upgrades were put on hold pending procurement of storage resources at these locations.

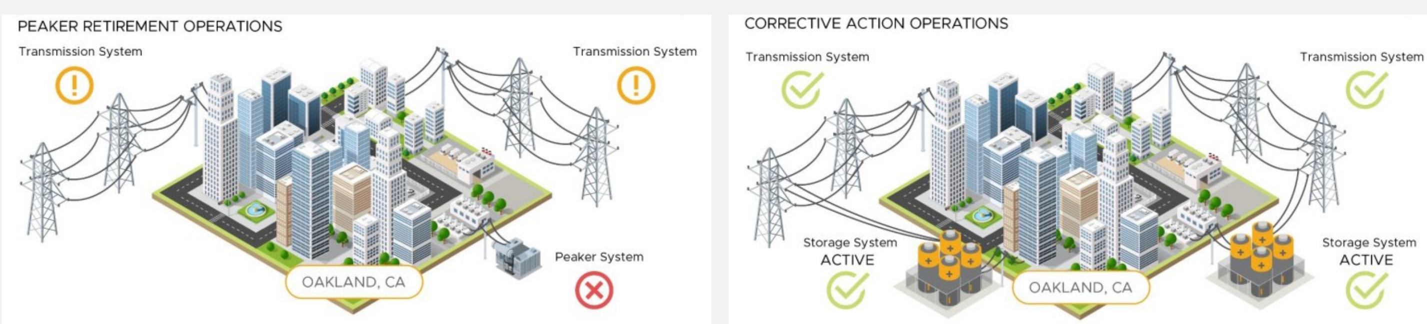


Figure 17: Illustration of how energy storage can address transmission needs driven by peaker retirements.

(Twitchell et al. 2022)

The second transmission deferral use case—storage operated as a controllable transmission asset—is still in a pilot and demonstration phase nationally with California as a leader. In 2017–2018 TPP, the CAISO approved a 7 MW/28 MWh energy storage projects as a cost-effective solution to manage a transmission contingency that would interrupt service to the town of Dinuba. PG&E conducted a competitive solicitation in 2019 and selected a winning bidder. However, when the transmission need increased to 12 MW in a later TPP, PG&E cited challenges with procurement and contracting. Assessment of transmission needs is a dynamic process and apparently in need of (a) a clearer understanding of how a specific need could fluctuate over time, and (b) procurement and contracting practices that better take advantage of the modularity of energy storage system and site designs.

A third use case—"dual-use" energy storage combining the two use cases above—presents major legal and policy challenges in that it envisions the operations of a single energy resource being split between generation and transmission functions. This use case is still in early development phase under initiatives led by the CAISO and the Midcontinent ISO (MISO). In 2018, CAISO launched the storage as transmission asset (SATA) initiative to explore how to enable energy storage projects provide cost-of-service based transmission services, while also participating in the wholesale electricity markets. This initiative is suspended until the storage resources' market participation model is further refined under the ongoing energy storage and resource adequacy initiatives. In the 2021–2022 transmission plan, CAISO noted that the SATA initiative is expected to remain on hold indefinitely based on recent developments, and the ISO will further explore market-based energy storage to meet transmission needs before shifting focus back to transmission asset treatment.

Other RTOs are also pursuing options for energy storage projects to function as transmission assets. In August 2020, FERC has approved MISO's proposal for storage to be treated like a "transmission only" asset (SATOA) with cost-based rate recovery. In the order, FERC highlighted that MISO's proposed tariff required that a storage facility qualifying as a SATOA must demonstrate it can address the transmission issue only as an asset under MISO's functional control, and not as a resource that participates in the MISO's markets. In its 2019 transmission expansion plan (MTEP19) MISO identified one SATOA project to address the reliability concerns in the Waupaca area of Wisconsin at a lower cost than the other wires and non-wires alternatives studied. The approved 2.5 MW/5 MWh battery project was initially planned to be in-service by December 2021, but it is now expected to be online in early 2023 according to ATC, the developer of the project. MISO has not identified any other SATOA projects under more recent transmission planning cycles.

Key Observations

There has been a significant effort in the industry, especially in California, over the past decade to achieve full economic potential of energy storage resources by unlocking access to a variety of value streams.

Historically, transmission- and distribution-connected storage resources participating in the CAISO wholesale markets did relatively well in stacking of energy, ancillary services, and RA capacity value.

Utility-owned distribution-connected resources developed for microgrid and other distribution-related services provided very little value overall, relative to their costs.

Customer outage mitigation needs, awareness, and value increased significantly after 2019 PSPS events, but lack of customer impact data makes it difficult to quantify resilience benefits of storage and the ability of distributed resources to stack grid benefits with customer resilience value is yet to be tested.

Storage served at scale as generators within local transmission-constrained parts of the grid, but no resource operated specifically as a transmission asset.

Developers utilized the modularity of grid-scale battery storage systems in their construction and market participation strategies to align services provided and storage capabilities needed over time, to maximize storage value.

Pumped storage hydroelectric technology can offer a unique way of value stacking across multiple sectors with non-energy benefits such as flood control, recreation, water supply, environmental benefits during droughts, and irrigation.

There has been a growing interest in California for developing energy storage resources paired with renewables, especially solar. Relative to standalone development, co-located or hybrid projects can provide cost synergies, but benefits need to be weighed against lost value due to more restrictive operational and siting constraints.

As California continues to decarbonize its electric system by deploying more clean energy resources, system flexibility needs and role of storage will evolve and longer duration storage systems will be needed. Timing and amount of the long-duration storage needs depend on the stringency of clean energy targets and extent of alternative measures taken, such as technology diversification (e.g., offshore wind) and increased regional coordination and market development across Western states.

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